Three Empirical Essays on Inputs, Institutions and Economic Growth

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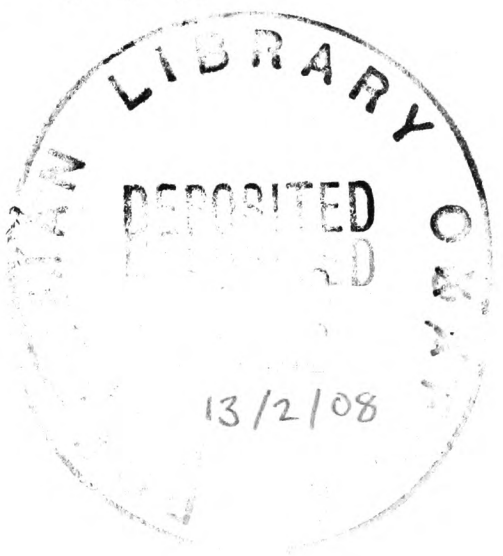

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Abstract

Chapter 1: From "Poorest of the Rich" to "Europe's Shining Light: Accounting for Growth in Ireland, 1980-2001. This chapter applies modern best-practice growth accounting techniques to understand Ireland's remarkable recent economic transformation. This is the first systematic and comprehensive application of growth accounting techniques devoted to examining Irish growth. Different explanations for rapid growth are assessed within this framework, and a variety of hypotheses regarding the sources and nature of the growth are tested. The results, which are compared to the findings of other studies, indicate that Ireland grew because of a substantial increase in labour input and an unprecedented increase in productivity.

Chapter 2: A Dynamic heterogeneous Panel Approach to the Equipment-Investment Growth Nexus This chapter studies the relationship between per capita income growth and equipment investment for a broad sample of countries for the years 1960 to 1990. The original contribution of this chapter is to model the relationship between equipment and growth using recently developed econometric techniques that allow for slope and intercept heterogeneity, and to examine whether allowing for heterogeneity in this fashion alters the conclusions of prior research in this area. The results, generated by an equilibrium correction mechanism framework which allows

for these forms of heterogeneity, do indicate that the conclusions of some of the earlier work regarding the relationship between equipment and growth may have been misplaced.

Chapter 3: **Did Labour Institutions Contribute to the Golden Age of Economic Growth?** This chapter studies the "Golden Age" of economic growth, a period of rapid growth which took place in many industrialized economies after the second World War. Specifically, this chapter tests new theories concerning the influence of labour institutions in sustaining a macroeconomic environment characterized by high output growth, high investment, and rapid productivity growth. The chapter utilises a recently created of dataset labour institution variables, and models the relationship between economic growth and these variables in a dynamic panel which is estimated using the 3SLS systems estimator approach, which allows institutions to have a direct effect on growth as well as an indirect effect through their influence on investment. The results indicate that institutions did play a role in shaping the growth of this period.

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Introduction

1.1 Introduction

This is an empirical thesis on economic growth. It is concerned with the influence of factor inputs and institutions on economic growth. The main body of the thesis is comprised of three chapters, the first two of which study factor inputs and growth, and the last of which studies institutions and growth. Specifically, this thesis contributes to knowledge by presenting original research on the following topics: the first chapter is the first piece of work to systematically apply modern best-practice growth accounting techniques to the spectacular recent growth experience of the Irish economy; the second chapter examines the effects of allowing for slope and intercept heterogeneity in models of equipment investment and growth, and the third chapter studies the relationship of labour institutions to growth during and after the so-called "Golden Age" of economic growth enjoyed by many industrialized economies after the second World War. The three chapters which comprise the main body of this thesis can be read separately, although some of the theoretical modeling in the final chapter on the Golden Age does make reference to related and similar theoretical modeling in the second chapter on equipment investment.

The three chapters are related to each other under the broad theme of factor inputs and institutions. The purpose of this introductory section is to introduce this

overall theme of thesis, to introduce and preview the chapters which comprise the main body of this thesis, and to describe the relation of each of the three main chapters to the overall theme of the thesis as well as to the modern empirical growth literature. Numerous high quality reviews of the empirical growth literature are now available[1], and it is not the intention here to needlessly repeat and regurgitate these contributions into a "review of reviews". Instead, the lessons from this research and their relevance to the investigations undertaken in the present work are reflected upon. This exercise is important as it contextualizes the methodologies, approaches and conclusions of the individual chapters, and the process therefore helps in interpreting outcomes and assessing the meaningfulness of these outcomes in a manner that is consistent with emerging thinking in the empirical literature.

1.2 Inputs, Institutions and Economic Growth

Rodrik (2003) classifies the determinants of growth as being either "proximate" or "deep". Proximate determinants of economic growth are functions of factor endowments of labour and capital, and the productivity with which these resources are deployed to produce output. Rodrik, noting that many candidates have been proposed as

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[1] These reviews include, but are not limited to, Temple (1999), Brock and Durlauf (2001), Pritchett (2003), Durlauf, Johnson and Temple (2005), Easterly (2005), and Pritchett (2006).

constituting the ultimate or deep growth determinant, argues the case for geography, integration by means of trade, and institutions.

This thesis addresses all of the proximate growth determinants in each of the chapters, and also explicitly studies institutions in Chapter Three. The topics of geography and trade feature indirectly in Chapter One, but are not directly modeled or analysed in great detail. With respect to the proximate sources of growth, aggregate production functions are used to represent the process by which inputs of labour and capital are combined in a productive manner to produce a flow of output. Decompositions of output into the relative contributions of the proximate sources of capital, labour and total factor productivity (TFP) provide the basis for the growth accounting methodologies which are used to study Ireland's recent remarkable economic transformation in Chapter One. The results of that chapter indicate a pre-eminent role for labour and TFP in creating rapid growth in Ireland, but also attempts to relate these findings to the deep sources of growth where possible. Chapter Two has an explicit emphasis on capital, and addresses some problematic econometric features of the earlier literature on growth and equipment investment. Chapter Three focuses closely on the relationship between labour market institutions and growth in the post-war era.

As such, proximate growth determinants in the form of factor inputs figure prominently in the first two chapters, whereas institutions are the central concern of

the third chapter. It remains to briefly preview and introduce the papers, and to discuss their relation to the overall theme of inputs, institutions, and economic growth.

1.2.1 Inputs and the Irish boom: Did factor accumulation account for the Celtic Tiger?

Chapter One uses modern best-practice growth accounting techniques, as laid out in the OECD's "Measuring Productivity" manual (OECD, 2001a), to undertake an exercise similar in spirit to that of Young (1995) in order to investigate whether the basis for Ireland's doubling of real GDP per capita between 1990 and 2001 was due to the accumulation of factor inputs which exhibit decreasing returns to scale. The accumulation controversy is one that has been well rehearsed since the publications of Young (1992, 1995) and Krugman (1994), and Chapter One examines whether the "tyranny of numbers" story applies to recent Irish economic history. Growth accounting is a useful means of addressing these questions, as the decomposition of growth in output into its constituent parts allows the quantification of the relative contributions of capital, labour and TFP.

However, the practice of growth accounting is not without its controversies, and some of the objections and qualifications that can be made regarding this method of economic investigation are discussed in Chapter One. It is worth bearing in mind that, following Barro (1999), growth accounting is best regarded as a means of identifying

and examining the proximate sources of growth, and as such should be considered as an intermediate step which is part of a wider analysis. Caution must also be applied when interpreting the results of growth accounting studies; Rodrik (2003) provides the following useful example: "...observing that 80% of the growth is 'accounted' for by accumulation and the rest by productivity does not tell us that growth would have been necessarily 80% as high in the absence of technological change; perhaps in the absence of productivity change, the incentive to accumulate would have been much lower and the resulting capital deepening significantly less". Clearly, structural interpretations of growth accounting studies are problematic and are to be avoided.

In the case of Chapter One, the fact that growth accounting is an intermediate step is recognised; however, the growth accounting is also an end in itself since the results are compared to those of Young (1995) regarding the experiences of the Asian tigers, as well as to the findings of other selected growth accounting studies. Therefore, the growth accounting fulfils the primary objective of the chapter inasmuch as it quantifies the relative sources of growth (which is interesting in its own right), but also examines these sources in a comparative manner in order to place the Irish experience in an international context. However, the results are also related to a number of hypotheses regarding Irish growth which themselves afford prominent roles to "deep" growth determinants. The results indicate that labour and TFP growth were the dominant proximate forces driving Irish growth during this period, and this has significance

for a range of hypotheses concerning the "deeper" reasons for Ireland's boom. The interlinked issues of geography and trade feature prominently in one body of explanations for Irish growth (see Krugman, 1997 and Barry, 1999b in particular) and it is interesting to note that the growth accounting results appear to deliver a measure of support for these theories, thereby linking proximate and deep determinants of growth using a technique especially well suited to making such a connection[2].

Pritchett (2002) reports that he has lost count of the number of papers in which he has read in which the country of interest "...is compared to East Asia to see how and where the country 'failed'". The practice of comparing other countries to Ireland in the hope of locating a "magic bullet" which will improve growth performance elsewhere has also begun, with international organisations and foreign governments making regular trips to Dublin in an attempt to locate the special formula. It was not feasible or sensible to attempt to review every possible unique and magical prescription which has been claimed as the key to Ireland's transformation (not least due to lack of data in some potentially interesting cases).

The idea that one particular policy or intervention has special growth-enhancing properties is a tremendously appealing notion to academics and policymakers for obvious reasons. Chapter Two studies the "special" properties of equipment investment,

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[2] It is perhaps worth noting in passing that these theories of Krugman (1997) and Barry (1999b) are not tested directly in Chapter One; rather, the growth accounting results can be given an interpretation which is not inconsistent with these theories.

on behalf of which numerous strong claims have been made with serious implications for policy-making and growth, especially as regards developing countries. Similarly, the final chapter examines claims that certain features of postwar labour institutions played an important role in creating and sustaining growth during the Golden Age of economic growth.

1.2.2 Is equipment investment "special", and can cross-country growth regressions tell us if it is?

Chapter Two applies recently developed econometric techniques to investigate whether the claims of the existing literature on equipment and growth are modified when slope and intercept heterogeneity are allowed for. It performs its analysis on a 49 country panel spanning the years from 1960 to 1990. As Chapter Two and Chapter Three both involve the estimation of cross-country growth regressions, it is worth briefly reflecting upon the current state of the art in growth empirics as it applies to cross-country regressions and the bearing that this has on Chapters Two and Three.

Following the resurgence of interest in growth economics in the 1980s, empirical research on growth has primarily taken the form of cross-country growth regressions. As the field has developed and matured, the criticisms and objections to cross-country growth regressions have mounted. The following problems have been identified as some of the main shortcomings of growth regressions.

- Open-endedness: Brock and Durlauf (2001) refer to the open-endedness as the idea that "the validity of one causal theory does not imply the falsity of another". This was a particular significant issue for early growth cross-sectional cross-country growth regressions, such as Barro (1991), in which variables were added to regressions without any particular regard being given to how one might interpret the coefficients on these variables, given that the variables had not been selected on the basis of a specific theory or body of theories.

- Parameter heterogeneity: Evidence of cross-country parameter heterogeneity has been found in numerous studies, including amongst others, Durlauf and Johnson (1995), Durlauf, Kourtellos and Minkin (2001), Desdoigts (1999), Lee, Pesaran and Smith (1998).

- Model uncertainty: Temple (1999) provides the following useful definition of model uncertainty: "The difficulty is that several models may all seem reasonable, but lead to different conclusions about the parameters of interest. In these circumstances, presenting the results of a single model is misleading. It ignores the researcher's inevitable uncertainty about the form of the model, and so leads the reader to underestimate the uncertainty actually present".

- Measurement error: This is a familiar problem in the broad general field of econometrics; Durlauf, Johnson and Temple (2005) note that measurement

errors are likely to be widespread in growth regressions, especially in developing countries.

- Outliers: Again, this familiar econometric problem poses many complications for cross-country growth regressions; for example, Easterly (2005) finds that the large estimated effects from policies in growth regressions are often driven by outlying observations which represent the effects of particularly bad policy interventions.

- Endogeneity: Durlauf, Johnson and Temple (2005) note that a frequent criticism of growth regressions is the failure, in most instances, of these regressions to establish directions of causality.

Open-endedness was defined above as the idea that the finding of evidence in support of one particular theory or growth determinant does not preclude other theories of growth from being valid and relevant. In the first stage of the empirical growth literature, starting with the well known convergence studies of Baumol (1986), Barro (1991) and others, cross country growth regressions were studied in which all "relevant" characteristics (see Maddala and Wu, 2000) of a country's dynamic growth performance were compacted into a single summary statistic: the average growth rate of per capita output. These papers then attempted to evaluate growth theories by inquiring how this statistic covaried with proposed explanatory factors in the cross section

by applying standard methods of inference to the estimated coefficients. These papers employed fairly *ad hoc* specifications, in that their estimated equations were not derived explicitly from production functions or otherwise informed by specific or detailed theoretical considerations. For example, Barro's (1991) regressions included a wide range of explanatory variables in a variety of econometric specifications which were not selected on the basis of an internally consistent theoretical model. As such, it is difficult to apply meaningful interpretations to these types of regressions. The same criticism could also be made of De Long and Summers (1991) cross-country equipment investment regressions. Mankiw, Romer and Weil (1992) (henceforth MRW) improved on this stage of research by grounding their empirical work in the neoclassical growth model. They estimated the exact equilibrium law of motion implied by a Solow model with a Cobb-Douglas production function augmented by human capital. This approach offered the distinct advantage over the earlier literature by being explicitly related to an established theory of growth.

Since the publication of MRW, researchers have generally been much more careful to avoid the open-endedness problem by relating empirical models to theoretical models. In this thesis, all cross-country growth regressions are based on theoretical models to avoid this problem.

Most cross country studies of economic growth have estimated equations which can be nested in the following general form (see Caselli, Esquivel, and Lefort, 1996):

$$y_{i,t} - y_{i,t-\tau} = \beta_1 y_{i,t-\tau} + \beta_2 W_{i,t-\tau} + \eta_i + \mu_t + \varepsilon_{i,t} \tag{1.1}$$

Here, $y_{i,t}$ is log per capita in country i at time t, τ is a unit of time, W is a (row) vector of variables thought to determine economic growth, η_i is a country specific effect, μ_t is a period-specific constant and $\varepsilon_{i,t}$ is an error term. The choice of regressors to be included in the W matrix depends on the particular growth model being investigated. Some researchers (see Durlauf and Quah, 1999 on this) divide the W matrix into two subcomponent matrices. The first matrix represents objects suggested directly by the Solow model such as country specific variables like initial income, savings rates and population growth. The other component matrix, in contrast, consists of additional variables that are thought to exercise a causal influence on growth and to differ significantly across countries.

These auxiliary regressors are usually added to the baseline Solow regressors in an attempt to build more sophisticated models of growth. However, this approach of adding additional regressors to the baseline Solow model is highly problematic in numerous respects, especially because such adding variables in this fashion may give rise to the problem of open-endedness. Durlauf and Quah (1999) say of these additional regressors "These are often highly correlated with one another and are neither mutually exclusive nor prioritized as possible explanations of growth. Hence, it is difficult to assign much import to the statistical significance of an arbitrarily chosen subset

of possible controls. We therefore find unpersuasive claims that these regression can identify economic structure". Moreover, these additional regressors can often imply unintended non-linear effects in the regression equation which are clearly not well captured by the use of linear estimation techniques.

Chapter Two uses the simple generalization of the augmented Solow model due to Nonneman and Vanhoudt (1996) to avoid the problem of open-endedness. However, the modeling strategy in Chapter Three is more vulnerable to this criticism because a vector of labour market institutions is included on the right hand side of an augmented Solow type specification. The problem of open-endedness is surmounted by explicitly allowing two influences on TFP; one is conventional technical progress, and the other is an efficiency term which is a function of labour institutions. This type of empirical specification has a firm basis in the theoretical contributions of Cameron and Wallace (2002) and the narrative and historical contributions of Eichengreen (see for example Eichengreen 1994 and 1996) and is consistent with these papers.

Parameter heterogeneity is a problematic aspect of the growth literature because it is so often neglected. Much cross-sectional work implicitly embodies implausible assumptions regarding parameter heterogeneity, in which the effect of a growth determinant has the same effect on, for example, US growth as it has on, say, Haitian growth. One solution to this is to use panel techniques which allow for fixed effects, but Pesaran, Smith and Im (1995) show that in the presence of slope heterogeneity

(and dynamics), standard panel techniques such as the fixed effect estimator, lead to inconsistent estimates even for panels of large dimensions (long time and cross section dimensions). As such, Chapter Two explicitly allows for both slope and intercept heterogeneity in its modeling of equipment and growth by using the Pooled Mean Group (PMG) estimator. The same techniques cannot be applied in Chapter Three for reasons related to data (essentially, some of the labour institutions do not vary over time and hence cannot be estimated on a single country basis). The Appendix to Chapter Two contains a detailed discussion of PMG estimator and provides an example of the biases that may arise when slope heterogeneity is overlooked.

Model uncertainty relates primarily (in the present context) to the interpretation of the outcomes of a regressions. For example, if a particular growth determinant is being investigated, and is found to be statistically significant and of the anticipated sign, the researcher is likely to conclude that the determinant "matters" for growth. However, the fact that one hypothesis has been tested and this hypothesis has not been rejected does not automatically qualify the hypothesis as being of wide applicability and generality. Equally valid hypotheses may exist, and accordingly one should be extremely cautious in assuming a wide degree of generality and applicability on results. This topic is perhaps of more relevance for the Golden Age regressions of Chapter Three than for the equipment investment regressions, as a primary goal in Chapter Two is to see how earlier conclusions might be modified by accounting for

parameter heterogeneity. Chapter Three presents a comprehensive literature review of competing theories which seek to explain the Golden Age, acknowledges that parts of most explanations are likely to correct, and is careful not to claim greater generality for the regressions than is warranted. Both chapters also employ a number of different econometric specifications in order to increase the robustness of the results and thereby attempt to reduce the uncertainty attached to the findings of the regression work.

The remaining econometric issues are familiar econometric problems. The problem of measurement error, especially in developing countries, is discussed in Chapter Two in relation to the Penn World Tables data. However, as Durlauf, Johnson and Temple (2005) remark, few empirical growth studies attempt to address the impact of measurement error, and accordingly solutions to this problem are sparse. Instrumental variables are only possible solution to the problem, but valid instruments are not always available. Bounds on the measurement error variances are one solution, and Temple's (1998) paper on equipment investment imposed such bounds. However, generating sensible information on the extent of measurement error is difficult (which is necessary to construct bounds), and may amount to little more than guesswork in some cases. As such, Chapters Two and Three do not formally address the issue other than recognise the problem and council that any measurement error present in the sample may have some impact on the final results.

The propensity of outlying observations to adversely affect the precision of parameter estimates is well known. A recursive sensitivity test is employed in Chapter Two to identify outlying countries and outlying groups of countries, while Chapter Three includes year dummies and studies the effects on the model of estimating the model for two distinct sample periods.

Endogeneity is also a familiar econometric problem. Brock and Durlauf (2001) summarise the problem as it applies to cross-country growth regressions: "Many of the standard variables used to explain growth patterns - democracy, trade openness, rule of law, social capital, and the like - are as much outcomes of socioeconomic decisions and interrelationships as growth itself is. Hence there is an a priori case that the use of ordinary least squares estimates of the relationship between growth and such variables cannot be treated as structural any more than coefficients produced by OLS regressions of price on quantity can be". This quote clearly illustrates the difficulty of identifying valid instruments for use in growth regressions, which greatly complicates the task of overcoming endogeneity problems.

Chapters Two and Three avoid these problems to a certain extent by including only those variables which are explicitly identified by theoretical work as having an influence on growth. Chapter Three addresses the problem of endogeneity by using the Three Stage Least Squares (3SLS) estimator, which involves specifying an instrument set with which to instrument the included regressors. Durlauf, Johnson and Temple

(2005) note that the main response to endogeneity problems has been to search for valid instruments. As such, researchers have also increasingly turned to Generalized Method of Moments (GMM) techniques to deal with endogeneity in growth regressions (see for example Bond, Hoeffler, and Temple, 2001) and the 3SLS estimator used in Chapter three is effectively a special case of conventional GMM estimator (for a discussion of the conditions under which the two estimators coincide see Wooldridge, 2002) and therefore can in principle deliver many of the advantages of GMM with respect to endogeneity.

The endogeneity problems involved in Chapter Two are accordingly more problematic than those in Chapter Three, as the estimators used in Chapter Two do not readily allow for instrumentation, and suitable external instruments are extremely difficult to find. Chapter Two involves estimating a production function, and the endogeneity problems with this type of econometric exercise have been well-rehearsed in both the microeconomic and macroeconomic literature. GMM estimators could potentially provide one solution to this problem, but unfortunately this would require abandoning the focus on examining the effects of introducing cross-country heterogeneity which is the main contribution of Chapter Two.

This raises important related issues. One issue is whether it is appropriate for growth economics to rely on the use of aggregate production functions. Temple (2006) provides an interesting assessment of this topic, and concludes that aggregate produc-

tion functions do not exist except in improbable special cases. He defends their use in growth economics by considering the standards by which economics research is judged. He suggests that aggregate production functions help researchers learn about the world, and therefore may be construed as "parables" in the spirit of Solow (1966). Similarly, Durlauf, Johnson, and Temple (2005) note that one position on endogeneity is to disregard growth regressions entirely, but note that as Mankiw (1995) and Wacziarg (2002) suggest, given the great difficulty in making definitive causal statements in economics, the partial correlations of cross-country growth regressions rule out some positions and add incrementally to knowledge by updating the prior beliefs of their researchers. Durlauf, Johnson and Temple (2005) in fact begin their review of growth econometrics with a similar observation "A traditional defense of empirical growth research would be in terms of expected payoffs. Each time an empirical paper is written, the probability of gaining genuine understanding may be low, but the payoff to that understanding is potentially vast". For example, the new econometric techniques applied in Chapter Two to the study of equipment investment and growth increase knowledge regarding the equipment investment-growth nexus by demonstrating the importance of heterogeneity to understanding this relationship. This clearly has benefits both in terms of understanding that relationship and for emphasizing the importance of heterogeneity in cross-country regressions more generally.

1.2.3 Did new labour institutions matter for the Golden Age of economic growth?

Many of the issues regarding cross-country growth regressions have already been discussed above, and the similarities and differences between the approaches taken to these regressions in Chapters Two and Three have been discussed. However, one issue specific to Chapter Three which deserves some scrutiny relates to the place of policies as explanatory variables. Chapter Three does not study policies *per se*, but it could be argued that the dataset used in that chapter is more a reflection of labour market *policies* than of labour market *institutions*. This is problematic as Glaeser, La Porta, Lopez-de-Silanes and Shleifer (2004) argue that some measures of economic institutions are actually choice variables to policymakers, whose decisions are constrained by the level and growth of pre-existing proximate growth determinants such as physical and human capital.

Pritchett (2003) also makes the point that including policy variables in growth regressions is highly problematic, because policies themselves are not determinants of growth; instead, they are conditional rules which map from states of the world to actions. In other words, this view argues that policies themselves are not actions or determinants, and therefore characterising a policy as being a determinant of growth is highly questionable, especially as policies are responsive to the state of the world in different ways. Rodrik's (2005) position on this matter is even more stark; in a

paper entitled "Why we learn nothing from regressing economic growth on policies", he suggests that treating policy as if it were exogenous (which is effectively what is happening when policy variables are placed on the right hand side of a regression) is inherently problematic from a conceptual viewpoint, because policies are used systematically by governments to achieve desired goals. Therefore, policy is endogenous in both an econometric sense and in a conceptual sense.

Do any of these criticisms apply to the econometric investigations undertaken in Chapter Three? A number of considerations suggest these criticisms do not in fact apply. The first point to be made is that the dataset on labour market variables (Nickell and Nunziata, 2001) used in the analysis was explicitly constructed as a database of labour *institutions*, and accordingly it seems reasonable to treat these variables as institutions. Another point is that even if the variables do reflect changes in policy (which they almost certainly do), the policies themselves are felt to reflect changes in labour market institutions; clearly, any change in institutions will affect the manner in which policies are formulated and implemented, so the regressions do indicate some degree of institutional effect. The point of Glaeser *et al.* (2004) is more difficult to address, and solutions to this particular issue have not been forthcoming in the literature and solutions to the problem are rather difficult to envisage. Despite this, and bearing in mind the standards that may reasonably be expected of economic research, Chapter Three does, at a very minimum, shift the burden of proof by requiring the ef-

fect of labour institutions to be accounted for in future explanations of the Golden Age growth, and also serves to update priors regarding the importance of institutions more generally.

1.2.4 Conclusion

This section introduced the thesis in terms of its overall themes and aims, and outlined the relation of individual chapters to each other and the overall theme of inputs, institutions and economics growth. The individual chapters themselves constitute separate original contributions to the field of empirical growth economics, but this Introduction has sought to briefly demonstrate the connections and similarities, as well as the differences, between the chapters. Some important methodological concerns and the implications of such concerns to the construction and interpretation of testable hypotheses were also touched upon. This introductory section has been relatively brief, and the themes and topics of the Introduction are discussed in more detail in the individual chapters, and therefore it now remains to consider the chapters themselves.

Chapter 1
From "Poorest of the Rich" to "Europe's Shining Light": Accounting for Economic Growth in Ireland, 1980-2001

1.1 Introduction

In January 1988 *The Economist* magazine ran a cover story on the Irish economy. The article was entitled: "Ireland: Poorest of the rich". The cover itself featured a female beggar, sitting on O'Connell Street, the main thoroughfare of Dublin, reaching out with a bowl to passers-by. The clear implication of this distinctly unflattering image was unmistakable. The main article began in uncompromising fashion: "Take a tiny, open ex-peasant economy. Place it beside a much larger one, from which it broke away with great bitterness barely a lifetime ago. Infuse it with a passionate desire to enjoy the same lifestyle as its former masters, but without the same industrial heritage...Inevitable result: extravagance, frustration, debt...Ireland is the poorest country in rich north-west Europe. Its gross domestic product is a mere 64% of the European Community average".

Just nine years later, the May 1997 issue again featured an article on the Irish economy as its lead story. The cover displayed a map of "rich north-west Europe",

showing an illuminated Ireland, presumably providing a beacon of guidance and inspiration to the sclerotic economies of "rich north-west Europe"; the title of the cover story this time was "Ireland: Europe's shining light". Perhaps the best summary of this remarkable change in economic fortunes was provided by yet another survey by *The Economist,* this time in October, 2004, which reflected that "Surely no other country in the rich world has seen its image change so fast. Fifteen years ago Ireland was deemed an economic failure....yet within a few years it had become the "Celtic Tiger", a rare example of a developed country with a growth record to match East Asia's, as well as enviably low unemployment and inflation, a low tax burden and a tiny public debt"[3].

This chapter studies the rapid rates of sustained economic growth recently enjoyed by the Irish economy. The main contribution of this chapter to the understanding of this remarkable economic transformation is to perform an aggregate-level growth accounting exercise for the Irish economy for the years from 1980 to 2001 using recommended modern best practice growth accounting techniques, as set out in the OECD Productivity Manual (OECD, 2001a). The results of this exercise, which is the first systematic aggregate growth accounting study of this remarkable economic transformation, are discussed in detail. The motivation for performing this research into the sources of recent Irish growth is to attempt to adjudicate between different hypotheses concerning the causes of the growth and thereby to contribute to the un-

[3] Murphy (2000) also begins his review of Irish growth by contrasting the various Economist magazine cover stories.

derstanding of Irish economic development. As such, this chapter seeks to contribute to an understanding of Irish growth at an aggregate level (in the manner of Young, 1995) and does not contain detailed sectoral and subsectoral analyses, and nor does it contain a comprehensive explanation for Irish growth encompassing and considering all possible influences. The layout of this chapter is as follows:

- The first section provides motivation and context. It contains a short literature review of other growth accounting studies of the Irish economy, and explains the differences and improvements in the approach taken in this chapter.

- This second section introduces the data

- The subsequent section contains an explanation of the assumptions, modeling techniques, and data issues underlying the construction of each of the components and variables in the growth accounting exercise.

- The results of the growth accounting exercise are then presented and analyzed in further detail where appropriate.

- The Appendices to the chapter contain more detail on the methodology used in the main part of the chapter, as well as a cross-country non-parametric comparison of the Irish productivity performance.

1.1.1 Motivation for the study

Why should anyone be interested in the experience of a small and geographically peripheral nation like Ireland? Perhaps the most compelling reason is simply the need to understand the quite dramatic rates of economic growth that have been enjoyed by Ireland for over a decade[4]. The graph below, based on the chain series of GDP per capita from the Penn World Tables (version 6.2), illustrates the rapid acceleration in the pace of economic growth that took place in the 90s, and which continued into the new century.

The aim of this study is to identify the reasons for this rapid growth. In one sense this is sufficient motivation for studying this topic when one considers declarations such as that of Hausmann, Pritchett and Rodrik (2005): "Accelerating the process of economic growth in a sustained manner is just about the most important policy issue in economics". In the words of Sarel (1997), discussing the East Asia experience, "...there is an urgent need to solve the puzzle of the phenomenal East Asian growth rates. After all, not being able to explain such an important economic phenomenon would be a major defeat for the economics profession". Although the Irish case perhaps constitutes a less dramatic change in economic circumstance and relative income levels than the development of the original "tiger" economies of East

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[4] This period of rapid growth lead to Ireland being bestowed the with sobriquet of "Celtic Tiger" in innumerable articles in the popular press during this period. This phrase was apparently first used in a Morgan Stanley research report of August 1994, and was intended to highlight alleged similarities between the Irish economy and those economies in South East Asia which have become known as the "Asian Tigers".

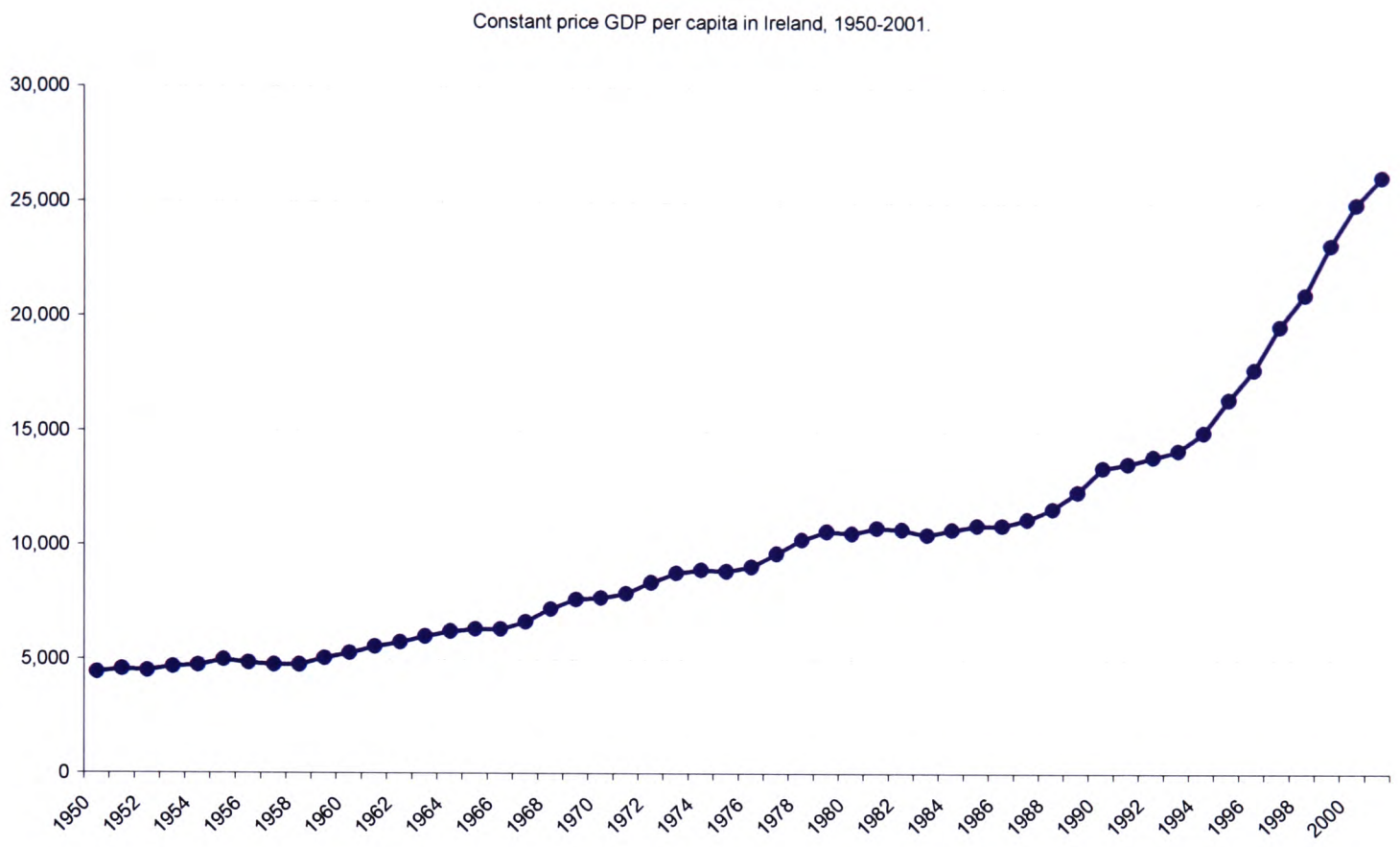

Figure 1.1: Growth of Irish GDP per capita.

Asia, the sentiment is still the same - "Like everyone else, economists find success irresistible", according to William Easterly (1995).

In addition to the inherent interest and need to explain this rapid transformation, there is also the possibility that analytical scrutiny of the Irish experience may yield insight on whether there was anything fundamentally unique about the recent Irish experience, thereby either encouraging or discouraging the transplantation of ideas, interventions or policy to other countries. Expressing related sentiments in another context was the Washington Post, quoted in Sarel (1995) "In a world full of countries desperately trying to get richer, the winners become influential models for the rest. But exactly what accounts for their success? This isn't merely an abstract

academic debate. The consensus tends to get built into the policies of dozens of ambitious countries, affecting the patterns of world trade and much else".

If the story of recent growth is not an inherently unique experience but is rather a standard tale of belated but rapid convergence, then answering why and how it was that Ireland suddenly embarked on a (delayed) convergence to Western European living standards becomes the critical question. *The Economist*, in its previously cited May 1997 survey of the Irish economy, wrote on this matter: "How much does it help Belgium, say, to be told: start dirt-poor, draw on your global network of migrants and corner the market in Anglophone pro-Europeanism?".

The main motivation for the work undertaken in this chapter is therefore the need to identify the sources of Ireland's exceptional performance. Research work on the topic of recent Irish growth has come in a variety of forms, ranging from impressionistic discourse to rigorous analytical scrutiny. A number of different questions, hypotheses and conclusions have been put forward in this body of research as to the sources of Irish growth, and some of these ideas are evaluated in this chapter.

One line of research, which received some prominence during the early stages of rapid growth in the early nineties, argued that the recent Irish growth was illusory, inasmuch as it was based on a statistical artifact whereby value added figures have been grossly and improperly inflated by the transfer pricing practices of the numerous multinational enterprises who have substantial presences in the local economy, with

the effect that Ireland's actual growth rate is below what one would obtain from relying upon the official output data. For this line of argument, see in particular the work of Murphy (1994).

Even by 1995, which was perhaps the first year of exceptionally rapid growth, the difference between GDP and GNP was 15%, a difference which was caused by net factor outflows, which was due to profit repatriation by foreign companies. Murphy suggested in this early paper that there were some grounds for reclassifying the Irish tiger as a tortoise, reflecting what he perceived was a rather turgid pace of growth, whereas O'Grada (2002) inquires whether the economy is best described as a "paper tiger". This line of research faltered in the face of the manifestation of growth in the real economy, notably with respect to employment, capital formation, and increases in house prices. However, there are still legitimate and important concerns over the reliability of Irish output statistics, even if the somewhat severe conclusions of the early work in this area ultimately proved to be perhaps unduly pessimistic. Other important contributions to this literature are O'Leary (1984), Stewart (1989), Conroy (1994), O'Leary (1997), Conroy, Honohan, and Maitre (1998) Birnie and Hitchens (1998), O'Leary (1999), and Honohan and Walsh (2002).

Although it does not appear to have been explicitly raised in academic research on Ireland, a major source of controversy in the literature on the dramatic economic transformation of the East Asian "tiger" economies[5] was the apparently preponderant

[5] The East Asian "Tigers" are Hong Kong, Taiwan, Singapore and South Korea.

role played by the accumulation of capital in the growth of these economies. These arguments and the beginnings of this literature are closely associated with the works of Young (1992, 1995) and Krugman (1994), who argued that the rapid growth in this region was not sustainable or even reliably secured, because of an over-reliance on the accumulation of capital. This was regarded as problematic because of the possibility that the growth in the region would soon halt, once diminishing returns to capital were encountered. This chapter is also concerned with establishing the role of capital accumulation in Ireland's recent growth and therefore another motivation is to examine whether the "tyranny of numbers" fable has any relevance to Irish growth[6].

Another set of hypotheses revolves around what might be described as the classification of the "economic geography" of Ireland. An important early contribution to that literature was Krugman (1997), who made the case that Ireland seemed more like a regional economy than a wholly national economy. This line of research was concerned with examining why Ireland, despite a productivity performance that appeared to be have been much better than the European average since the 1960s, still failed to converge to European living standards. The failure to converge was attributed to a failure to become internationally competitive in sectors other than agriculture (on

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[6] Young (1995) beings by announcing that his paper is "fairly tedious and uninteresting", but is one which is concerned with providing a careful analysis of historical patterns of output growth and factor accumulation. This chapter shares with Young's paper the desire to treat data issues seriously and to account for output growth and factor accumulation as accurately as the available data allows. It is left as an exercise to the reader to decide whether this chapter is tedious and uninteresting.

this see in particular Barry, 1999b). This hypothesis is discussed in more detail in the results section.

All of these hypotheses are expanded upon in more detail in the results section of the chapter. One might make predictions as follows: if the capital accumulation argument is correct, one would expect to see a large and influential role for capital services in the growth accounting decomposition, and a relatively low importance accruing to labour services and TFP. Conversely, one might expect to see an opposite scenario in the Krugman-Barry story of Irish growth, which suggests a much more important role for labour input and productivity. This hypothesis would predict that the (relatively) high productivity growth of recent decades would continue, with labour becoming more and more important for growth over the period studied in this chapter. The "tortoise" argument is also critically examined in the results section; evidence in support of the "tortoise" hypothesis would need to somehow demonstrate that true Irish growth was below the official rates. Given the types of hypotheses and questions raised (especially in respect of the relative importance of contributions from labour, capital and productivity), a growth accounting framework would seem a particularly suitable and potentially fruitful avenue of inquiry.

This chapter is the first to use a detailed and rigorous growth accounting framework to understand recent Irish growth. The growth accounting framework, as noted earlier, is based on the best practices set out in the OECD Productivity Manual. The results of the growth accounting exercise are then subjected to further analysis and

scrutiny, both to certify the robustness of the basic growth accounting results, and to provide alternative and potentially more informative perspectives on Irish growth and thereby identify the Irish economy within the diverse and exotic menagerie of economic animals which have been advocated as most accurately representing the true nature of Ireland's economic transformation. Of course, it must be pointed out that this chapter cannot hope to give definitive conclusions on all of these issues. Instead, it limits itself to the examining the contributions that growth accounting can offer to these debates. Before commencing the technical analysis, it is helpful in exercises of this sort to provide some contextual narrative to better understand the results generated by the formal analysis, and context is the subject of the next section.

1.1.2 Context of the study

What was the historical background of the apparently remarkable success story to be described in this chapter? Recent economic success was not the inevitable outcome of a century of steady economic achievement and foresight in Ireland; nor was it a dramatic piece of luck for an underachieving economy. Instead it could be regarded as the culminated outcome of a series of changes in domestic policy begun in the 1960s in regard to, *inter alia*, education and industrial development, the fruits of which were ready to flower once the external economic environment was favourable and destructive domestic macroeconomic policies had been decisively abandoned.

Twenty six counties of Ireland secured legislative independence from Britain in 1921, while six of the nine counties of the province of Ulster continued to be part of the United Kingdom[7]. In 1921, it could be argued with some justification that the newly formed Irish Free State contemplated much more favourable future economic prospects than many other European countries, including those countries like Finland and Estonia that were likewise about to embark, or had already embarked, on a new existence that would be independent of former imperial masters. As Haughton (1995) notes, "At independence Ireland had a literate population, good infrastructure, substantial foreign assets, a functioning bureaucracy. It was close to some of the world's biggest markets. It had substantial natural resources, of sea and soil if not iron and coal. The destruction of war bypassed the country. It was fortunate indeed compared with Denmark, or Austria, or the Netherlands". The table below shows that the Ireland of the early part of the 20th century[8], while not in the highest echelon of European wealth, was nevertheless respectably placed in the league table. It was to emerge largely unscathed from the first World War, and the newly formed state could view the future with a degree of justifiable optimism as it gained full control of domestic economic policy for the first time in centuries.

The subsequent economic performance of the new state was to confound and mock that early hope. In the words of one chronicler of the twentieth century Ire-

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7 Henceforth, all references to Ireland refer to what was to become, in 1949, the Republic of Ireland.

8 The figures for Ireland relate to 1911; for all other countries the figures relate to 1910.

Ratio of domestic to mainland UK national product per capita, 1910	
Belgium	75.6%
Germany	70.3%
France	69.6%
Denmark	67.6%
Ireland	62.0%
Norway	60.4%
Sweden	60.3%
Italy	40.5%
Finland	34.6%

Figure 1.2: Comparison of British and European national products in early twentieth century.

land, the historian Joseph Lee (1989) wrote the following from the perspective of the late eighties: "Ireland recorded the lowest per capita growth of per capita income between 1910 and 1970 of any European country except the United Kingdom. Every country ranked above Ireland in the twentieth century pulled much farther ahead. Every country below Ireland either overtook her, or significantly narrowed the gap. The result was that Ireland was reasonably representative western European economy at the time of independence, to a position far below the western European average in 1970". Kennedy, Giblin and McHugh (1988) compared Irish and British performance between 1926 and 1985 and found that GNP grew at the same rate (2.1%) in each country but per capita growth of this aggregate grew at an annual rate of 1.8% in Ireland and 1.7% in Britain.

O'Rourke and O'Grada (1995) have concisely summarised these findings in the following way: "...this performance was unsatisfactory for a number of reasons.

First, per capita incomes in Ireland were lower than in the UK over this period, so Ireland should have been catching up rather than merely keeping pace with the UK. Second, British growth rates were low by European standards, and so keeping pace with Britain ensured long-run decline with respect to the Continent". The table below, taken from O'Grada and O'Rourke (1996), makes clear this disappointing performance.

	Ireland		**UK**		**Western Europe**	
a) Percentage average annual growth rate of GDP						
	HS	**Maddison**	**HS**	**Maddison**	**HS**	**Maddison**
1950-1960	2.15	2.19	2.51	2.46	4.73	4.75
1960-1973	4.21	3.71	2.68	2.61	4.34	4.19
1973-1988	0.85	2.68	1.94	1.89	1.91	1.9
1950-1988	2.33	2.9	2.34	2.29	3.48	3.34
b) Percentage average annual growth rate of GDP						
	HS	**Maddison**	**HS**	**Maddison**	**HS**	**Maddison**
1950-1960	1.67	1.71	2.89	2.87	5.64	5.64
1960-1973	4.87	4.36	3.22	3.17	5.2	5.05
1973-1988	1.87	3.65	2.03	1.99	2.25	2.24
1950-1988	2.83	3.38	2.66	2.62	4.14	4.09

Figure 1.3: Growth in Ireland, UK and Europe. 1950-1988. The table is taken from O'Grada and O'Rourke (1996). HS refers to the Heston - Summers dataset (Penn World Tables Mark V), Maddison refers to unpublished work from Angus Maddison.

What went wrong? After a relatively uneventful first decade of independence - the new nation makers being described by minister Kevin O'Higgins as "the most

conservative revolutionaries in the world"- the newly elected government of 1932, in the depths of the global depression, embarked upon an autarkic self-sufficiency programme of import substituting industrialization, a policy that was to remain largely intact until the late 1950s. Interestingly, this highly protectionist and inward looking policy received a blessing from no less a personage than John Maynard Keynes, given in his lecture on "Economic self-sufficiency", delivered at University College Dublin in 1933 (see Sachs, 1997). The inappropriateness of this blessing was to ultimately be made manifest in the decades of stagnation that were to follow it.

The Irish Free State remained neutral during World War Two, and avoided the devastation suffered by so many other European countries. It did experience in common with these other countries a shortage of many important raw materials in the post-war era (O'Rourke and O'Grada, 1995), and received only very modest assistance under the terms of the Marshall plan. It was only in the fifties that the bankruptcy of the inward looking policy began to make itself clear, as the living standards of the economies of Europe (see the discussion of the European Golden Age in Chapter 3 of this thesis) pulled further and further ahead of that of Ireland (O'Grada, 1997). Foreign ownership of Irish enterprises was prohibited, and the exploitation of many potentially viable (and even lucrative) export markets was denied. The inefficient farming sector was relied upon as a means of securing foreign reserves. Economic conditions deteriorated, mass emigration recommenced and a pervasive pessimism took hold of the country.

After two decades of failure, made clear by a glaring difference in economic performance between Ireland and the rest of Europe that the Irish policymakers could not fail to perceive, the inward looking self sufficiency programme began to be decisively reformed in the late 1950s[9]. In its place emerged an industrial policy that was in many ways diametrically antithetical to what had gone before. Subsidies, reduced protection, grants and very favourable tax rates on company profits were introduced, all with a view to attracting more foreign industry and ultimately to encourage domestic enterprise. Secondary schooling was belatedly made free to all children, and an important feature of the Irish economy from this date onwards has been its commitment to investment in all sectors of education. The 1960s witnessed sustained employment and population growth for the first time since the devastating famine of the 1840s (O'Rourke and O'Grada, 1995), as well as significant structural change. The increasingly outward orientation of the economy was greatly enhanced by its entry into the EEC in 1973[10].

Unsurprisingly, the small and ever more open economy was buffeted by the global macroeconomic convulsions of the 1970s, and the pace of the progress that was begun in the 1960s steadily moderated. As in other countries, Ireland increased

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[9] The time of the change in government policy is often associated with the publication in 1958 of a Government White Paper, which was to become known as the "The Programme for Economic Expansion", which advocated greater openness and less government interference in the economy. The White Paper was developed by a team of civil servants lead by a Department of Finance economist called T.K. Whitaker. In 2001 he was voted Ireland's "Man of the Twentieth Century" in a programme made by RTE, the Irish state broadcasting company. This was in large part due to his work in writing the White Paper.

[10] Ireland, Denmark and the UK became members of EEC on the 1st of January 1973.

spending during the first half of the seventies to deal with the problems created by the oil shocks. Real disaster struck in 1977 when a new government was elected by a large majority on a populist mandate to spend its way out of stagflation, thereby imperilling the increasingly fragile state of public finances. It embarked on a massive procyclical fiscal expansion, which unsurprisingly delivered a short spurt of rapid growth in the late 1970s, but was ultimately to have disastrous consequences for the economy. Between 1974 and 1986, the government budget deficit exceeded 10% in all but two years. The national debt, which had always been comparatively small and manageable (Lane, 1995), rose from 71.3% of GDP in 1980 to 116% by 1987.

The period between 1977 and 1987 was a time of considerable economic and political turmoil, and it is probably no coincidence that the government of 1977 was the last in Ireland to be elected a single party to an overall parliamentary majority. Industrial relations became difficult as disputes between unions and employers intensified, as both rampant inflation and an increasingly onerous personal taxation burden eroded living standards. The deficit in the balance-of-payments rose from 2.4% of GNP in 1978 to 10.1% in 1979 (Lee, 1989), and was to remain in, or close to, double figures for much of the first half of the next decade. In the words of Fitzgerald (2000), "This is a period which virtually all Irish commentators now regard with something near horror".

In 1987, matters came to a head. A new minority government was supported by the other major political parties in its drive to cut government spending. The

Minister of Finance's point blank refusal to award a pay rise to the public sector set the tone for a more responsible managing of the public finances. Some commentators had feared that the cut in government spending would have a negative effect on an already weak economy, but instead the economy enjoyed what has come to be known as an "expansionary fiscal contraction" (see Giavazzi and Pagano, 1990)[11]. Output began to grow rapidly and the national debt stabilized and began a long term secular decline.

Whilst all of this macroeconomic turmoil was taking place, successive governments had avoided drastic cuts in educational expenditure and had continued in their attempts to attract foreign industry with generous incentives. This was the macroeconomic background with which Ireland entered the boom years of the 1990s. A penetrating summary of Ireland's economic development since Independence is provided by Fitzgerald (2000) : "While the stance of domestic economic policy began to change in the late 1950's, over the following thirty years the process of catching up was delayed by bad luck and further bouts of inappropriate policy making. With the benefit of hindsight one might think that Ireland had worked hard at being a failure and that, of late, even that policy has thankfully failed!". With this background in mind, the questions to be addressed in this chapter then are the hypotheses dis-

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[11] An expansionary fiscal contraction may be said to occur when a credible cut in government spending leads private agents to form the expectation that the future path of public spending and taxation has been reduced. This expectation helps to stimulate private consumption and output. In the Irish context, it is plausible that this cut in anticipated taxation helped encouraged increased female participation in the labour market.

cussed in the introduction to this chapter. The next sections of the chapter involve a detailed discussion of the methodologies applied for the growth accounting exercise, framed against the background of data constraints. As the standard growth accounting methodology is familiar from sources such as the OECD Productivity Manual, an exposition of the basic approach is included in the Appendix to this chapter for completeness and may be read before the next section of the chapter.

1.2 Implementing the growth accounting framework

1.2.1 A brief literature review of Irish growth accounting studies

This section of the chapter provides detailed explanations regarding the construction of the elements of the growth accounting framework. Before doing so, it is useful at this point to briefly discuss efforts that have been made to study Irish economic growth in terms of a growth accounting framework. Papers in that have studied the recent Irish growth experience in this way are Slevin (2002), de Freitas (2000), Cardoso and Souziakas (2003) and Bosworth and Kollintzas (2001).

Bosworth and Kollintzas(2001) compare Irish and Greek economic growth in the context of a wide-ranging macroeconomic study of Greece's poor economic performance over the period 1965 to 1998. They assume rather than construct a share of capital in national income, which is likely to lead to serious biases in identifying the sources of growth in Ireland, for reasons discussed in detail below (in which the

changing Irish factor share was discussed). Labour input is calculated on the basis of simple headcounts of employed and self employed, and quality of the labour force is controlled for using the Barro-Lee (1994) dataset. The capital stock was calculated using a simple perpetual inventory method with a seemingly arbitrary depreciation rate of 5%; it is not clear how retirement and age-efficiency effects were dealt with.

de Freitas (2000) compares Ireland's economy to the economies of Spain and Portugal for the period 1974 to 1998. This again uses simple headcounts and stocks of capital and borrows heavily from the data calculated in OECD (1999). Another paper comparing Ireland and Portugal is that of Cardoso and Soukiazis (2003). The growth accounting here relates changes in GDP to changes in labour force participation.

Slevin (2002) studies Irish growth over the period 1960 to 2000, with a particular emphasis on determining the role of information and communication technology (ICT) in very recent Irish performance. Her growth accounting methodology again uses simple headcounts of the numbers employed in the industrial, services and agricultural sectors. The labour input index is constructed by aggregating headcount data of the broad sectoral shares in total compensation, implying that all differences among labour input can be captured by classifying them in this extremely broad sectoral scheme. Again, it is not clear how the capital stock estimates dealt with the efficiency decline and the effects of retirement on capital services estimates.

This chapter improves upon these papers in a number of ways. A basic and general theme is that this chapter attempts to use modern, best practice growth accounting techniques to weight flows of labour and capital services by the marginal productivities of those flows. Factor shares are calculated using all the available data, rather than assumed to be some conventional value. The importance of these points should emerge with more clarity as the subsequent sections of this chapter are developed.

1.3 Data

The main data source for almost every variable in the parametric growth accounting section of the chapter comes from two sources. The first data source is the Economic and Social Research Institute (ESRI) Macroeconomic Databank, which is publicly available from their website[12] (subject to certain restrictions). It is a detailed and comprehensive macroeconomic dataset. Most variables start at 1960 and continue on a yearly (at least) basis to 2001. The dataset includes careful calculations of many variables essential to a study such as this, including investment deflators and other helpful information, but there are nevertheless gaps in the series in terms of coverage and availability. All historical time series variables in the database are available in both euro and Irish pound denominations. In all cases, real Euro denominated data were used in this chapter.

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[12] www.esri.ie

One drawback of the ESRI dataset is that value added variables are available only at a fairly high level of aggregation. Using the Groningen Growth and Development Centre[13], 60-Industry Database, (available at www.ggdc.net) it was possible to obtain much more disaggregated data on sectoral value added, which permitted a more careful distinction to be drawn between the business sector and the (non-market) public sector[14].

Data is available from 1980 to 2001 for all of the variables included in the Groningen dataset. One possible complication in this regard is the role played by publicly owned utilities. Value added figures from the "Electricity, gas and water supply" sector in the Groningen database are retained in the analysis when aggregating value added since one would expect that pricing and related decisions in this sector would be, to some extent at least, reflective of competitive considerations and therefore suitable for inclusion in a growth accounting study. The 60-Industry Database draws its value added data from OECD National Accounts sources, and data is again available in constant value Euros. An important deficiency in the ESRI dataset is that it does not include any data on hours worked; data from the Groningen Growth and Development Centre, 60-Industry Database was used to obtain data on hours worked. This data is itself based on Eurostat's Labour Force Survey and OECD sources.

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13 www.ggdc.net

14 I am grateful to Ana Rincon-Aznar of the NIESR for informing me that a new and extended version of this dataset was due to be released in Autumn 2006, which was unfortunately not available at the time of writing in Summer 2006.

The gross fixed capital formation data that were used to generate estimates of capital services were taken from the ESRI dataset, which were in turn taken from the Irish national accounts. This data was used because time-series of GFCF data were available back to 1960, in contrast to the Groningen dataset (the Total Economy Growth Accounting Database), where the data begin in 1980. The longer time period used helps to facilitate a more accurate computation of starting capital stocks, and provides a long-run perspective on trends in these variables[15]. The labour share was also calculated using the ESRI databank, which contains a good deal of detail (not available from the Groningen dataset) on the variables required to calculate factor shares (discussed below).

To summarise, value added and labour data was taken from the Groningen database, whereas data on capital input and factor shares were drawn from the ESRI databank.

1.4 Value added calculations

As the OECD (2001a) notes, estimates of TFP can be calculated from different conceptions of the production process. The two standard ways of representing the production process involve measures of output known as gross output and gross value added. Choosing which measure to use therefore constitutes the first step in growth

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[15] The separate data used to calculate the non-parametric Malmquist index is discussed in the Appendix, where the results of that analysis are presented.

accounting. To understand the alternative representations of production, we must define our terms. Gross output measures the goods and services created by an enterprise unit that are made available for sale outside that unit. It measures the value of sales and (net) additions to inventory, but does not include the purchase of intermediate inputs.

Value added is obtained by deducting the value of intermediate inputs from calculated gross output. Therefore, in terms of representations of the production process, gross output is described by a function relating it to intermediate inputs as well as primary inputs, whereas value added is described by a function relating it to primary inputs alone. One should also note that these output measures are only calculated for the private business sector, since this sector reflects productive activities in a market setting in which competitive conditions are more likely to prevail, a distinction therefore being drawn between "non-market" sectors of the economy such as education and health care where the provision of services is often not cost reflective or based on competition.

It is useful to spell out in more detail the differences between the two measures. Consider a general production function with output-augmenting or Hicks-neutral technical progress

$$Y = H(A, X, M) = A.F(X, M) \tag{1.1}$$

TFP growth, that is, growth in the variable A, is positive when the growth rate of output exceeds the growth rates of primary (X) and intermediate inputs (M). When technology is Hicks neutral, TFP is measured by the shift in the production function over time, so that $\frac{\delta \ln H}{\delta t} = \frac{\delta \ln A}{\delta t}$. On the other hand, a value added function represents the maximal amount of current price value added that may be produced with given prices of intermediate inputs and output, and given a particular set of primary inputs. One may write this relationship as follows:

$$G = G(A, X, P_M, P) \tag{1.2}$$

Where P_M is the price of intermediate inputs and P is the price of output. Again, TFP may be defined as the shift in the production function over time. We can now write the following useful formula (due to Bruno, 1978) which makes clear the relationship between the two measures.

$$\frac{\delta \ln G}{\delta t} = \frac{1}{S_{VA}} \frac{\delta \ln A}{\delta t} \text{ where } S_{VA} = \frac{G}{P.Q} \tag{1.3}$$

This demonstrates that value added estimates of TFP growth will always be higher than gross output TFP growth measures, since the share in value added in an industry will be unity or less. As the OECD (2001a) notes: "This does not constitute a bias, but calls for an interpretation that is different from the gross output-based productivity measure". An example of this from the same source is the fact that a

constant rate of TFP as measured using gross output is consistent with an acceleration of growth when TFP is measured using value added.

Changes in the share of value added (S_{VA} above) therefore imply different rates of growth in gross output and value added measures. This highlights the importance of the need for careful interpretation of results, and also the need to exercise caution when comparing the results of country level growth accounting studies. Another important point when comparing cross country studies relates to the three ways that prices can be measured: at basic prices[16], at current market prices, or at factor cost. Lal (1999) offers a useful discussion of the problems of international comparability when prices are measured in different ways by different countries.

Given all of this, which measure should be used? Studies of what production processes actually look like in reality have failed to offer convincing support for one measure over the other (OECD, 2001a). The significance of the choice is also diminished, to a certain extent, by the fact that certain superlative index numbers, such as the Tornqvist index below in the Appendix to this chapter, can provide a good approximation to technical change, even if output is not of the basic Hicks neutral sort described by the production functions above. The choice of the two measures is also more important at the industry level, so that in an aggregate study such as this

16 "Value added at basic prices is calculated from the production value plus subsidies on products less the purchases of goods and services (other than those purchased for resale in the same condition) plus or minus the change in stocks of raw materials and consumables less other taxes on products which are linked to turnover but not deductible. It represents the value added by the various factor inputs in the operating activities of the unit concerned" - from the Eurostat Concepts and Definitions database, available at http://forum.europa.eu.int/irc/dsis/coded/info/data/coded/en.htm.

one would not expect to see significant differences between the two measures. More prosaically, data availability is often likely to determine which measure is used in practice.

Value added measures tend to be much easier to obtain, although one would not expect any differences in availability given the way in which value added is constructed by subtracting intermediate inputs from gross output. Gross output statistics are not published for Ireland, and instead a value added measure is used, calculated using factor prices. Indeed, value added measures appear to be used in most modern growth accounting TFP papers.

The value added measures used in this paper were calculated using the most disaggregated sectoral or industrial level possible. The ESRI databank contains sectoral value added figures, but the these figures were very poorly correlated with GDP growth, especially during the boom years. Instead, the value added figures from the O'Mahony and van Ark (2003) Groningen database are used, which are available at a much lower level of aggregation than are the ESRI sectoral value added figures.

Gross value added was calculated on this bottom up basis, and then expressed in terms of annual indices, so as to obtain an exact and superlative Tornqvist index. Annual indices of constant price value added for sector classification j are of the form:

$$\frac{GVA_t^j}{GVA_{t-1}^j} \tag{1.4}$$

where the t subscript indicates the time period. The annual series of current price shares are calculated for each industry j is:

$$O_t^j = \frac{P_{GVA,t}^j GVA_t^j}{\sum_j P_{GVA,t}^j GVA_{t-1}^j} \tag{1.5}$$

The Tornqvist index can then be calculated using this formula:

$$\frac{GVA_t^A}{GVA_{t-1}^A} = \Pi_j \left(\frac{GVA_t^j}{GVA_{t-1}^j} \right)^{\frac{1}{2}\left(O_t^j + O_{t-1}^j\right)} \tag{1.6}$$

Where the A superscript indicates that this is an aggregate measure.

There are a few other general points to be made. As is evident from the above sequence of equations, the output measure needs to be deflated using an appropriate price index. The biases that can be introduced into economic calculations that arise from incorrectly or imperfectly measured price indices are well known. The introduction of new classes of goods and improvements in the qualities of existing ones constitute important and complex problems to be addressed by the national accounts statistician. When using value added measures, care must also be taken to apply appropriate additive constant price estimates when double deflation is used to calculate gross value added. Double deflation calculates gross value added by subtracting intermediate consumption at constant prices from output at constant prices (SNA, 1993). OECD (2001a) discusses this issue in detail. Another caution to be

exercised when gross value added results are computed is the point that the results based on a gross value added calculation, relative to a gross output based measure, can be misleading if there are dramatic changes in relative material input prices. The oil shocks of the mid-eighties are an example that happens to fall within the time frame of this study. Other things being equal, gross value added will be understated relative to output growth because of the increase in the price of the oil input. This will bias downwards the estimated TFP growth. On the other hand, the reduction in oil prices in the 1990s will moderate this effect for the Irish case.

1.5 Labour Input

This section describes the analysis and calculation of the contribution of labour inputs to productivity. Labour input is arguably the most important of all inputs into a production process due to the fact that it often earns the majority of income and therefore the accurate measurement of its contribution is a particularly important task. Labour input is correctly measured as a flow of productive services and the appropriate means of quantifying this flow of services is to measure the number of hours worked by individuals engaged by a particular industry. Labour input should also be distinguished by as many differentiating characteristics as is feasible. This differentiation by characteristics such as, *inter alia*, skill level, age, and sex reflects the fact that workers contribute flows of productive input that are functions of these and other personal characteristics. The implication is therefore that labour inputs are hetero-

geneous and hence contribute different amounts to the productive process, and this heterogeneity should be taken into account in assessing labour's overall productivity contribution.

This section of the chapter proceeds as follows. The most suitable way of measuring the flow of labour services in a growth accounting context is described, and then the data actually used for this purpose in this chapter is discussed. The much more difficult exercise of differentiating labour input by relevant characteristics is then discussed. This involves a discussion of the "best practices" in the literature on this field, and the problems and data constraints that arise when attempting to implement these recommended practices in the Irish context.

1.5.1 Measuring the flow of labour services

The labour input into production processes is a flow of services rendered by individual units of labour to a particular economic entity. Measures of this flow of labour services have in the past included simple headcounts of employees, and this means of measuring the labour input was used in many early growth accounting studies and continues to be used in modern studies that employ growth accounting techniques; for instance, the previously cited papers by Slevin (2002) and de Freitas (2001) use the number of employee jobs as their measure of labour input in their growth accounting studies of Irish growth. Such a measure is inadvisable as its use does not capture the possible effects in changes in number of hours spent working, changes

in multiple job holdings, the quality of labour nor the role of self employed persons. The graph below, based on data from van Ark and O'Mahony (2003), shows the sharp increase in numbers employed in Ireland from 1980 to 2001.

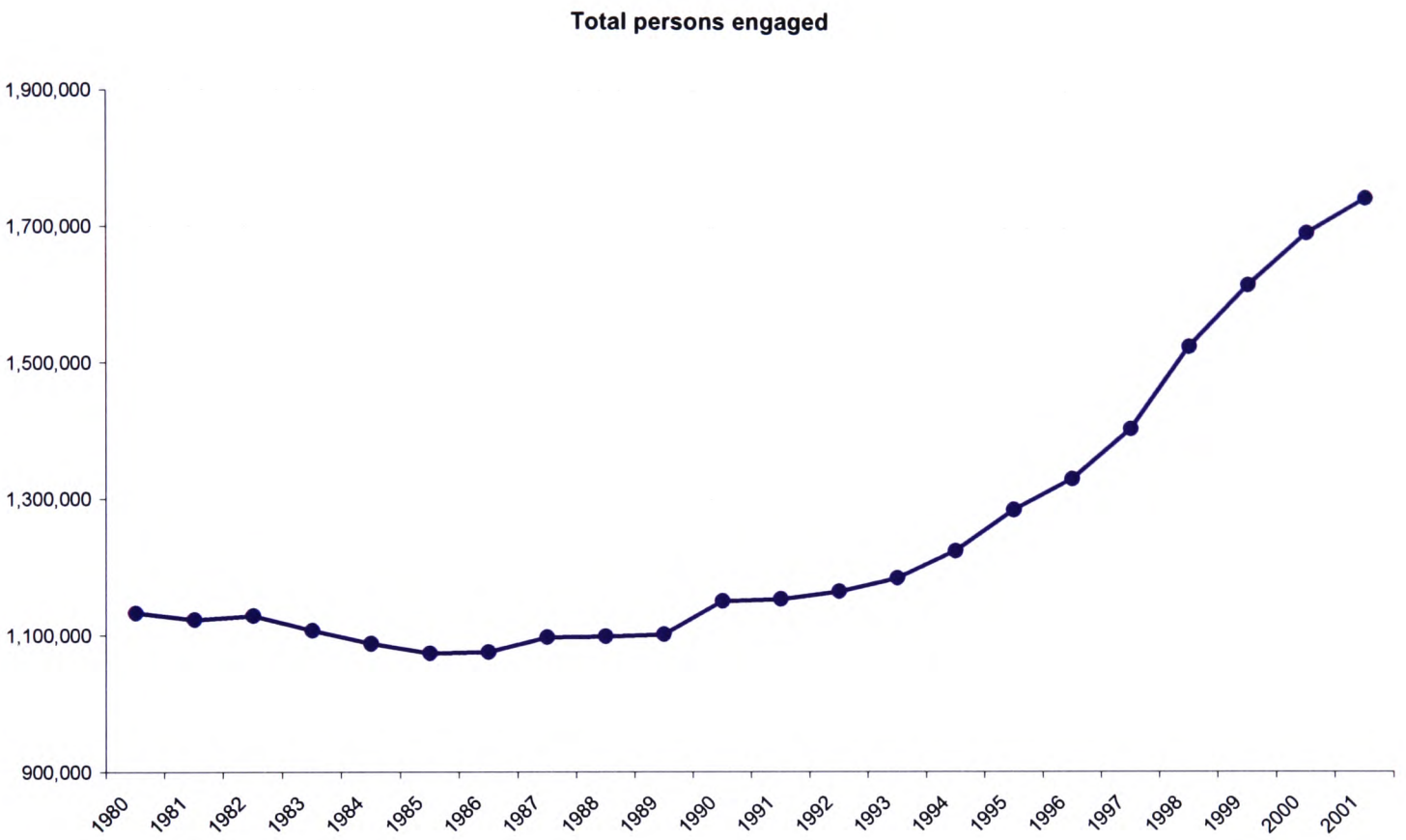

Figure 1.4: Employment, 1980-2001.

As the OECD (2001a) notes, rates of change of employment differ from rates of change in hours worked because of certain types of labour market change that have been observed in many OECD economies. Such labour market developments include more vacations, more part time work and regulations specifying particular working hours. Instead, it is more appropriate to use a quality adjusted measure of

the number of hours worked, together with suitable adjustments required to measure accurately the contribution of the self employed. These issues will be discussed in more detail below.

One general criticism of the use of hours worked as a measure of labour input is that he makes no attempt to control for the effort of work exerted during any particular hour. Denison (1962) made an adjustment to his hours worked data to control for the intensity of effort, but in general data are unavailable for this task. For a discussion of this point see Jorgenson and Ho (2001) and Becker (1962). Becker (1962) highlights the importance of studying the issue of intensity of work, given the widespread decline in actual hours worked that has been observed in many countries over the twentieth century. However, Jorgenson and Ho (2001) suggest that "..until the importance of intensity as an additional dimension of labour input can be demonstrated empirically, the principle of Occam's Razor can be applied", and therefore no adjustment is made here in respect of the intensity of effort.

The first step in constructing a measure of the labour input involves collecting data on hours worked. Data on hours worked are typically published (only) by industry, and ideally such data should be collected at the lowest possible level of industrial aggregation and should also adjust for worker quality. In practice, most national and international data on hours worked contains little or no adjustment for quality and such adjustments have to be made using other data sources. Overall hours worked are found by multiplying the number of workers by average hours worked in that

industry; the numbers employed data are available for the same industry classifications.

For the Irish case, Groningen Growth and Development Centre, 60-Industry Database is used. This database is based on Eurostat's Labour Force Survey. Eurostat's Labour Force Survey provides data on hours worked by employees, classified by industry. Vacations taken are explicitly controlled for in the data. The use of the Groningen and Eurostat data reflects the paucity of hours worked data available for Ireland[17].

As described in the section above on growth accounting methods, the data should be aggregated using the exact Tornqvist index number formulation, as opposed to simply summing hours worked in different industries. As further noted above, the correct means of aggregating the data is to use the price component of the flow of labour services. Data on average compensation per hour were based on the Groningen data.

These data on hours worked are collected for employees only, and as such do not include the income of the self employed, and this fact is important when calculating the overall share of labour in income and hence more generally in determining the productive contribution of labour. The labour share is adjusted in the manner suggested by the literature on this topic by assuming that the self employed earn the

[17] Hours worked data were published by Eurostat once every two years between 1979 and 1986. After this time, it was published on an annual basis, and the 2000 is the last year for which data are available; this data is used to construct the data in the Groningen database.

same average compensation as the employed, and this assumption is combined with data on the number of the self employed to adjust the labour share. The table below, also based on the Groningen data, shows how total hours worked have increased over the period, even though average hours worked have been falling. Clearly, the rise in participation has compensated to some extent for the fall in the average number of hours worked.

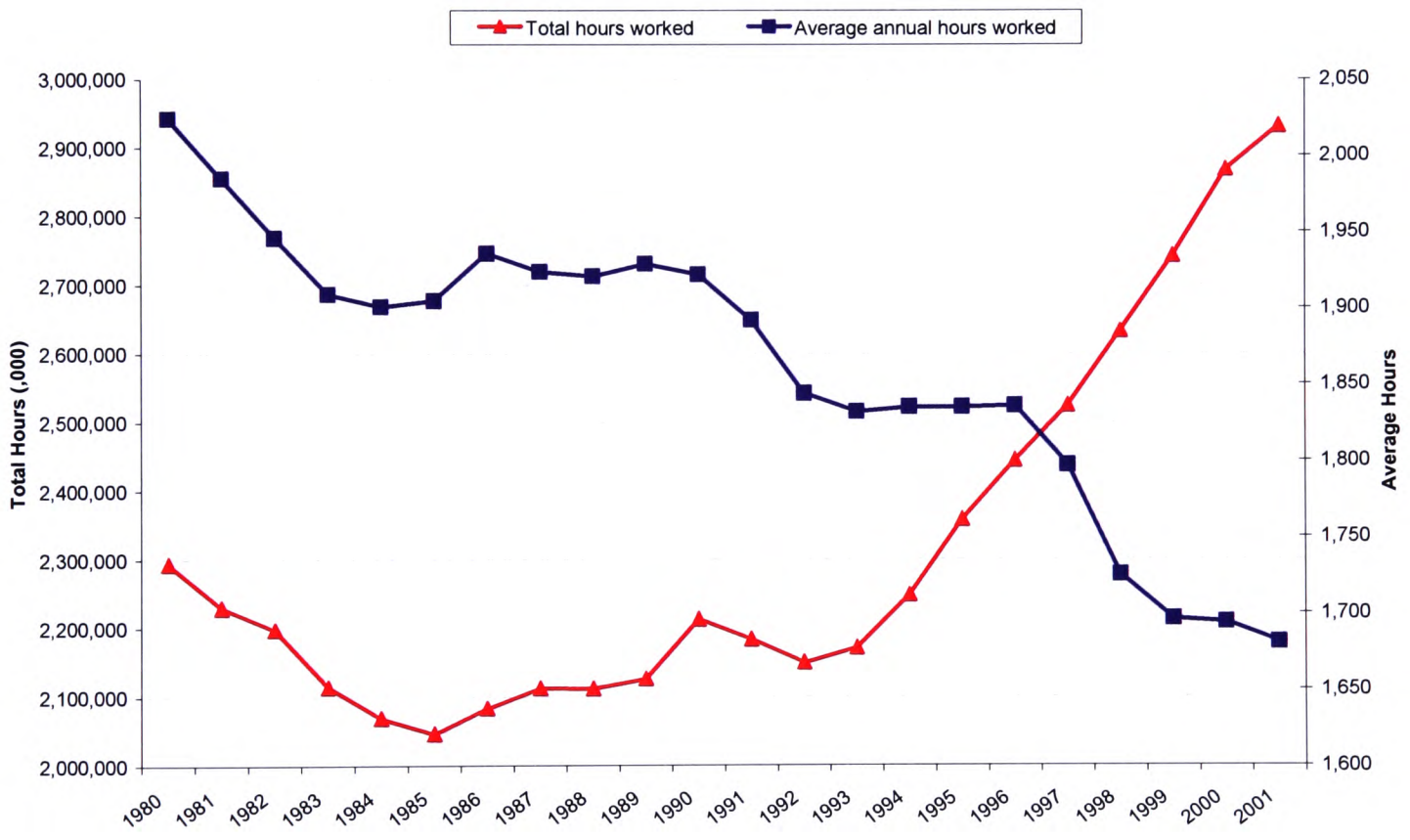

Figure 1.5: Total and average annual hours worked.

1.5.2 Adjusting for the quality of labour

Introduction

The theory of index numbers and the principles of growth accounting require that, for any input, the contribution of any particular component of that input be weighted in aggregate indices of the overall input by the marginal productivity of each distinct component. As was made clear in the section on growth accounting above in the context of measuring the productive contribution of labour, this requires weighting all of the different types of labour input by the wage rates earned in the market by those different types of labour. This idea reflects the notion that in a competitive market the wage rate paid (or more precisely, the share of each type of labour in total labour compensation) to a particular type of labour will equate with the marginal product of that same type of labour.

In a sense, this requirement is tantamount to the notion that labour input should be measured using constant quality indices of labour input; a change in the quality of labour implies a change in the composition of labour. In turn, a change in the composition of labour implies individuals with different marginal products have entered the labour force and are contributing to productivity in different ways.

As the OECD (2001a) points out, if the quality of the labour force is rising over time, as appears to have been the case recently in many OECD countries including Ireland, then using a measure of labour input that does not adjust for quality will have the effect of understating labour's contribution in growth accounting stud-

ies. Understating labour's contribution in this manner will correspondingly increase the contribution of the "unexplained" total factor productivity residual in growth accounting studies, since this residual represents growth in output not "explained" by inputs of labor and capital. This fact has obvious implications for any conclusions reached on the sources of growth. In the words of the OECD (*ibid.*) "...substituting quality-adjusted labour input measures for simple ones can shift the appreciation of the sources of growth, from externalities or spill-overs captured by the productivity residual to the effects of investment in human capital".

Indeed, a simple comparison between the adjusted and unadjusted labour inputs gives a measure of compositional change in the labour input, and could be interpreted as the contribution of investment in human capital. Interestingly, other growth accounting studies of recent Irish growth have in general not adjusted the labour input for quality.

Quality Adjusted Labour Input-Review of the literature

The fundamental requirement for a quality adjusted measure of labour input is a classification of the different types of labour. This apparently straightforward requirement is not easy to implement for the Irish case and therefore a review of best practice in the literature is useful. Should types of labour be distinguished according to one or all of occupation, sex, age, skill level, or education level? Different approaches have been used.

One approach assumes a hierarchical ranking of skills among occupations, and studies the distribution of hours worked across occupations to obtain differentiated measures of labour input. This is the approach adopted by studies of Lavoie and Roy (1998) and the OECD (1998). Lavoie and Roy's (1998) primary concern is not with economic growth as such, but rather to present a portrait of employment trends in the Canadian economy. They do, however, use their methodology in a growth accounting exercise and this is discussed below. The authors follow Wolff (1996) and Baumol, Blackman and Wolff (1985) in defining a number of categories and subcategories of occupations, though their classification is different and more detailed than the Wolff *et al.* studies. Their motivation in using employment by occupation and not by industry is based on their argument that establishments in particular industries tend to produce output other than their primary output, which has the implication that the workforce composition is a function of secondary output as well as primary output.

Their classification of different occupations follows from their assumption that there is heterogeneity in the contribution and productivity level of workers, and that this heterogeneity is best captured by an accurate categorization of occupations. Their growth accounting methodology decomposes the total change in the proportion of a given number of workers into three components: the first component relates to skill substitution, which is based on the notion that technological advance or economic reforms may give rise to a greater demand for a particular type of worker.

The second component reflects the productivity of labour; industries with declining labour productivity will require an increasing fraction of total employment. The final component relates to final sales: an increase in the demand for a particular type of worker will ultimately increase the number of such worker types in the economy. For a survey of the related literature on skill-biased technological change, see Card and DiNardo (2002).

The data for this exercise were taken primarily from Canadian Input/Output tables and covers the period 1971 to 1991. The data required to implement the type of approach used by Lavoie and Roy is not readily available for the Irish case. Input/Output tables are compiled infrequently by the Irish statistics office, and the last one was published in 1990. Therefore, relying on data from this study would not provide an accurate picture of the events of the 1990s in Ireland. Although this method of compiling a measure of labour heterogeneity does have some advantages, not least fact that it does not require data on wages, the main general criticism of these studies based on examining the distribution of hours worked across occupations is that they are likely to exclude other important sources of labour heterogeneity such as sex, age, education and so forth.

In fact, the use of these more "fundamental" characteristics has been more common in the literature than the occupation-based methods described above. One may wish to use as many characteristics as the data permit, or only a small subset of available characteristics. For example, one may wish to isolate the effects of one or two

variables on productivity; the United States Bureau of Labor Statistics (1993) cross-classified hours worked only by educational attainment and work experience. This approach minimizes the correlation between the measures used to differentiate labour input so that independent sources of change in labour quality can be identified (on this, see also OECD, 1998).

Interestingly, a study by Fosgerau, Jensen, and Sorensen (2002) supported the idea of using only a limited number of educational categories in accounting for labour quality. They compared a four category education index for Denmark to a 29 category index for the same country. They found that these measures of education were so highly correlated that the practice of using less rather than more educational characteristics was defensible.

Jorgenson and Ho (2001) is an excellent example of this type of analysis and arguably represents "best practice" in this field. This work updates and improves upon the important work of Jorgenson, Gollop and Fraumeni (1987). It presents annual indices of labour input for the US civilian workforce for the period 1948 to 1995, and the labour input is classified according to sex (2 categories), age (7 categories), level of educational attainment (6 categories), employment class (2 categories) and industry (51 categories), giving rise to $2 \times 7 \times 6 \times 2 \times 51 = 8,568$ types of workers. The measures incorporate individual data from various Censuses of the Population, individual data from the annual Current Survey of Population, National Accounts data, BLS data and others.

The methodology employed in this paper follows the "recommended" way of constructing an index of labour input by expressing this volume of labour input as a weighted translog function of its components, where the weights are given by the average shares of the individual components in the value of labour compensation. Value shares are calculated from data on labour compensation cross-classified by sex, age, education and the employment class of the worker. The effects of substitution are taken into account using partial indices of the volume of labour input, using the techniques discussed in detail in Jorgenson, Gollop and Fraumeni (1987).

Young (1995) employs essentially the same types of technique, although his data for Hong Kong, Singapore, South Korea and Taiwan are less detailed than the Jorgenson and Ho (2001) paper. He attempts to estimate the working age population, cross-classified by up to seven characteristics: sex, age, education, industry, class of worker, income and hours of work. Sex is classified into two categories, age into nine to eleven countries, depending on the country and time period, and education into two to seven categories, likewise depending on the country and time period.

Quality adjusted labour input - Data limitations in the Irish case

These studies are good examples of the methodologies and types of data required to create a comprehensive, consistent and detailed measure of heterogeneous labour input. With this in mind, this chapter attempts to replicate as far as possible

the methodologies and principles used in these papers. However, this proved to be difficult given the limitations of available data.

The most important data needed to implement a study along the lines of Jorgenson and Ho (2001) are earnings data on different types of worker, where the different types of worker are distinguished on the basis of the categories discussed above: sex, age, education, industry, and so on. This type of data are not collected by the Central Statistics Office (CSO) in Ireland. The data are neither published nor are they collected for the data underlying the compilation of the Irish Labour Force Survey. The CSO only started collecting wage data for their National Employment Survey on the distribution of individual employee earnings by region, sector, occupation, age, education and other variables from the Summer of 2003.

Eurostat likewise neither publish nor collect earnings data for different types of workers, nor do they collect data on earnings by individual characteristics to use as underlying data to help build their Labour Force Survey. The OECD publication "Education at a Glance" contains a limited series of data of the earnings of Irish workers, distinguished by various characteristics. However, the data are only available for the years 1993 through 1997, and include a major classification change. The ILO publication "ILO Handbook of Labor Statistics" only contains data on the wage data by gender, but these data are only available for the years 1999 onwards. Another option is The European Community Household Panel survey (ECHP), but these data

are collected only in discrete waves and does not cover comprehensively the period under review in this paper.

This lack of data requires an examination of alternative sources of information on wages. Some authors, notably Harrigan (1999), have managed to get around a lack of wage data when constructing measures of heterogeneous labour input for growth accounting type exercises. Harrigan (1999) obtains hours- worked data and occupational data from the Yearbook of Labor Statistics, and disaggregates hours worked data into three occupational categories. These are then aggregated using each occupation's share in total labour cost. Using this American data, he assumes the other countries in his sample display the same occupational wage structure as the US. To support such an assumption for an economy like Ireland, during a period of massive change in the structural characteristics of its economy, would be to strain credibility. Harrigan's paper also focuses only on the manufacturing sector, and hence is not applicable to an economy-wide study of the type developed in this chapter.

Cameron, Proudman and Redding (2005) use United Nations data on the proportion of production and non-production workers in a panel of industries to control for cross-country industry variation in the skill composition of the workforce. They argue that there is a high correlation between the share of non-production workers and the share of high-education workers in employment, so in this way this provides a simple way of controlling for heterogeneous labour quality. Again, these data are

only available for manufacturing sector workers, and were not collected after 1991 for Ireland.

In other respects, the data for Ireland is lacking compared to almost every other OECD country. For instance, Irish census data contains comparatively little information on wages and education levels, and nothing on the wage rates enjoyed by workers with different levels of educational attainment. The 1981 and 1991 censuses contain only basic data on the educational accomplishments of the working force, and even these data were not collected in 1986 or 1996 censuses (Durkan, Fitzgerald, and Harmon, 1999). The CSO did however provide quite detailed unpublished data on levels of educational attainment in Ireland, over six categories of attainment of persons aged 15-64 years, for every year between 1988 and 2002.

However, these data did undergo a classification change in 1998, so that the 1988-1997 are not directly comparable with the results from subsequent years. Nevertheless, it is evident that in this short 14 year period a major change in the composition of the workforce took place. For example, the proportion of the workforce with only a primary school education fell from 33% in 1988 to 21.5% in 2001. The proportion of people with third-level qualifications rose from 11% in 1988 to 20% in 2001.

These changes highlight the need to properly account for this same change, as educational change may justly be regarded as being one of those distinguishing char-

acteristics of labour input that is likely to have a very significant impact on productivity. As Durkan, Fitzgerald and Harmon (1999) note, "the question...is the extent to which this increase in the level of educational attainment represents an increase in the effective employed labour force, that is, what weights must be attached to education differences to generate an 'education-adjusted employment/labour force' ". The correct way of weighting these educational attainments is to use marginal productivity, that is, the wage rate of each type of worker.

Given the lack of wage data available for the Irish economy, Durkan *et al.* (1999) take a more indirect approach. They use data from a large scale survey of earnings and education from 1987 to derive weights to use for the census results from 1981 and 1991. The survey's results only related to 1987 but are applied to their data from 1981 and 1991 on educational attainment on the basis that the 1987 survey results are approximately the same (on this see Barrett, Callan and Nolan, 1997, who find limited changes in the returns to different levels of educational attainment in 1987 and 1994 samples) as the results of a similar study using the 1994 data, suggesting that the returns to different levels of education were not changing over time during this period. The 1994 study is based on the CSO's Household Budget Survey for that year, which is a similar but different survey to the ESRI (1987) survey. Durkan *et al.* then use their estimated returns to years of education from different categories of education to create a simple constant quality index of educational attainment.

The Household Budget Survey is a representative survey which is conducted periodically - the three most recent surveys took place in 1987/1988, 1994 and 1999/200 The primary task of this survey is to determine expenditure weights used in creating price indices and as such the survey asks respondents questions about household consumption of goods and services, as well as a range of demographic and socioeconomic questions. In each of the three surveys, approximately 7,500 households responded to the survey.

Useful data are also collected on income, expenditure and employment (on this, see O'Neill, 2000). The approach adopted here to overcome the data limitations enumerated above is to estimate the returns to education by using the complete set (1987, 1994 and 1999/2000) of available Household Budget Surveys to estimate a simple wage equation to control for changes in the compositional quality of the labour force.

A simple wage equation

Using the three Household Budget Surveys, a parsimonious "Mincerian" wage equation is estimated using a Two Stage Least Squares (2SLS) instrumental variable estimator. The dependent variable used for the three regressions is the gross hourly wage. This wage data is available only for the head of household, whether male or female. Wage data is also reported for only for employed persons. To ensure

consistency, the analysis focuses on male heads of household who were in receipt of a wage during the survey period[18].

Wage data is only available for those in employment, and therefore heads of household who are unemployed, retired, incapacitated or otherwise not earning a wage are necessarily excluded. Excluding these groups as well as the female heads of household results in a sample size of 2,906 male wage earners from a sample of 7,705 households in 1987, 2,325 from 7,877 households in 1994 and 2,230 from 7,644 households in 1999/2000.

The same regression specification and estimation technique was applied to each survey. Gross hourly wages were modeled as a function of the logs of education, age squared (to capture the effects of experience and the concavity of the earnings profile), the social group of the head of household (to help control for unobserved factors influences such as ability or motivation), marital status, and a binary variable denoting urban residence. The estimated model therefore takes the following form:

$$\log(HourlyWage) = Education + Age^2 + Urban + SocialClass + MaritalStatus \tag{1.7}$$

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[18] There are clearly some econometric complications introduced into the analysis by overlooking the possible effects of sample selection bias, since the analysis focuses only on those males in full-time employment, and the characteristics of these groups of individuals may differ in a material way from excluded groups of individuals. As noted, this position therefore admits the possibility of introducing sample selection bias into the analysis. Since this bias is not tested for, the results should be interpreted in a manner which reflects this fact.

This simple specification is chosen because of its close relation to the empirical models used by Mincer (1974) to estimate the return to schooling as predicted by the theoretical neoclassical human capital framework. As Harmon, Oosterbeek and Walker (2003) note, this model is an important benchmark for research on the returns to education, as it was one of the first papers to estimate returns to education on the basis of an empirical model based closely on a consistent underlying theoretical model[19].

The equation is estimated using a 2SLS approach, in which spousal educational attainment serves as an instrument for the education of the head of household. Given the well known endogeneity problems of wage equations of this nature, using this spousal instrument seems a reasonable choice. One could make any number of objections to this instrument (perhaps men, for example, choose more or less educated wives, and so on) but in the current context this instrument seems to be a reasonable compromise.

Some classification changes took place between surveys, notably between the 1987 and 1994 surveys with respect to the measurement of education. The 1987 figure is based on years of education, calculated from reported data on the age at which the head of household ceased education, whereas for the other two years the survey measures the highest level of education attained by the head of household. This dif-

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[19] More recent empirical work in this field has placed increasing emphasis on the role of natural experiments that randomly assign individuals to different groups with correspondingly different educational experiences, but this type of analysis is beyond the scope of the present chapter and not possible given the available data.

ference requires some assumptions to be made about the actual years of education received by these family members.

For 1987 it was assumed that the head of household enjoyed $n - 4$ years of education, where n represents the reported year at which education ceased, and 4 reflects the fact that Irish children generally start school at 4. For the other two surveys, the highest level of education attained is reported, and this is converted into a years of education figure by assuming that a degree holder has enjoyed $21 - 4 = 17$ years of education, a senior school leaver has enjoyed $18 - 4 = 14$ years of education[20], and so on.

The results are presented in the table below.

Note that in this table, as elsewhere in this thesis, one asterisk indicates significance at the 10% level, two asterisks indicate significance at the 5% level, and three asterisks indicate significance at the 1% level. The results in this table indicate a return of roughly 6.5% per annum, a figure which is broadly the same for each sample period. There is a premium to residing in urban areas, and to being part of a high-ranking social group. Interestingly, there does not appear to be a premium connected to being married, in contrast to the findings of Denny and Harmon (2000). The estimated rates of return are similar, if somewhat lower, to those in other Irish studies, including Durkan *et al.* (1999) who find a return of approximately 8% per

[20] This reflects the typical ages at which these levels of education are completed.

	1987	1994	2000
Log gross hourly earnings			
Years of education	0.0657	0.0720	0.0607
	(0.006)***	(0.006)***	(0.022)**
Age squared	0.0063	0.0082	-0.0190
	(0.006)***	(0.001)***	(0.007)**
Urban	0.0151	0.0349	0.0216
	(0.007)**	(0.009)***	0.0511
Marital Status	0.1082	-0.0785	0.0326
	0.1440	(0.008)***	0.1870
Social Group	0.0111	0.0230	0.0977
	(0.006)**	(0.006)**	0.0610
Constant	-0.3130	0.6354	0.8490
	0.1780	(0.097)***	(0.468)*
Adjusted Rbar-squared	0.12	0.28	0.15
No. of observations	2906	2325	2301

Figure 1.6: A simple wage equation for males heads of household.

additional year of schooling. Denny and Harmon (2000) find a return of between 7% and 13%, depending on the regression specification used.

This figure is used to create an index of educational attainment. The educational index is calculated by using the finding from the estimated wage equations that an additional year of schooling for males is worth 6% per annum. In the absence of any information on returns to female education in Ireland, the conservative assumption that females do not enjoy higher returns to education is employed in the analysis.

An individual of either sex who has no recorded educational experience whatsoever is given a value of unity for their productivity contribution. A person who has only completed primary school has received 8 years of education, and this corre-

sponds to a productivity contribution of 1.06^8. Likewise, a person who has completed a postgraduate tertiary education receives a value of 1.06^{19} in the productivity calculations. Each type of educational attainment is then weighted by the share of that level of attainment in all attainment levels; for example, if 22% of the male population did not receive education after the primary level then this category is awarded a weight of 22% as part the construction of the input measure.

1.5.3 Aggregation of labour input

The labour aggregation proceeds by constructing a Tornqvist index, in which weights applied to the labour hours data reflect each industry's share in total compensation at current prices. The aggregate index for labour input is calculated as follows:

$$\frac{L_t^A}{L_{t-1}^A} = \Pi_j \left(\frac{L_t^j}{L_{t-1}^j} \right)^{\frac{1}{2}\left(O_t^j + O_{t-1}^j\right)} \tag{1.8}$$

Again, the O_t^j are current price industry shares (in total labour compensation); L_t^j measures total hours worked in industry j. The adjustment for labour quality is applied equally to industry hours worked at the aggregate level because it was not possible to obtain educational attainment by industry.

1.5.4 Conclusion on labour input

This section was concerned with calculating labour input. The difficulties of complying fully with the recommended practices in the literature were noted and discussed.

A variety of data sources and alternative methods were suggested to overcome the limitations of Irish data in this regard A solution involving the calculation of a simple instrumented wage equation was used to control for quality.

1.6 Capital Input

This section of the chapter discusses the many involved economic and statistical issues that commonly arise in the measurement of capital, and uses the available Irish data to generate a measure of capital services[21].

Perhaps the most important difference between measuring labour and capital input is the fact that the enterprise unit or sector generally tends to own the capital it employs in its business. This means that in general there is no market transaction recorded for the use of a capital service, unlike labour services for which the hourly wage provides a measure of the marginal productivity contribution of a particular type of worker. Measurement of the cost component of capital services in these circumstances is often the key element in productivity studies. Capital services are flows of productive services that are contributed by a unit of capital to a production process.

Traditionally, economists have used estimates of capital stocks to quantify capital's productivity contribution, and this practice continues to be used as a matter of

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[21] A very useful introduction to the theory and practise of the measurement of capital services is provided by Oulton (2001a).

routine in many contemporary studies. However, economists have long interpreted relationships of the form $Y = F(K, L)$ as being a description of how flows of inputs determine the flow of output (Hulten, 1990), and the importance of using capital services and not capital stock will be made clear below. The appropriate means of including flows of capital services in growth accounting studies are discussed. Modeling the way in which the price and efficiency of a capital asset declines over its lifetime, and the manner in which these assets are retired, are further problems that are addressed below.

1.6.1 Constructing a measure of capital services

It is helpful to start with some definitions. The gross capital stock of an asset is the cumulated flow of all past investments in that asset, corrected for retirements, disposals, and accidental damage. The productive capital stock is the gross capital stock adjusted for declines in efficiency as an asset ages. Intuitively, it represents a measure of the size and usefulness of the capital stock that is available for use in productive activities. The net or wealth stock of an asset is the productive capital stock valued a market prices. These definitions have been for a single asset, but can be readily extended to aggregate measures.

Since in general the price of capital services is not observed, and since the goal is usually in aggregating heterogeneous capital inputs into aggregate indices, user

costs of capital must be calculated, which can be shown to be equivalent to marginal productivities of capital under certain circumstances.

User costs are the correct weights to use in aggregating flows of capital services from individual assets or classes of assets, and these user costs will be discussed in some detail below. This general approach to the measurement of capital input was pioneered by Jorgenson(1963) and Jorgenson and Griliches(1967). If market prices had been used instead of user costs to aggregate a productive stock measure, a measure of net or wealth capital stock would have been obtained.

It is helpful to see in mathematical form the variables that influence the productive stock (OECD, 2001a). Below, $K^P_{i,t}$ is the productive stock of capital asset i and time t:

$$K^P_{i,t} = \sum_{\tau=0}^{T} h_{i,\tau} \cdot F_{i,\tau} \frac{IN_{i,t-\tau}}{q_{i,t-\tau,0}} \tag{1.9}$$

$IN_{i,t}$ is nominal investment expenditure at time t for asset i, $q_{i,t-\tau,0}$ is an investment price index for a new asset i (i.e.. one that is zero years of age), $F_{i,\tau}$ is a retirement function that describes the distribution of discards for asset i, h_i is an age efficiency profile which models the decline in the productive capability of asset i as it ages. The empirical implementation of these variables is desribed in turn.

1.6.2 Classification of assets

The first step in measuring capital services is to calculate a measure of capital stock for as many and as disaggregated classifications of capital asset types as is feasible.

The ESRI databank contains national accounts statistics on investment expenditure and producer price indices. These series, on gross fixed capital formation, are available from 1960 (and earlier in some cases) to 2001 for the following assets:

- Roads
- Dwellings
- Non-residential construction
- Transport equipment
- Agricultural machinery
- Other machinery and equipment
- Software

This represents the most disaggregated series of investment data available in the ESRI Macroeconomic Databank[22].

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[22] There is no reason why other types of assets such as human capital and so on ought not to be included, except that it is difficult to include these types of assets in the analysis in a way consistent with the underlying production model (Harper, 1997). Even when data is available, it is not clear how one would relate the management of say, a firm's portfolio of human capital assets to its production decisions.

1.6.3 The retirement of assets

Once the series of real investment expenditure has been generated, the next requirement in arriving at an estimate of the productive capital stock is to model the retirement of assets, since no asset is used indefinitely. This must be done using indirect methods, since as Hulten (1990) notes, "...most fixed capital is produced and sold in markets, there is a data 'trail' that can in principle be followed...the same cannot be said about deletions from the stock. The reduction in capital can occur through in-place declines in efficiency and through retirement. Neither presents a broad trail of market data that can be used to determine the magnitude of deletions".

Data on the mean productive life of assets and a retirement distribution centered on that mean life is needed to model the retirement of assets. Estimates of the mean useful service life of these assets are not available for Ireland, although there are estimates of asset life which have been collected for the purposes of tax assessment, but these figures would not be appropriate for use in a capital services study, in that the figures are not based on scientific estimates or calculations of actual mean useful life.

In the absence of any studies specific to Ireland, estimates of mean useful service life had to be taken from other countries; the simple average of the lives of identical or highly similar classifications of assets in the US, Canada, the Czech Republic and the Netherlands was used. This data was taken from the OECD Capital

Manual (2001b). The averaging of the data from the four countries, and the fact that all of the countries are advanced industrial countries[23] will hopefully remove or at least attenuate any biases that might have prevailed had a single country been relied on for the estimates. The calculated value of mean service life appear in the table below:

Asset Class	**Mean Service Life (years)**
Transport Equipment	19
Agricultural Machinery	12
Other machinery and equipment	14
Software	3
Roads	42
Dwellings	70
Other building and construction	42

Figure 1.7: Selected average OECD asset lives.

The next step is to apply a retirement or mortality function to the investment series. In practice, a variety of approaches have been used, and the choice of mortality function is in part arbitrary. Any mortality function must at least approximate the actual empirical retirement profile endured by assets, and to correspond to some degree to what we would expect on a priori theoretical grounds. As Blades (1983) observes, fixed assets that are installed at the same time are generally not withdrawn from use at precisely the time they reach the mean service life for that asset. Assets

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[23] It is perhaps debatable as to whether the Czech Republic qualifies as an "advanced" industrial economy, but it was once one of the most advanced and prosperous of the industrial economies and has been one of the stronger performing transition economies in Central and Eastern Europe.

will be retired from use before and after the mean service life, and this means that a retirement distribution must be either assumed or a distribution be generated from empirical observation[24].

A wide range of such mortality functions are used in practice. These functions are usually based on bell shaped distribution, reflecting the idea that the main mass of retirements will occur around the mean service life, but there will be retirements before and after the service life. The skewness of the distribution can also be modified to accord more closely with the expected or actual retirement behaviour of the asset in question. Bell shaped functions that are used, or have been used to simulate the actual retirement of assets include the normal, log-normal, gamma, logistic, quasi-logistic, and Weibull distributions. Most countries use symmetrical distributions (OECD, 1993), but Germany uses left skewed gamma functions, while Sweden and Australia have used symmetrical and right- skewed Winfrey mortality functions.

Mortality functions which are not based on bell-shaped distributions are also used. An extreme and unrealistic form of mortality function is the simultaneous exit approach. This assumes that assets of the same vintage are retired simultaneously on

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[24] One notable piece of work, which continues to be influential and is still used by some national statistical agencies, is due to the American engineer Robley Winfrey (1935), who carefully studied the retirements of industrial fixed assets in the United States in the 1930s. He generated a wide family of skewed bell shaped type functions to correspond with the observed retirement pattern of different types of assets. Opinion is divided as to the usefulness of this class of these distributions for modern capital stock estimation. While they do have the advantage that they have been derived from empirical evidence on actual retirements, the composition of the assets Winfrey studied reflected the prevailing industrial structure, and was heavily biased towards railway stock. Hence, it is unclear why a certain type of skew Robley distribution should be applied to a particular asset. Therefore, in this study, and in common with other studies and the practice of many OECD statistical agencies, I examine more general types of mortality functions.

the day they reach their mean useful life. Such an assumption is clearly unrealistic, but it continues to be used due to its very simple and tractable form.

Another related retirement function that is sometimes used for its simplicity, is the linear retirement function: assets are assumed to be disposed of at exactly the same rate every year from the date of first use until exactly twice the average useful life for that asset. The constant rate of annual retirement is equal to $\frac{50}{L}\%$ where$L$ is the average life for a particular asset. A related mortality function is the delayed linear approach. Retirements are assumed to occur at a constant rate over some interval centered symmetrically around the mean service life. For instance, some statistical agencies, including the UK and New Zealand, have used delayed linear retirement profiles where assets are retired over the period from 80% to 120% of the average service life, thereby meaning that $\frac{1}{L(1.2-.8)}$ or $\frac{250}{L}\%$ are retired every year during the retirement period.

To model the retirement of assets for the Irish case, both bell shaped and non-bell shaped retirement profiles are used to help improve the robustness of the results. In the first instance, a delayed linear profile (of the form described above) was used, due to its inherent simplicity and because of the fact that it has in the past been applied by national statistical agencies in the past to real world investment data. This is the main retirement pattern used to model discard patterns. As a test of the basic robustness of this approach, a Weibull distribution was also used to model discard patterns. This distribution is widely used by national statistical agencies to model

these discard patterns, as well as in a number of other fields including, amongst others, reliability analysis of manufacturing equipment and the mortality patterns of living organisms. Its popularity is due to its reasonably tractable mathematical form and the fact that its flexibility allows it to replicate or approximate other distributions, including various Winfrey curves. For replicative and comparative exercises of this nature, see Blades (1998) and Sim and Soon (1999).

Meinen, Verbiest and de Wolf (1998) provide another justification for the use of this distribution: they discuss how the Weibull distribution arises theoretically as the limit for the smallest of a large number of non-negative variables, and interpret this in the context of mortality modeling by assuming that the limit law is directly related to the net present values of future revenue generated per unit of time by the asset. The working life of the asset obviously ends when the net present value falls below a limit value, and they argue that the "...latter process strongly suggests a Weibull distribution of service lives". The Weibull probability density function is given below:

$$f(x) = \alpha\lambda(\lambda x)^{\alpha-1}\exp(-(\lambda x)^{\alpha}) \tag{1.10}$$

Here, x is the number of years since the asset was installed; α and λ are shape and size parameters, respectively[25]. The λ parameter determines the kurtosis of the

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[25] The following useful summary is provided by OECD (2001b).
$0 < \alpha < 1$: risk of discard increases over time.
$\alpha = 1$: risk of discard is constant
$1 < \alpha < 2$: risk of discard increases (at a decreasing rate).

distribution. The α determines the skewness of the function and may be interpreted as a measure of the changes in the risk of an asset being discarded (OECD, 2001b, and Meinen, Verbiest and de Wolf, 1998). The choice of discard pattern (delayed linear or Weibull) had almost no material impact on the estimated TFP figures, and therefore the delayed linear model was used to model retirements.

1.6.4 Age efficiency profiles

The next step in constructing a measure of productive capital stock is to model the age efficiency profile of assets (h_i in the equation above). The age efficiency profile is a portrait of the quantity of capital services rendered by an asset. Assets tend not to have a constant level of productive efficiency for the duration of their useful lives. Assets which do exhibit this unusual feature are referred to as having an age efficiency profile of the "one hoss shay" type[26].

However, richer and more general functions are often needed to describe the age efficiency profile so as to more accurately capture the flow of productive capital services from an assets. In practice, there is a lack of empirical evidence concerning the actual shape of the profile and some subjective judgment needs to be exercised. In the words of Hulten (1990), "A definitive appraisal of alternative methods is im-

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$\alpha = 2$: risk of discard is linearly increasing.
$\alpha > 2$: risk of discard is progressively increasing.

[26] After the poem by Oliver Wendell Holmes in which a one-horse chaise is built and works perfectly until collapsing into total disrepair after one hundred years of use. Light bulbs are often described as being one hoss shay, although whether the useful life of a light bulb is long enough to qualify it as a capital asset is open to debate. One could imagine a piece of furniture as possibly having a "one hoss shay" efficiency profile.

possible without an independent benchmark". Profiles actually used include the one-hoss shay, the straight line, the geometric and the hyperbolic. The choice of profile has implications for the shape of the age price profile (which is simply the pattern of prices of an asset over its service life) and this important link is elaborated upon below. First, it is useful to have a brief discussion of the different types of productivity decline modeled by each of the age efficiency profiles.

The one-hoss shay profile has already been discussed. Straight line efficiency decline implies the difference between an efficiency parameter β between adjacent time periods is constant. Mathematically, this may be written as:

$$\beta_{\tau-1} - \beta_{\tau} = \frac{1}{T} \text{ for } \tau = 1, .., T-1. \tag{1.11}$$

This approach has the advantage of computational simplicity, but it is unlikely that such a age efficiency pattern would ever be observed for a large class of assets. The geometric profile is very widely used. Geometric decline implies productive efficiency declines by a constant rate every period. Mathematically, this may be written as:

$$\frac{\beta_{\tau-1} - \beta_{\tau}}{\beta_{\tau-1}} = \delta. \tag{1.12}$$

The use of the geometric profile has been popular for a number of reasons, not the least of which is its computational simplicity. When a geometric function is used for the age-efficiency profile, it can be demonstrated that the corresponding age-price

profile is also geometric. In other words, there is no distinction between the net and productive capital stocks.

Hulten and Wykoff (1981a,b,c) used this feature of geometric profiles to estimate the relative efficiency of capital goods of different vintages. Since the age-price profile is the same as the age-efficiency profile (in the geometric case), they studied the prices of assets of different vintages in second hand markets. They found that the acquisition price of an asset declines roughly geometrically with age, suggesting that productivity studies should use the geometric age efficiency profile, both for its analytical tractability and the empirical support it received from these studies. These studies proved influential, and many notable contributions to aggregate productivity analysis used this geometric approach, including Jorgenson, Gollop and Fraumeni (1987).

However, this approach is not without its problems. The most basic objection is that only a small number of capital assets are ever actively traded in liquid second-hand markets, thereby raising doubts as to the generality of the Hulten-Wykoff conclusions. Geometric efficiency decay also seems rather rapid under certain circumstances; for example, 34% of an asset's productive efficiency is lost over four years with a 10% rate of decline (Hulten, 1990). Furthermore, under geometric decline, an asset obviously never reaches a state of zero efficiency. Perhaps a more penetrating criticism, due to Harper (1982), is that very different age-efficiency schedules can give rise to very similar age-price profiles. Studying the age-price profile of

used assets in secondhand markets is therefore subject to an identification problem, since one can not be sure to which age-efficiency profile it is related. For example, a hyperbolic age-efficiency profile with a scaling parameter of .5 will give rise to an almost geometric age-price profile[27].

The hyperbolic age-efficiency profile offers a partial solution to some of these problems, and is used by the Australian Bureau of Statistics (ABS) and the US Bureau of Labor Statistics (BLS). With hyperbolic decay, efficiency decline is relatively modest in the years immediately after the initial installation before the rate of decline increases as the age of the asset nears its average service life. Mathematically, for any asset i it is of the form below:

$$h_t = \frac{L - t}{L - \beta t} \tag{1.13}$$

h_t is the relative efficiency of a t-year old asset, L is the average service life for the asset, t is its age since installation, and β is an efficiency decline parameter (constrained to lie between zero and unity), and this parameter can be used to nest other forms of efficiency decline. $\beta = 1$ implies that there is no efficiency decline, (since the function value is constant and this obviously corresponds to one-hoss shay decline) while $\beta = 0$ implies straight-line efficiency decline. $\beta = \frac{1}{2}$ results in a

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[27] As an example, consider again the case of the light bulb; this specific example is due to Harper (1982): a light bulb is one-hoss shay efficient for 1,000 hours. What is the corresponding age price profile? After 500 hours of burning, its price would simply be one half of its original price, since it is only capable of producing one half as many capital services as a new bulb. In other words, the age-efficiency profile is one-hoss shay, but the age-price profile is straight-line.

concave efficiency profile, and a convex age-price profile, similar to the geometric age-price profile revealed by the econometric studies of Hulten and Wykoff.

The concave efficiency profile of this particular hyperbolic function could be seen as being a more realistic portrayal of efficiency decline than the convex shape of the geometric function (Harper, 1982). The ABS (Australian Bureau of Statistics) and the BLS (the American Bureau of Labor Statistics) both set $\beta = \frac{1}{2}$ for machinery and equipment, and set $\beta = \frac{3}{4}$ for buildings and structures, since such capital assets may be expected to decline in productive efficiency more slowly than machinery and equipment. These are the parameter values used in this paper. Absent detailed empirical work for every capital asset, it can be argued that the choice of the exact value of the β, the efficiency parameter, is no more or less arbitrary than choosing the constant rate of decline in geometric functions (Harper,1982). See Table 5 for a pictorial representation of the hyperbolic function for different values of the shape parameter.

1.6.5 Age-price profiles

This brings us to the relationship between age and age profiles. Why is an asset age-price profile needed? The answer lies in the need for a variable describing the rate of depreciation in the user cost term. Depreciation here is defined as simply the price differences between successive vintages of a capital asset. The user cost of capital is the (rental) price component associated with the flow of capital services

produced by an asset, and represent the amount of rent that would have to be charged to cover the costs of q dollars worth of an asset (OECD, 2001a). The simplest possible mathematical expression for the user cost formula is given below:

$$\mu_t = q_t \cdot (r_t + d_t) - (q_t - q_{t-1}) \tag{1.14}$$

Here, q is cost of new asset, d is rate of depreciation, and r is a measure of the cost of financial capital[28]. The first term, $q_t \cdot (r_t + d_t)$ measures the cost of financing the asset. $q_t r_t$ can be seen as either the interest cost of financing the asset or the opportunity cost of employing capital in other activities. $q_t d_t$ reflects the loss in value of the machine as it ages. The second term in the user-cost equation measures capital gains or losses.

One should further note that the above expression does not allow any role for taxation, even though tax is often an important component in the cost of capital. As the OECD notes, "It is apparent that the inclusion of tax variables comes at a non-negligible cost. For a full implementation, historical and current tax laws have to be monitored, by type of asset and by industry, along with assumptions of tax lives and estimates of business income tax rates". It is for these reasons that the lead of many other studies is followed and the effect of taxation is simply ignored in this chapter.

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[28] Oulton (2005) contains an interesting discussion as to which of ex ante or ex post measures of user costs is the most appropriate measure to use in growth accounting. In theory, ex post measures are the correct measure to use, and researchers generally use ex post measures, but this is legitimate only if realised expectations are correct. Oulton recommends a hybrid approach based on ex ante and ex post measures. However, the simple ex post measure is used in this chapter.

This brings us to the question of how to calculate the variables appearing in the user cost equation. The r term is the cost of financial capital. Hall and Jorgenson (1967) present an indirect way of calculating r residually based on the observation that total non-labour income is the difference between value added and labour compensation.

A more straightforward approach is simply to take the average value of borrowing and lending that is faced by producers, and this is the measure which is used in this chapter. The interest rate is calculated as the average of interest rates on three-month business deposits and of interest rates on business overdrafts. As the OECD (2001a) notes, no definitive answers have been provided as to which financing measure to use and "much speaks for solutions that are governed by data availability". The capital gains and losses term can be derived from price indices of new assets.

This leaves the depreciation term d as the only variable yet to be determined. Recall that depreciation in this context involves a comparison of the price a t year old asset in a particular year with the price of a new asset in that same year. It is not the change in the market price of the asset from one year to the next. Econometric studies like the Hulten-Wykoff (1981a,b,c) papers cited above can pin down depreciation values, but this is of assistance only for those capital goods that are traded on secondhand markets. One could assume a particular age-price profile, but this has implications for the shape of the corresponding age-efficiency profile, and one must

be careful in this regard since a reasonably shaped age-price profile can give rise to age-efficiency profiles that one would not expect to observe in practice.

An alternative solution, proposed by Harper (1982), the OECD (2001a, b) and the ABS (2001) is to assume a particular form for the age-efficiency profile, and then infer the corresponding age-price profile. The age-profiles are used to estimate net stock, from which depreciation is obtained indirectly. This method ensures consistency between both varieties of profiles, and yields a figure for depreciation that is consistently constructed.

Derivations of the link between efficiency and price profiles are available in Harper (1982), Hulten (1990) and OECD (2001a); the presentation here closely follows OECD (2001a). A fundamental theorem in capital theory states that in competitive equilibrium, the cost of an asset is equal to the value of the asset; the value of the asset is equal to the discounted expected future rents (user costs) yielded by the asset over its lifetime. The price of an asset that is s years old in year t is given by the formula:

$$q_{i,t,s} = \frac{\sum_{\tau=0}^{T} \mu_{i,t+\tau,\tau+s}}{(1+r)^{\tau+1}} \tag{1.15}$$

Where the notation is defined as above; r is a discount factor. This equation does not say anything about efficiency, but a relationship does arise from cost minimization. Note that the ratio of user costs between different vintages of the same asset is the same as the ratio between the relative productive efficiency of these dif-

ferent vintages of the same asset, once one corrects for the survival probability of the vintage. If these vintages are perfect substitutes for one another, then they must differ only in their relative efficiency and the rental price will reflect this, so we may write:

$$\frac{\mu_{i,t,s}}{\mu_{i,t,0}} = h_{i,s}F_{i,s} \tag{1.16}$$

Where the h and F functions are defined as above. Using this relationship, we can rewrite the fundamental asset market equation as follows:

$$q_{i,t,s} = \frac{\sum_{\tau=0}^{T} \mu_{i,t+\tau,0}h_{i,\tau+s}F_{i,\tau+s}}{(1+r)^{\tau+1}} \tag{1.17}$$

We know that the age-price profile is the pattern of asset prices over the service life of an asset. We may express this a function $z_{i,\tau} = \frac{q_{i,t,\tau}}{q_{i,t,0}}$. Writing this expression out in full gives:

$$z_{i,\tau} = \frac{q_{i,t,\tau}}{q_{i,t,0}} = \frac{\sum_{\tau=0}^{T} \mu_{i,t+\tau,0}h_{i,\tau+s}F_{i,\tau+s}(1+r)^{\tau+1}}{\sum_{\tau=0}^{T} \mu_{i,\tau}h_{i,\tau}F_{i,\tau}(1+r)^{\tau+1}} \tag{1.18}$$

As the OECD (2001a) notes, we now make a simplifying assumption that the nominal future income of the asset grows at a constant rate β so we may write:

$$\mu_{t+\tau,0} = \mu_{t,0}(1+\beta)^{\tau} \tag{1.19}$$

This allows us to rewrite the expression for $z_{i,\tau}$ as follows:

$$z_{i,\tau} = \frac{\sum_{\tau=0}^{T} \mu_{i,t,0}(1+\beta)^{\tau} h_{i,\tau+s} F_{i,\tau+s}(1+r)^{\tau+1}}{\sum_{\tau=0}^{T} \mu_{i,t,0}(1+\beta)^{\tau} h_{i,\tau} F_{i,\tau}(1+r)^{\tau+1}} \tag{1.20}$$

$$= \frac{\mu_{i,t,0}(1+\beta)^{-\tau} \sum_{\tau=0}^{T} h_{i,\tau+s} F_{i,\tau+s}(\frac{1+r}{1+\beta})^{-(1+\tau)}}{\mu_{i,t,0}(1+\beta)^{-\tau} \sum_{\tau=0}^{T} h_{i,\tau} F_{i,\tau}(\frac{1+r}{1+\beta})^{-(1+\tau)}} \tag{1.21}$$

Cancelling identical terms in the denominator and the numerator, and picking a discount rate of 4% for the $(\frac{1+r}{1+\beta})$ parameter yields the final expression for the age-price profile, which also shows the dependency of this profile on the age-efficiency profile:

$$z_{i,\tau} = \frac{q_{i,t,\tau}}{q_{i,t,0}} = \frac{\sum_{\tau=0}^{T} h_{i,\tau+s} F_{i,\tau+s}(1.04)^{-(1+\tau)}}{\sum_{\tau=0}^{T} h_{i,\tau} F_{i,\tau}(1.04)^{-(1+\tau)}} \tag{1.22}$$

Now that an expression for the age-price profile has been obtained, the asset's net stock may be calculated. The age-price profile is applied to all of the vintages of investment for that asset, in the same way that the age-efficiency profile is applied to different vintages of investment as a means to calculate the gross stock. When expressed in real terms, year to year changes in the net wealth stock are due to the effects of new investment and to depreciation.

The ratio of the level of depreciation to the net stock gives a value for the rate of depreciation δ that appears in the user cost formula. A significant advantage of this approach is that it ensures consistency between age-price profiles and age-efficiency profiles, thereby ruling out the problems that sometimes affect growth accounting studies, whereby one of the profiles has a grossly unrealistic form due to inconsistent

assumptions about depreciation being applied to the other profile. On this particular problem, see ABS (2001).

The initial capital stock

One practical issue that has not been addressed thus far is the problem of calculating initial capital stocks. The investment data for each asset class begins in 1960. Henry (1989) undertook research to determine the Irish capital stock, including the use of direct survey data, but his findings are of limited use in this context as there is little or no concordance between his investment and asset classification and the classifications used in this chapter.

Various other methods have been adopted, but it is worth noting that whatever method used is likely to have only a small effect on estimates of capital services, given that the investment data start in 1960 but the period of analysis used for this paper begins in 1980 and therefore, for assets that have a less than 20 year mean service life, the influence of the initial capital stock is reduced. Nevertheless, this value does have to be somehow determined, and I use two different established methods among the many available to calculate the initial capital stock are used. The first was initially developed by Harberger (see Harberger and Wisecarver, 1977 and Harberger, 1978). The value of initial stock is found by inverting an equation of the form:

$$I_t = (\delta + y)K_{t-1} \tag{1.23}$$

Harberger (1978) provides a clear explanation of this technique and the variables involved. This method was applied to all of the actual investment data, since it seems reasonable to assume that the early years of the 1960s in Ireland were reasonably representative years, in that the full structural effect of the incipient reforms were not to be felt for a number of years[29].

An alternative means of calculating the initial stock was also employed. capital/output ratios of 2, 2.5 and 3 were assumed for Ireland in 1960, and apportioned this stock to the various assets on the basis of their average relative investment rates over the next three years. The results for each capital output ratio were similar to each other and to the Harberger method, and the effects were essentially indistinguishable when capital services in 1980 were computed. One should note that other approaches have been used in the literature, including constraining the initial capital output ratio to equal its average value over the entire sample period, and regressions which backward forecast investment flows to a starting value of zero; for applications of this type of analysis see Ball and Witzke (1993) and Mohtadi (2000).

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[29] Griliches (1980) presents a modified version of this procedure for countries that are away from their steady state.

Aggregation of assets

Once all of these figures have been calculated for individual classes of assets, they must be aggregated, using user costs as the aggregation weights, into superlative index numbers. This approach mirrors that used for other inputs, being based on the use of marginal costs as the aggregation weight, and hence the mathematical form of the Tornqvist index will be familiar:

$$= \Pi_i (\frac{K^P_{i,t}}{K^P_{i,t-1}})^{\tilde{O}_i} \tag{1.24}$$

Here, $\tilde{O}_i = \frac{1}{2}(O_{i,t} + O_{i,t-1})$ and

$$O_{i,t} = \frac{\mu_{i,t} K^P_{i,t}}{\sum_i \mu_{i,t} K^P_{i,t}} \tag{1.25}$$

One should note that an important assumption has been made in the first equation above. This formulation implicitly assumes that capital services are proportional to the productive capital stock. This is a reasonable assumption in the context of a growth study, since we are interested in the changes between periods as opposed to the level of capital stock and capital services, so the precise level is not absolutely critical. However, there is a clear problem with this approach if the proportionality is not constant over time; in other words, if the proportionality is changing over time, capital utilisation is also changing and therefore capital utilisation is the topic of the next section.

Capital utilisation

Beaulieu and Mattey (1998) present a formula that is useful in making explicit the role of capital utilisation. They model capital services as being a function of a binary variable s_t^K that takes on a value of 1 or 0 depending on whether or not the capital asset is in use or not (it is common for manufacturing and other economic entities not to be in operation during the night and at weekends). The "intensity" with which the asset is used, represented by ϕ_t, also determines the flow of capital services. One may think of the intensity as capturing effects like how many works-in-progress pass through an assembly line, or the volume of a gas or liquid that is moved through a pipe during a particular period.

$$K_t^S = \phi_t s_t^K K_t^P \tag{1.26}$$

As the OECD (2001a) notes, failing to adjust for capital utilisation leads to large procyclical movements in measured TFP, caused by the fact that the data will pick up swings in output, but will fail to capture the true movements in capital and labour inputs. For instance, Beaulieu and Mattey (1998) and Shapiro (1993) find that a workweek of capital adjustment lowers the cyclicality of measured TFP.

A variety of indirect approaches to control for capital utilisation have been deployed in growth accounting studies, including the use of electricity consumption (Foss, 1963), although the instability of the relationship between capital utilisation and this variable was shown to be unstable over time by Denison (1969). See Chris-

tiano (1981) and Beaulieu and Mattey (1998) for a review of direct and indirect approaches to the general problem.

One simple approach that was formerly popular is to simply to define and compare peaks in output. Peaks in output are taken as representing periods of full utilisation. Capacity utilisation for other periods is calculated by examining the ratio of output in the period of interest to "peak" output. This approach is subject to a number of criticisms, not least its very subjective nature and its strong assumption that periods of high output are, by construction, periods of full utilisation. This approach is even less applicable in context of this chapter, given the sample period of this chapter from 1980 to 2001.

Econometric techniques have also been applied to the problem, with many studies attempting to estimate peak output by specifying some functional relationship between outputs and various inputs. Peak output is simply that point where input resources are estimated to be, in some sense, fully utilized. However, this approach requires an extremely careful specification of the production function so that common econometric pitfalls in estimating these types of systems are avoided. Moreover, the data requirements of this type of analysis are quite onerous, requiring a coherent specification of stocks of inputs and outputs. Other econometric approaches, based more closely on the economics of production and cost theory, have recently sought to overcome these deficiencies, and good examples of this type of thinking can be found in Berndt and Morrison (1981), Berndt and Hesse (1986) and for the Irish

case in Kenny (1996). Berndt and Fuss (1986) formally allow for variations in capacity utilisation by discarding the convention assumption of long-run production equilibrium to allow for short-run deviations and disequilibrium and study production and cost functions in which particular inputs are quasi-fixed. They argue that the effects of varying utilisation can be picked up by examining a profit share variable (as opposed to a utilisation variable) and in this regard it is interesting that it is interesting to note the similarity between the utilisation variable used in this chapter (see Figure 1.8) and the profit share over the same period which be determined by examining Figure 1.9 (which shows a declining labour share and therefore an increase in the profit share which would appear to bear some similarities to the profile of utilisation apparent in Figure 1.8).

A final option is to rely on survey data, and this is the approach that is ultimately applied in this section. This decision is in part determined by data availability. Specifically, the approach adopted is to use survey data on manufacturing *capacity* utilisation to measure *capital* utilisation. Capacity and capital utilisation are different things, the difference arising from the fact the questions asked of firms about their capacity could conceivably include all inputs that might affect overall capacity and not just capital, but it seems likely that they would be in any event rather highly correlated.

The survey data used is the IBEC[30] Monthly Industrial Survey[31], which provides information on capacity utilisation for a wide variety of industrial sectors and which also forms part of the EC harmonized Business Survey. The two questions asked of respondents in relation to capacity utilisation are as follows:

- "For the coming year do you consider your present capacity is: Excessive(+): Adequate(=): Insufficient(-)"
- "During the month, you were operating at about what percent of capacity - please indicate to the nearest 10%, e.g. 50%, 60%, 70% etc."

Responses to these questions indicate the direction of change in capacity utilisation, and give a broad overall picture of the general trend in utilisation. Clearly, there is amount of subjectivity, conjecture and intuition inherent in the responses to these questions, but the survey approach nevertheless represents a reasonably direct method of quantifying capacity utilisation, and one that has been applied in other growth accounting studies.

It should be noted that the survey relates only to utilisation in manufacturing, so applying the results of the survey to other sectors involves the assumption that the utilisation measure is correlated across economic sectors; this cannot be tested and therefore remains as an assumption. A further point to note is that the survey data

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30 Irish Business and Employers Confederation

31 Available from www.ibec.ie.

is only available from 1984 onwards. The utilisation data used to adjust the capital services for the years from 1980 to 1984 was taken from Kenny's (1996) production function estimates. The time profile of the capacity utilisation variable as determined from the survey (and Kenny's estimates for the early eighties) is shown graphically below:

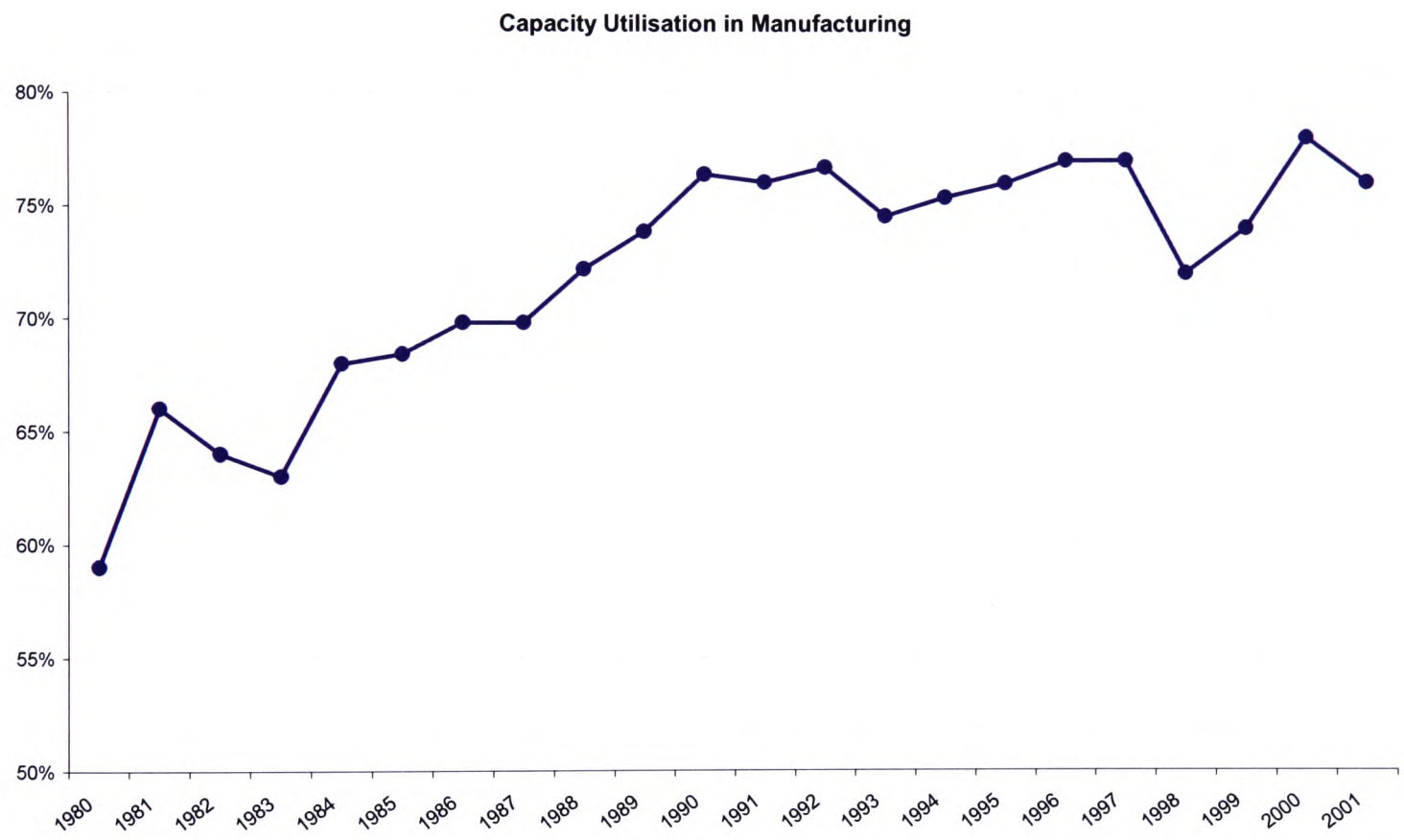

Figure 1.8: Capacity utilisation in Irish manufacturing.

The graph indicates a pattern of capacity utilisation which appears to correspond to the time profile one might have expected on *a priori* grounds: the profile is relatively stagnant in the early eighties, before reaching and maintaining a relatively high plateau at the start of the nineties.

These methods of adjustment may seem rather crude, but given data restrictions and uncertainty about the actual improvement that you would be yielded by complicated econometric models, they seem to offer a reasonable compromise. In the words of Griliches (1971), "half a loaf is better than none."

1.7 Factor Shares

An important element in any growth accounting exercise is the calculation of factor shares. The calculation of factor shares is necessary so as to weight the respective contributions of the different inputs. Errors in these calculations can significantly change the conclusions reached about the sources of growth; on this topic see the paper by Sarel (1997) for a sensitivity analysis of factor share data for the East Asian "tiger" economies. Traditionally, much of the literature either assumed values for the labour and capital shares, or relied on crude assumptions or incomplete data to calculate them. These practices are still common today, especially in cross-country studies.

1.7.1 Calculating factor shares

Many studies calculate the labour share in a naive fashion by simply expressing employee compensation as a fraction of output. At a minimum, this measure should be modified to include an adjustment for the compensation of the self-employed in both the labour and capital shares. Gollins (2002) demonstrates that the adjustment

for the self-employed is a particularly important one; his cross-country study reveals that much of the differences between national labour shares is attributable to a failure to incorporate this adjustment. The standard assumption (see Gollins (2002), Blanchard (1997), Bentolila and Saint Paul (1999), OECD (2001a)) is made in this chapter that the self-employed earn the same compensation as employees.

Another related issue is that of how to allocate gross mixed income to capital and labour. Gross mixed income is the income earned by the self-employed, some of which is attributable to capital and some to labour. Again, a standard method for allocating gross mixed income between capital and labour is used by multiplying numbers of self-employed by average employee compensation, and then subtracting this amount from the gross mixed income total to arrive at a figure for that part of mixed income that is attributable to capital.

Factor shares need to be calculated from the perspective of producers because, as Battini, Jackson and Nickell (2000) make clear, the share must be derived from a measure of value added that is net of indirect taxes, since firms and their owners may only lay claim to that part of firm revenue that is not taken by the government. This means that the value added measure used in the factor calculations should exclude direct and indirect taxes on production, but should include public subsidies to production. The data that used for this purpose come from the Irish national accounts. Finally, as Battini *et al.* (2000) further point out, public sector compensation and

value added should be removed to be further consistent with the production model and growth accounting framework used in this chapter.

Applying these techniques to the data yields the changing factor share presented in the graph below.



Figure 1.9: The Irish labour share.

The most striking fact is the decline in the labour share, a phenomenon already documented and analyzed for the Irish case by Lane (1998). However, it should be noted that this appears to be merely the continuation of a long standing trend. Data from the European Commission (2003) identifies a precipitous drop in labour shares from the 1960s, at which time labour shares in many countries (including

Ireland) stood at around 80%. Although this chapter is not primarily concerned with explaining this phenomenon, it is worthwhile to briefly reflect on this marked change in the labour share. Interestingly, much cross-country research has found a similar but less dramatic pattern. Blanchard (1997) discusses the fall in the labour share that began in the 1980s and continued through the 1990s in France, Germany, Italy and Spain. Jones (2004) likewise finds a downward trend the labour share for many countries over the last 25 years.

1.7.2 The changing factor share

Nevertheless, it is still useful to briefly review the reasons for the decline in labour's share. A variety of different approaches have been proposed to account for the decline in labour shares observed in the OECD. Jones (2004) advances a model based on differences between the long-run and short-run elasticities of substitution between labour and capital, but it is difficult to know how one would apply his general theoretical model to the case of a specific country . Instead, much of the literature has followed the lead of Blanchard (1997) and Bentolila and Saint- Paul (1999) and looked for evidence of changes in the markup, changes in labour adjustment costs, changes in union strength (and hence their bargaining ability) or biased technological change. Cameron and Wallace (2002) suggest that the breakdown in the postwar consensus on wage bargaining between employers and unions has played in role in shaping the evolution of the labour share. They argue that the "golden - era" postwar

consensus artificially inflated the power and influence of labour unions, and a decline in the labour share was inevitable once economies adjusted to the low-productivity scenario of the post oil-shock environment[32].

Blanchard's (1997) story is based around a series of adverse labour *supply* shocks in the 1970s emanating from a failure to adjust to the productivity slowdown, allied with adverse labour *demand* shocks in the 1980s, caused by either biased technological change in increases in business markup rates. These labour shock effects, he argues, provided the macroeconomic conditions for the labour share to decline in continental Europe. His econometric analysis leads him to conclude that the culprit for the falling labour share is biased technological change. He also argues that increases in markups over this period are implausible given the increasing openness of European countries to EU and world trade.

One general observation of his that appears to support the overall thrust of his paper is that countries where the labour share has decreased (primarily continental European countries), the unemployment rate has trended upwards. Countries where factor shares have remained relatively stable, such as the US and the UK, have enjoyed much more favourable labour market conditions. Ireland is an exception to this trend. de Serres, Scarpetta and de la Maisonneuve (2002) find changes in sectoral

[32] The theories of Cameron and Wallace (2002) are explored in a different context in more detail in Chapter Three.

labour composition as having an important effect in shaping labour share evolution in 5 European countries. Dell'Aringa, Franzosi and Vignocchi (2001) find that biased technological change explains the fall in the labour share in Italy, whereas Riputti and Vilmunen (2001) argue that increases in the markup explain the same phenomenon in Finland. Lane's (1998) paper suggests that Ireland's strategy of national wage moderation explains much of the decline in the labour share. He rejects the explanation of biased technological change on the grounds that the Irish capital/labour ratio actually declined between 1992 and 1996 (the end point of his sample period). He also rejects the oft-made accusation that the transfer pricing activities explain much of the increase in officially recorded Irish output data, and his arguments are discussed below.

1.8 Results

This section presents the results of the various forms of analysis discussed above, and begins with the results of the Tornqvist estimates of TFP that are derived from the parametric growth accounting. This section then explores in greater detail some of these results and examines the correspondence of these results with the predictions of the various hypotheses discussed previously.

1.8.1 Growth accounting results

Basic results

The first set of results contains the raw figures: capital is not adjusted for utilisation and labour is not adjusted for quality. Presenting the unadjusted figures is useful in portraying the general underlying features of the data and the size of any potential bias that would result from not adjusting the figures. More importantly, as will be apparent, it serves to emphasize the role played by educational quality in the case of labour services. These results clearly indicate that the two most significant driving forces behind growth in value added during the boom years were labour input and TFP.

The next table shows the results of including capital utilisation and the available quality data on labour. As educational quality data is only available from 1987, and education attainment only available from 1988 onwards, it is only possible to present these adjusted results from 1988 to 2001.

The quality-adjusted results have the expected effect of reducing the value of the residually measured TFP, since the residual will pick up the influences of any excluded variables that could potentially affect the contributions of the capital and labour inputs. This set of results, including adjustments to labour input for educational quality and to capital for utilisation should be regarded as representing the preferred specification and thus constitute the main results of this chapter. Again, the results indicate important roles for growth in the quantity and quality of labour, and

Year	Value Added	Labour	Capital	TFP
1980	2.37%	0.60%	1.40%	0.37%
1981	2.76%	-2.73%	1.40%	4.09%
1982	2.75%	-2.65%	1.10%	4.30%
1983	-0.20%	-5.68%	0.90%	4.58%
1984	4.41%	-2.57%	0.90%	6.08%
1985	5.12%	-1.92%	0.80%	6.24%
1986	-0.10%	-1.21%	0.70%	0.41%
1987	6.18%	-0.15%	0.60%	5.73%
1988	5.12%	0.65%	0.60%	3.87%
1989	4.97%	1.72%	0.70%	2.55%
1990	8.94%	2.92%	0.90%	5.12%
1991	2.05%	0.29%	0.70%	1.06%
1992	3.48%	-2.43%	0.60%	5.31%
1993	0.29%	0.20%	0.60%	-0.51%
1994	6.55%	2.97%	0.60%	2.98%
1995	8.10%	5.12%	0.90%	2.08%
1996	11.09%	4.12%	1.00%	5.97%
1997	13.66%	6.69%	1.60%	5.37%
1998	12.67%	4.56%	2.00%	6.11%
1999	15.23%	5.56%	2.30%	7.37%
2000	11.91%	4.30%	2.40%	5.21%
2001	6.72%	2.29%	2.40%	2.03%
Average	6.09%	1.03%	1.14%	3.92%

Figure 1.10: Baseline (quality unadjusted) growth accounting results.

Year	Value Added	Labour	Capital	TFP
1988	5.12%	0.65%	0.43%	4.04%
1989	4.97%	1.72%	0.51%	2.74%
1990	8.94%	2.98%	0.68%	5.28%
1991	2.05%	0.29%	0.53%	1.23%
1992	3.48%	-2.53%	0.46%	5.55%
1993	0.29%	0.21%	0.44%	-0.36%
1994	6.55%	3.16%	0.45%	2.94%
1995	8.10%	5.53%	0.68%	1.89%
1996	11.09%	4.55%	0.77%	5.77%
1997	13.66%	5.02%	1.23%	7.41%
1998	12.67%	7.48%	1.44%	3.75%
1999	15.23%	5.28%	1.70%	8.25%
2000	11.91%	6.44%	1.87%	3.60%
2001	6.72%	2.72%	1.91%	2.09%
Average	7.91%	3.11%	0.94%	3.87%

Figure 1.11: Quality-adjusted growth accounting results.

for growth in TFP. It is reassuring that these results are similar to TFP figures estimated for the Irish economy by other sources, including the OECD (see for example, Pilat 2001, Raven, 2001 and Roeger, 2001).

Comparison with selected growth accounting studies

In performing comparisons with other growth accounting results, the work of Timmer, Mpema, and van Ark (2003) is a useful point of comparison as their paper followed a similar methodology using comparable data to that applied in this chapter. For the period from 1995 to 2001, they find a larger role for capital, but their estimate of Irish TFP for this period almost of 4% is similar to that found in this chapter for

the same period (4.68%). In any event, this figure is much higher than the average TFP growth rate in the EU-15 countries and the US, where the average growth rate of TFP for these countries is just 0.97%, according to the paper by Timmer *et al.*

Another interesting feature of the high estimated TFP growth rates is that, according to the European Commission, (Guidelines for Economic Policy, various years) Ireland has had a TFP growth rate much higher than the European average since the early seventies. The estimated average annual TFP growth rate for Ireland between 1974 and 1985 in that work was 2.1%, compared with 1% for the EU15, and 3% for the period from 1986 to 1990, compared with 1.5% in EU15. Indeed, the work of the Commission also estimated a very high average annual growth rate of TFP in the nineties of 4% (again similar to the figure estimated in this chapter), compared to a much more modest growth rate of approximately 1% for the EU15 countries.

Another interesting comparative perspective is provided by comparing the results of this paper to those of Young's (1995) famously controversial results on the growth of the East Asian "tiger" economies of Hong Kong, Singapore, South Korea and Taiwan. The results were controversial because of Young's finding that productivity growth had been relatively anaemic and that growth had been driven by a Soviet style mobilization of capital. Young's conclusion was that fast growth based on the rapid accumulation of capital was unlikely to be sustainable given the like-

lihood that diminishing returns to physical capital would soon begin to retard the continued economic progress of these countries.

As noted above, the Irish results presented in this paper suggest a relatively small role for capital in explaining recent Irish growth. Young's sample of economies grew very quickly on average over his sample period (1966-1991): Hong grew at an average annual rate of 7.3%, Singapore at 8.5%, South Korea at 10.3% and Taiwan at 9.4%. These growth rates are comparable to those enjoyed by Ireland in the second half of the nineties, although for the Asian economies this growth occurred over a much longer period and from a far lower initial income position. The average annual TFP growth rate for these economies was: Hong Kong 2.3%, Singapore -1%, South Korea, 1.7%, and Taiwan 2.6%. The quality adjusted results for Ireland indicate a TFP growth rate of almost 4%.

One interesting re-interpretation of the Young (1995) results was provided by Klenow and Rodriguez-Clare (1997). They noted that the return on capital will increase if technology is improving, and therefore capital accumulation is responsive to TFP growth. In other words, it is argued, capital accumulation is high because TFP must have been high. Therefore, according to the calculations of Klenow and Rodriguez-Clare , the influence of capital in East Asian growth is lower than is suggested Young's work.

Nevertheless, the Irish capital figures, as estimated above, are still lower than the Asian figures. Moreover, the arguments of Klenow and Rodriguez-Clare apply to the Irish case as well, so the role of capital in the Irish will also be slightly less than is revealed in the type of neoclassical growth accounting which was the basis for the calculations in this chapter. On the other hand, the shorter time frame considered in this chapter reduces the impact of this type of effect (since here in this chapter capital responds to improvements in TFP over relatively short time horizon between 1980 and 2001).

Again, the Irish results compare very favourably to this productivity performance, both in the boom years of the nineties (almost 5% between 1994 and 2000) as well as over the entire "adjusted" sample period from 1988 to 2001 (3.87%). This represents evidence that the Irish experience of rapid growth has taken a materially different form from the East Asian experience.

A sectoral perspective

Having presented aggregate results, it is useful to examine the sectoral performances which drove these figures. The first graph below represents changes in the share in value added for five sectoral classifications of economic activity, calculated using the Groningen dataset.

There are a number of significant features of this graph that merit closer scrutiny. A particularly notable feature is the decline in the relative importance of the agricul-

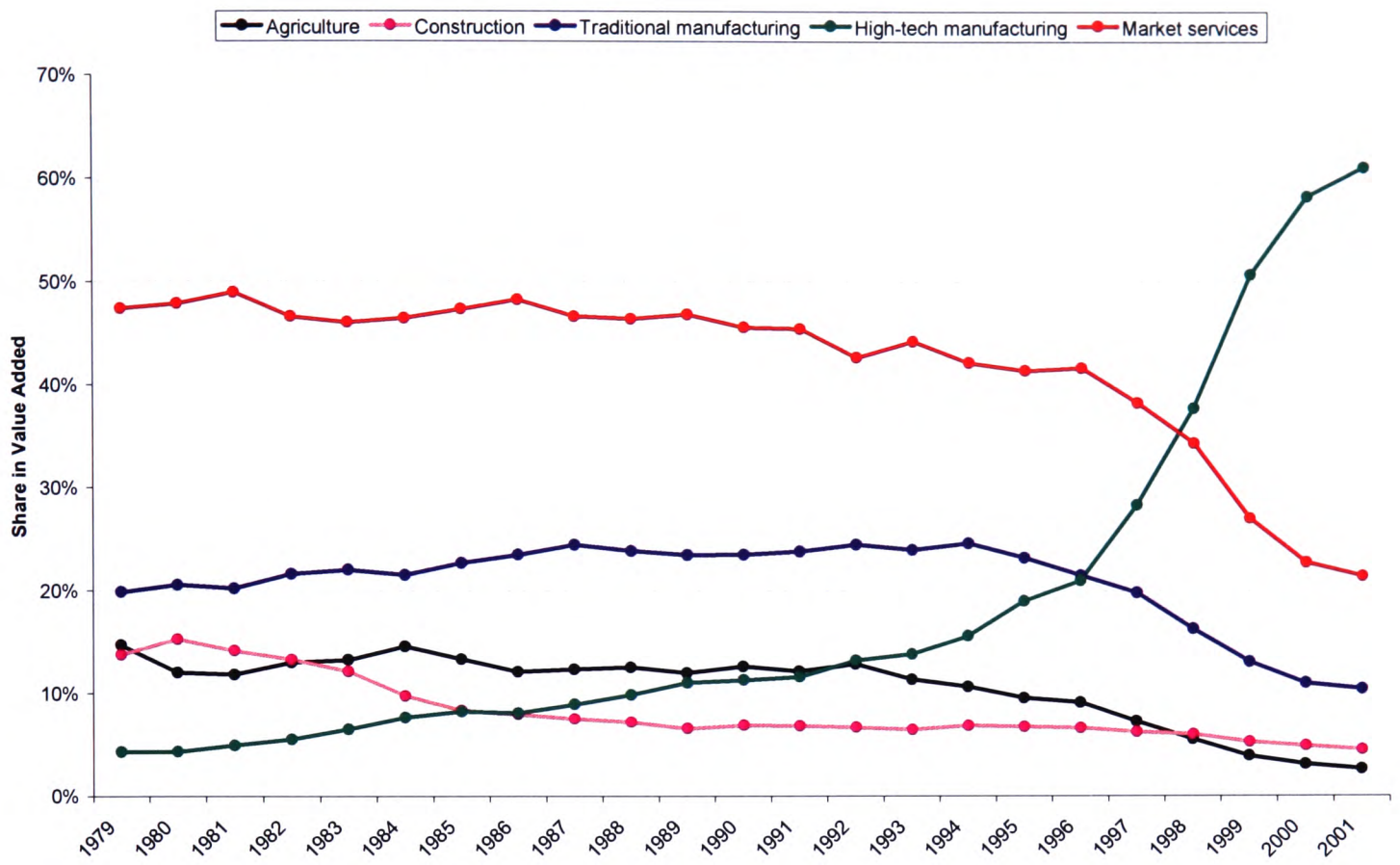

Figure 1.12: Sectoral shares in value added

tural sector as a source of value added, falling from 15% in 1979 to just 3% by 2001. Apart from a slight recovery in the early 1980s, this decline has been steady over the period, and reflects the increasing dominance of manufacturing in the economy. A surprising finding is that the share of market services declined after the mid-1990s. The fact that the share of this economic sector was relatively high in the late 70s indicates that a fair degree of structural reallocation is likely to have taken place in that decade, reflecting the earlier reforms of the 1960s and the increased openness of the economy. Its decline after 1995 reflects the increased importance of high-tech man-

ufacturing. Despite a massive construction boom in the late 1990s, the share of the construction sector in value added declined over the period[33].

The massive increase in the importance of high-tech manufacturing is clearly the dominant aspect of the graph. Its extremely sharp growth after 1995 dominates all other sectors, and it is no coincidence that this increased share of this sector in value added is associated with the acceleration in TFP presented above. Therefore, the jump in TFP appears to reflect both the increased importance of this form of manufacturing, as well complications introduced into the official output statistics. This topic is discussed in some detail in the next section, although the graph of employment changes presented below also sheds some light on this issue.

The main point of interest in the employment graph is the difference with the value added graph. It displays much more stability (in the sense that there are no dramatic changes in levels); moreover, the growth in employment in the high-sector is extremely modest compared to its growth in the share of value added. This indicates an ever-increasing level of labour productivity, which, as noted, is likely to be in part due to the poor measurement of output. It was noted how the share in the construction sector in value added fell over the period, which was somewhat surprising in light of the construction boom of the 1990s. Here, the effect of the boom is more

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[33] In part because substantial investment in the late 1970s also gave rise to a property and construction boom, although this earlier boom was much less long-lived than the later one

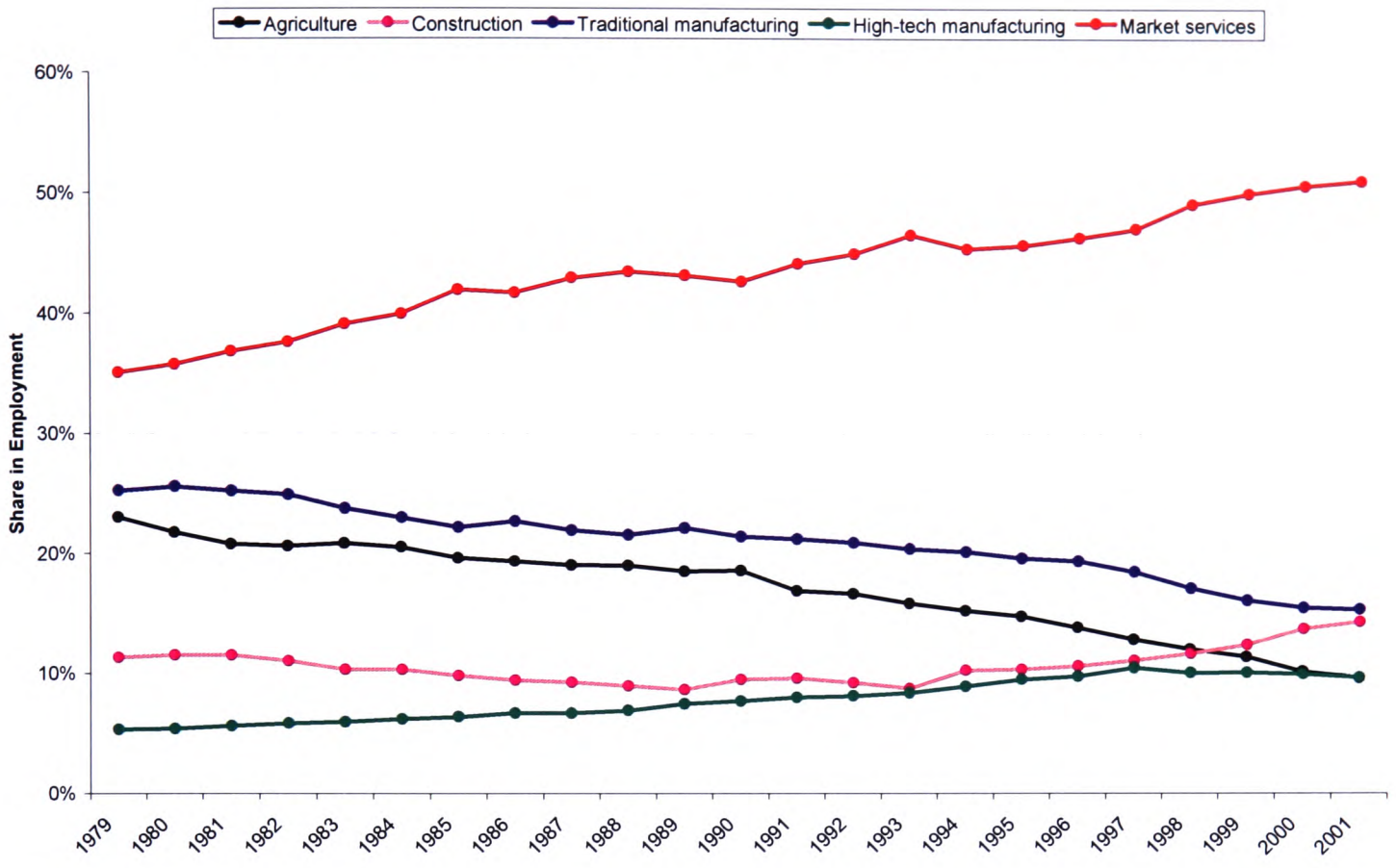

Figure 1.13: Sectoral shares in employment.

apparent, with a steady increase occurring after 1993. Likewise, employment in services displays healthy growth over the period, befitting the increasing significance of this sector over the period. The value added shares for services were likely skewed by the overpowering dominance of high-tech, whereas the employment figures give perhaps a more accurate perspective on the role of this sector.

The sectoral analysis presented above therefore provides a very useful perspective on recent structural changes in the Irish economy. It also reveals the extraordinary output and productivity performance of the high-tech sector. Concerns have been raised that the officially reported output statistics for this sector in particular do

not truly reflect the reality of the underlying economic conditions, and these concerns are one of the topics addressed in the next section.

1.8.2 Interpreting the Results

This section examines the results in more detail. One initial question that immediately suggests itself when examining the value added figures is: why does value added apparently grow so much faster than officially reported GDP? The answer to this is simply that the value added figures used in this chapter, unlike the economy-wide GDP figures, focus solely on the business sector, and exclude the public or non-business sector. Another point relates to the use of gross value added as the output measure. It was noted above that if there are large and material increases in input prices, such as increased oil prices in the 1980s, then TFP calculated on the basis of gross value added will be biased downward. Despite this, TFP on both an unadjusted and adjusted basis nevertheless managed to grow quite quickly throughout the 1980s, suggesting that the effect of any bias is relatively unimportant. A much more controversial issue connected with the GDP and VA figures relates to their statistical reliability, and this is the topic of the next section.

Examining the "Tortoise" Hypothesis .

In the introductory section of this chapter, this was referred to as the Tortoise Hypothesis, following the question posed by the title of Murphy's (1994) paper. A

good degree of research effort has gone into examining this issue[34]. This issue was studied in detail by Conroy, Honohan and Maitre (1998). This paper discusses the unusual features of Irish manufacturing, namely that manufacturing output is dominated by foreign owned firms (foreign owned firms own a much higher proportion of manufacturing facilities than in any other European country), that employment in Irish manufacturing has been growing, (which is in contrast to the experience of many other European countries), and that foreign-owned manufacturing appears to be very profitable. While these facts are well established, they study in particular four specific industrial sub-sectors where this industrial structure is especially extreme. These sectors are certain specialty chemicals (this includes the "other organic basic chemicals" studied in Honohan and Walsh, 2002), software reproduction, computers, and the "cola concentrate" subsector of the food sector.

The sectoral graphs presented in the previous section illustrate this point well - despite widely divergent developments in value added and the dominance of high-tech manufacturing, employment changes were less dramatic, implying widespread differences in labour productivity. To get another flavour of the debate, consider the following example from Honohan and Walsh (2002) of the manufacturing sector classified as "other organic basic chemicals" (this is essentially the same "specialty chemicals" sector studied in Conroy *et al.*, (1998) and was included in the sectoral graphs of the previous section under "high-tech manufacturing"), which accounted

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34 See the references cited in the introductory section of the chapter.

for 0.3% of economy wide employment in 1999, but which nonetheless accounted for 8% of total GDP (after subtracting out the import component). These figures imply a labour share of less than 2%, and output per worker of $2.5 million; and, relatedly, the figures therefore imply massive returns on capital. Similar results are also reported for certain other manufacturing classifications - these sectors were the same as those identified in the earlier work of Conroy *et al.* (1998). Again, this later paper found that in these sectors labour productivity appears to be ten or twenty times higher per worker than same industries in the rest of Europe.

Conroy *et al.* (1998) suggest that these sectors with extremely low labour shares may be interpreted as *entrepôt* sectors. They draw an analogy with the ports of Hong Kong and Singapore, who disassemble and re-assemble goods for onward shipment to other destinations. These activities add substantial value and employ considerable amounts of human and physical resources, but these goods are not actually "made" in these countries. As Conroy *et al.* point out "The value of the cargo being transhipped is seen as something that is effectively "offshore" of the cities' economies". While the authors concede that the ratio of material inputs to labour inputs in the four Irish sectors that they study is not high enough for these sectors to be classified as authentic entrepôts, they do suggest that there is "invisible" entrepôt-type activity taking place alongside the genuine manufacturing processes. The excess profits, royalty payments and other payments which appear to give rise to the exceptionally high measures of output and labour productivity in these sectors do

not reflect meaningful underlying activity, but are instead evidence of what they call "invisible entrepôt" activity.

Part of the explanation for these anomalous results resides in the fact that Ireland has long had extremely low corporation tax rates, and such low labour shares and extremely high productivity per worker are generally found in industries dominated by multinational corporations. Manufacturing companies attempt to register the profit on goods, perhaps developed through R&D conducted outside of the state, to take advantage of the benign taxation regime which at present taxes corporate profits at 12.5%. The pricing of inputs and outputs between different branches of the same multinational corporation is governed by strict transfer pricing rules, but there has long been suspicion that the multinational corporations and their tax advisers are adept at exploiting every possible means to ensure that as much profit is taxed under Ireland's low rates as is possible. Altshuler, Grubert and Newton (1998) find evidence of an increased sensitivity of US FDI to taxation considerations, perhaps suggesting that the incentives to engage in thus type of activity are increasing.

Does this suggest that the aggregate value added figures are therefore unreliable for the purposes of economic analysis? Several different but related considerations are necessary to answer this question. One basic point, made by Lane (1998), is that if the extent of this activity is stable over time, then the *growth rate* of aggregate GDP will be unaffected, although the validity of this claim is questioned by Honohan and Walsh (2002), who argue that this type of behaviour has been growing faster than

the size of the economy so that the effect will therefore manifest itself also in growth rates.

Bosworth (2002), in his comments on Honohan and Walsh (2002), provides a lower bound to the GDP growth rates one would observe if all multinational profit was the result of fabricated transfer pricing activity, and his results in the table above demonstrate that, even in this most pessimistic of assessments, the real growth rates were still huge.

Period	Real GDP (yearly average)	Real GDP less MNC profits (yearly average)
1973-1987	2.7%	2.8%
1987-1992	4.2%	3.6%
1992-2000	8.5%	6.3%
1995-2000	9.9%	7.4%

Figure 1.14: Effect of multinational profits on GDP. Based on Bosworth (2002).

As Honohan and Walsh (2002) point out, such adjustments to the data are inevitably very crude, since they are in the nature of sweeping generalizations and it is unreasonable to argue that all multinational profits reported in Ireland are contaminated by transfer pricing misdemeanors, but is helpful in providing a type of upper bound to the magnitude of the problem. Indeed, Honohan and Walsh (2002) are rather skeptical that "credible" productivity estimates can be obtained from the use of GDP-based output statistics. They present some alternative estimates of productivity

which provide some further bounds - they find, for example, that estimated productivity over the period 1995 to 2000 was about 5% when a GDP/employment proxy is used to measure productivity[35]. Their other measures produce estimates which are roughly half of the estimated GDP/Employment productivity measure. These measures are GDP less multinational profits over employment, non-agricultural GDP less multinational profits divided by non-agricultural employment, and a measure based on GDP less value added from the four entrepôt sectors discussed earlier.

An alternative set of arguments that transfer pricing effects were a relatively unimportant influence on *growth* is provided by Lane (1998). He finds a statistically significant negative relationship between wages and profits, which he takes as constituting strong evidence against the transfer pricing hypothesis. In other words, if profits were not responsive to changes in costs in the local (Irish) economy, then that would suggest that much of the multinationals' contribution to reported output statistics does not really reflect meaningful economic activity being conducted in Ireland. The fact that multinational profits do indeed depend on local costs suggests that a sizeable proportion of output is performed in Ireland. He also discusses the increasing stringency with which illegal transfer pricing activities are viewed by international tax authorities.

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[35] Below a different employment type proxy is calculated; the annual TFP growth using this method is estimated as a more modest 3.5%

Is there any other means of examining this issue in the growth accounting framework used of this chapter? The 2003 OECD Economic Survey (OECD, 2003a) of Ireland contains a discussion of these measurement problems of the Irish value added statistics, and the attendant problems this causes for productivity measurement. They note how many multinational corporations in Ireland are characterized by low labour shares (as noted above), and that only a small proportion of their gross value added is distributed to the domestic workforce. They suggest, following Nordhaus (2001), that these apparently anomalous sectors should not be completely discounted from productivity analysis, and should instead be incorporated into any analysis. This notion is somewhat contrary to the spirit of Honohan and Walsh (2002), who are understandably wary of including the low labour share sectors in any analysis. The OECD solution to this problem is to propose the use of current industry wage bill shares as aggregating weights in place of current value added weights.

Clearly, this approach gives more weight to those industries which distribute surplus to the domestic workforce, and in turn, it is argued, this gives a clearer picture of the real changes in living standards and productivity taking place in the local economy. The growth accounting framework studied in this chapter is therefore the ideal means to examine the OECD proposal, and therefore to subject the "illusory growth" argument to further scrutiny. The graph shows how value added and TFP change when this approach is applied to the data studied in this chapter.

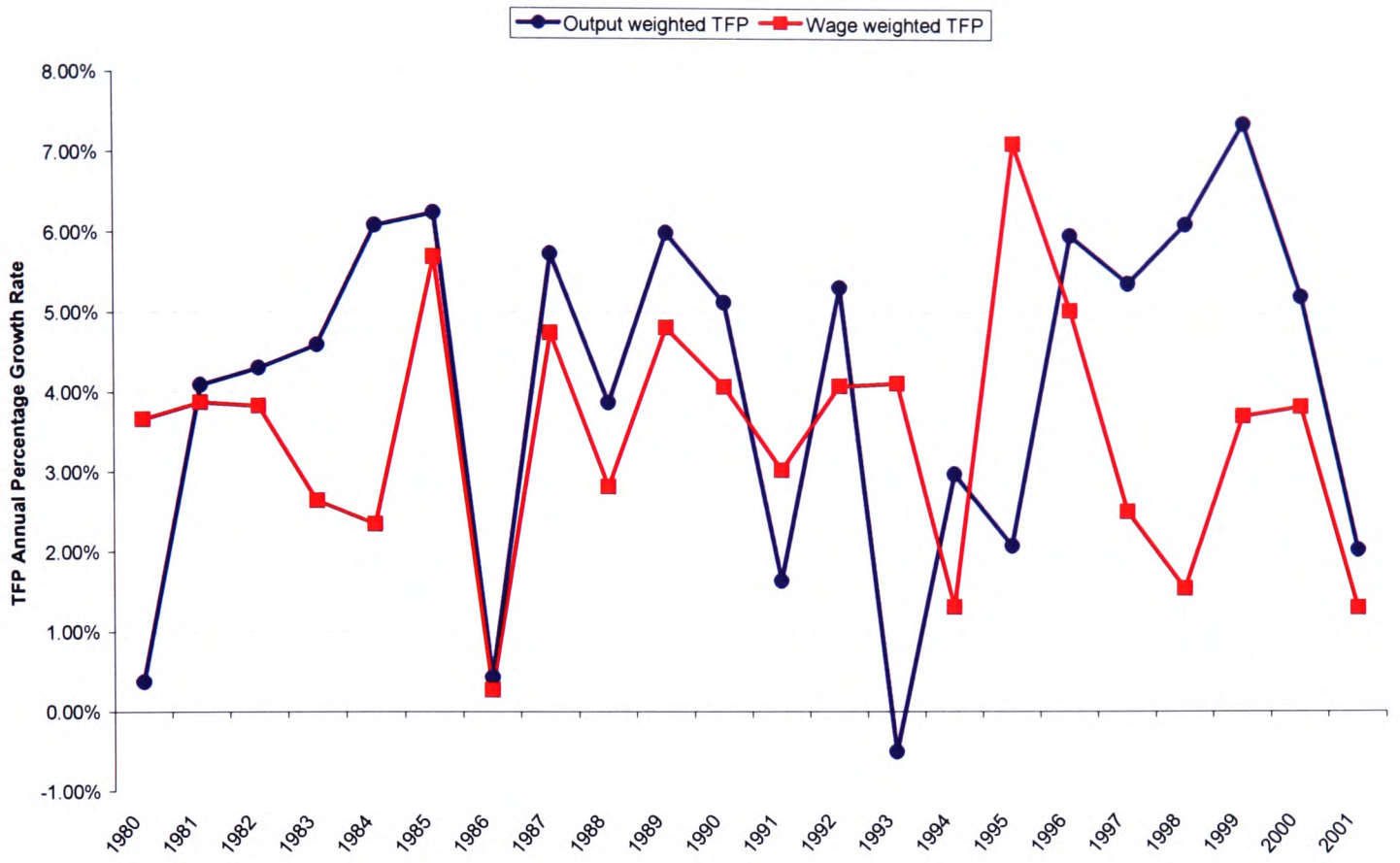

Figure 1.15: Output weighted value-added, wage-weighted value added, and differences in TFP.

The graph above shows how closely the two measures of TFP track each other; the two series become less correlated in the mid-to late nineties although this seems to be attributable in part to an outlying jump in TFP from 1.3% in 1994 to over 7% in 1995 for the wage weighted series. This may be due to an outlying observation for 1995, which is perhaps likely to reflect the increasing dominance of high-tech in value added; it will be recalled that the share in value added of this sector increased sharply after 1995. Therefore, it seems reasonable to conclude that most output growth was "real", but the increased dominance of high tech in the late 1990s suggests vigilance and caution should be applied to output figures after this period. The figure below shows the numbers which underlie these findings.

Year	Output-weighted valued added	Wage-weighted valued added	Output-weighted TFP	Wage-weighted TFP	Difference in TFP
1980	2.37%	5.67%	0.37%	3.66%	-3.29%
1981	2.76%	2.54%	4.09%	3.87%	0.22%
1982	2.75%	2.27%	4.30%	3.82%	0.48%
1983	-0.20%	-2.14%	4.59%	2.64%	1.95%
1984	4.41%	0.69%	6.08%	2.35%	3.73%
1985	5.12%	4.58%	6.24%	5.69%	0.55%
1986	-0.10%	-0.23%	0.43%	0.27%	0.16%
1987	6.18%	5.20%	5.73%	4.74%	0.99%
1988	5.12%	4.08%	3.87%	2.82%	1.05%
1989	4.97%	3.79%	5.99%	4.81%	1.18%
1990	8.94%	7.90%	5.12%	4.07%	1.05%
1991	2.05%	3.45%	1.64%	3.03%	-1.39%
1992	3.48%	2.25%	5.31%	4.08%	1.23%
1993	0.28%	4.92%	-0.51%	4.12%	-4.63%
1994	6.55%	4.88%	2.98%	1.31%	1.67%
1995	8.10%	13.13%	2.08%	7.11%	-5.03%
1996	11.09%	10.16%	5.97%	5.03%	0.94%
1997	13.66%	10.81%	5.37%	2.51%	2.86%
1998	12.67%	8.11%	6.11%	1.55%	4.56%
1999	15.23%	11.58%	7.37%	3.71%	3.66%
2000	11.91%	10.54%	5.21%	3.83%	1.38%
2001	6.72%	5.99%	2.03%	1.30%	0.73%
Average	6.09%	5.46%	4.11%	3.47%	0.64%

Figure 1.16: Output weighted value-added, wage-weighted value added, and differences in TFP.

The average difference in calculated TFP is relatively modest at 0.64% over the entire sample period, which suggests the choice of wage or output weights is not critical[36]. However, the average value for the period as a whole conceals an interesting story underlying the results for different periods. Characterizing the period from 1980 to 1987 as the "pre-reform period", TFP differed between the two measures by 0.60%, roughly the same as for the period as a whole. For the 1988-1994 "consolidation" period, the difference was miniscule at only 0.02%. The rapid growth

[36] This average value is calculated as the simple average of the differences; calculating the average using the absolute value of the differences renders a value of 1.94%.

period of 1995-2001 witnessed, unsurprisingly, the biggest divergence between the two measures at 1.3%[37].

Examining different periods therefore reveals that the difference in TFP based on wage and output weights increased quite substantially during the rapid growth period. This finding can be interpreted in different ways. One is that the quality of output statistics deteriorated once the presence of growing numbers of multinational corporations manifested itself in the data. Alternatively, one might interpret the results in the context of the declining labour share discussed above; these results could indicate that a greater proportion of national income is distributed as a reward to capital and not to labour, reflecting the repatriation abroad of profits earned in Ireland. Finally, since output weights are the conventional weights used in growth accounting exercises of the type applied in this chapter, and therefore it may be the difference between the two sets of weights may be attributable to the unconventional practice of applying wage weights; in other words, the wage weighted TFP results may simply be "wrong", although the fact the difference between the measures changed fairly substantially over the period suggests this explanation is likely to be too simplistic. It seems likely that changes in the quality of output data and the increasing importance of profit repatriation are both culpable in some measure for the increased difference during the rapid growth period of 1995 to 2001.

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[37] The absolute differences between the measures were 1.42% for 1980-1987, 1.74% for 1988-1994, and 2.74% for 1995-2001.

Nevertheless, additional considerations serve to undermine the view that transfer pricing ought to be accorded a predominant role in recent growth, although clearly any account of Irish growth in the 1990s should pay some regard to this activity. One of these objections is a very simple one: there have been massive real changes to the economy during the period of high recorded GDP growth. Total employment in the economy increased from 1,132,570 in 1980 to 1,743,403 by 2001. Between 1991 and 2001, the working age population rose by 400,000 and net inward migration was 110,000, compared with an outmigration figure of 125,000 over the preceding five years (Fitzgerald, 2000). The real effects of the boom can also be seen in the increased purchasing of, for example, cars and houses, the latter having recorded spectacular and sustained price increases throughout the country since the early 1990s.

To offer a conclusive opinion on this issue is difficult for, as Honohan and Walsh (2002) note, the scale and complexity of transfer pricing activities appear to be large and significant, so that aggregate economic analysis faces unusual and difficult problems in accounting for the existence of this behaviour. Nevertheless, the real effects of growth that have been observed, in addition to the fact that only a relatively small portion of recorded GDP are likely to be badly biased by transfer pricing type activity, suggests that value added statistics are mostly accurate. It is worth closing with the cautionary opinion of Blanchard (2002) on this matter: "Beware of numbers, especially in a small economy with a large export-import sector, low taxation of

profits, and transfer pricing...but even after correcting the performance of output and of implied productivity remains impressive".

Capital services and ICT

As is clear from the results, a large increase took place in the importance of capital services; the average annual change in the adjusted capital services figure from 1990 to 2001 is approximately 9%. Such an increase is easily rationalizable given, amongst other factors, the falling interest rates faced by the Irish economy as it adjusted to the prospect of membership of monetary union in Europe; the large shares of EU FDI received by Ireland and of the huge past and expected future increases in GDP. The long term nominal interest rate fell sharply over the sample period, reflecting the improving macroeconomic conditions as the nineties progressed and Irish participation in the Euro.

It is also noteworthy that capital services increased over this period, as discussed above. Despite the increase in capital services and in capital shares, the results of the growth accounting analysis still suggest a small contribution from capital. Honohan and Walsh (2002) reach the same conclusion, noting that "we have said little about physical capital formation, as we do not see this as a central part of the story behind the boom... it would be very hard to argue that physical capital formation was a major growth driver. Indeed, having touched 30% of GDP in 1979, gross domestic capital formation declined sharply, averaging only 17% of GDP during the

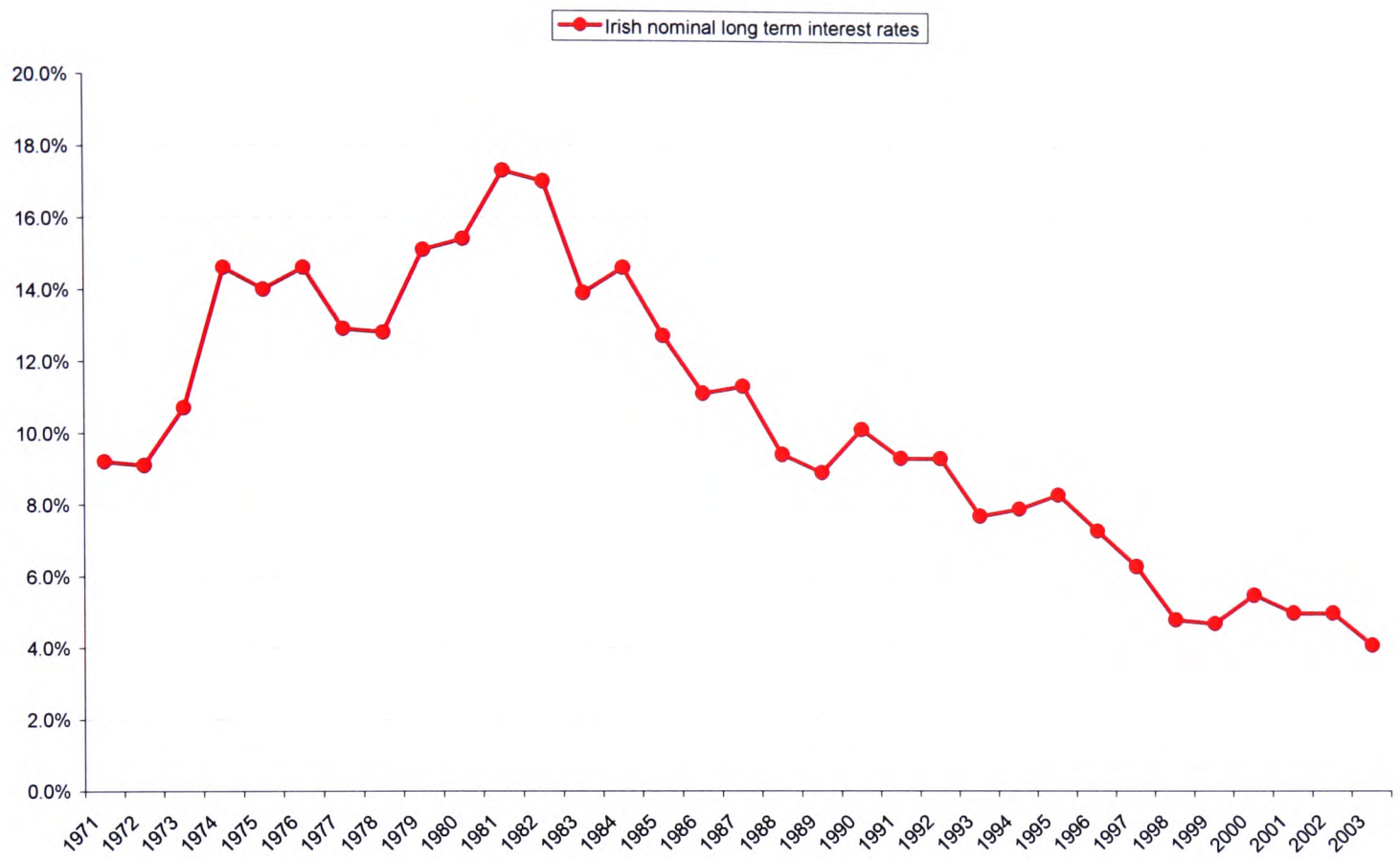

Figure 1.17: Irish nominal interest rates.

recovery period 1986-95, much of the decline being due to the shrinking importance of the public capital programme, which fell by four percentage points of GDP between 1981 and 1990. The recovery in the second half of the 1990s was largely due to a resurgence of investment in housing. Even in 1996-2000, the investment ratio was well below the figures recorded by the other rapidly expanding economies of the1990s in the Far East. Furthermore, less than one-seventh of the total was attributable to manufacturing". Therefore, the findings of this chapter with respect to the role of capital services in recent Irish growth are consistent with this earlier work of Honohan and Walsh.

The effect of allowing for changes in utilisation in the capital services data is demonstrated in the diagram below (in this diagram the effect of utilisation is emphasized by not adjusting the labour statistics for quality). The effect of adjusting capital input for utilisation has the effect of increasing estimated TFP by approximately 0.30% per annum.

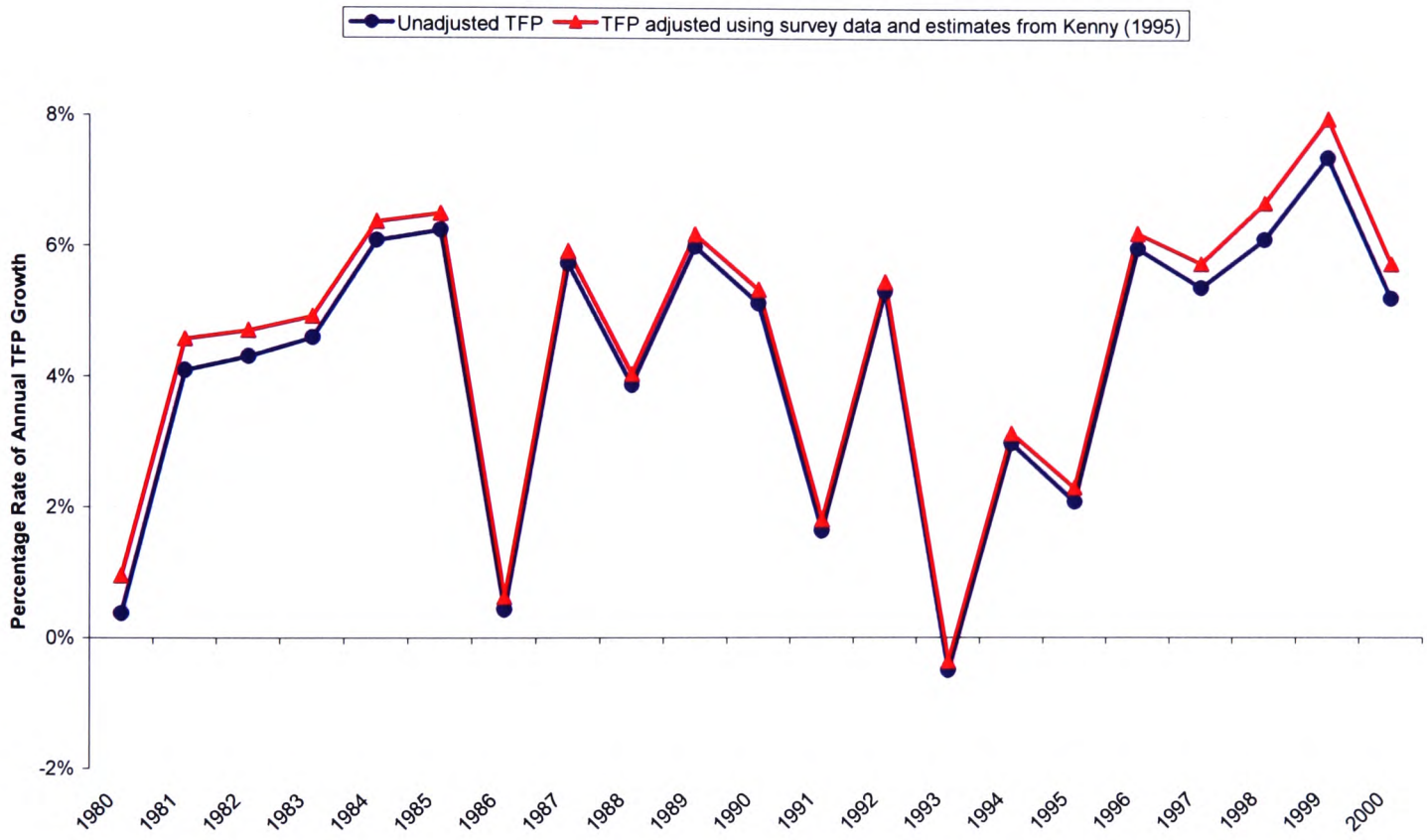

Figure 1.18: Effect of capacity utilisation on calculation of TFP.

One avenue of research that has attained a good deal of prominence in recent growth accounting studies is the examination of the role in growth played Information and Communications Technology (henceforth ICT). This topic was addressed in a growth accounting framework for Ireland by Slevin, 2002 (subject to some lim-

itations of her analysis mentioned above), and for the OECD (including Ireland) by Pilat and Lee (2001) and OECD (2003b) and hence the analysis is not repeated here; instead, a short and selective review of the relevant findings from the literature is presented[38].

Slevin (2002) found, in line with the results presented above, that Irish productivity grew rapidly in the nineties, with a significant increase occurring in the mid 1990. She calculated the output contribution from the high-tech sector (defined in her analysis as the chemical, metal and engineering sectors) in the 1995-1999 period as being greater than the sum of all other output contributions from all other sectors; in fact, she calculates the contribution from this sector as contributing 80% to TFP growth over this period. For the period from 1985-1995, the high-tech sector generally contributed about half of all TFP growth. This is significant because in 2000 Ireland had the largest share of any OECD country of ICT business sector employment, and the highest share of ICT sector in valued added for the non-agricultural business sector (OECD, 2003b).

Therefore, there is some evidence that the productivity acceleration of the late 1990s was attributable in large part to high tech industries. However, there are several reasons to be cautious about reaching the conclusion that ICT was therefore of importance for growth in this period. The first issue relates to the reliability of out-

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[38] It is worth noting in passing that the software component of the Tornqvist index of capital input calculated above contributed less than approximately one fifth of one percent to the value of the index in 2001.

put measures from these sectors, a topic which was discussed in some length above; indeed, Slevin (2002) is skeptical regarding the reliability of output figures in manufacturing generally and high tech manufacturing in particular. A second issue is that most of the productivity growth and output contributions within the high tech sector was dominated by contributions from the chemicals sector (in 2001 its calculated contribution to output growth was more than five times the sum of the contribution of other high-tech sectors), a sector not typically classified as ICT producing and one which exhibits exceptionally high levels of labour productivity, which again relates to the problem of the reliability of output data.

A third issue is that this analysis looks exclusively at the ICT *producing* sectors, and does not look at ICT *using* sectors which may be important for growth and identifying the presence of a "New Economy". However, studies such as those for the US by Jorgenson (2000) and Gordon (2000), and Pilat (2001) and OECD (2003) for the OECD, have found that ICT producing sectors were more important for growth than those sectors classified as ICT using; ICT might have productivity benefits over and above those accruing to investors and owners. Pilat and Lee (2001) consider the productivity in ICT using sectors but unfortunately data on Ireland is not available to facilitate this.

OECD (2003) finds that investment in ICT contributed 0.8% to GDP growth between 1995 and 2000, and only 0.2% between 1990 and 1995 in spite of the fact that the share of investment in ICT in total GDP in 2001 places Ireland ahead of

only France and Portugal (OECD, 2003), thereby suggesting that this low amount of investment was extremely productive in 1995-2000 era. The 1990-2000 performance places Ireland behind Australia, the Netherlands, Canada and the United States, but roughly equal with Japan, Ireland, Sweden, the UK, and Denmark. However, the same study does find that the contribution of ICT manufacturing to aggregate (labour) productivity growth was high in Ireland over the period from 1996-2001 (in line with Slevin, 2002) and behind only Korea and Finland.

To conclude, this rather mixed evidence suggests that the growth impact of ICT has been somewhat anaemic[39]. Slevin's (2002) sectoral analysis revealed that much of the productivity gains attributable to the high tech sector were due to the Chemicals sector. Investment in ICT has been rather low, suggesting that is unlikely that there would be many productivity gains emanating from the ICT using sector), but such investment as there was appears to have been highly productive in nature, which can possibly be explained either by poor output statistics or perhaps by the transfer of frontier knowledge and best practices from other countries into Ireland by means of foreign direct investment (FDI)[40].

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[39] Likewise, Oulton (2001b) finds no evidence to support the idea that a "New Economy" suddenly emerged in the UK, but like Ireland there is evidence that the ICT share in GDP is rising, suggesting that the importance of ICT capital for growth may increase in both countries in the future.

[40] The issue of FDI and Irish growth is also a topic that has been studied quite extensively elsewhere and it is not the intention to repeat this analysis. Honohan and Walsh (2001) is a useful general discussion of FDI. The role of FDI and multinational corporations in complicating output data has already been discussed. Honohan and Walsh identify FDI as a "catalytic factor" in kick-starting rapid growth. They also note that export-driven manufacturing (dominated by foreign companies) was particularly important in creating new manufacturing jobs, a trend which was the opposite of what was happening elsewhere in the OECD. Barry, Hannan and Strobl (1999) provide a useful discussion of employment growth in indigenous and foreign industry in Ireland, while Barry and Bradley (1997)

1.8.3 Labour and its relationship to economic growth

As is evident from the tables of results above, labour input accounted for a significant part of recent economic growth. What explains the importance of labour in this context? At their most fundamental level, labour market changes of this magnitude must have at least some basis in wider demographic trends, and the case of Ireland is no exception. In the EU (including the new EU accession states), Ireland had the second greatest proportional increase in population, after Luxembourg, between 1992 and 2001 (CSO, 2003). Moreover, the rate of natural increase of the Irish population was 0.8% in 2002, compared to an average of just 0.1% in the EU. Another important feature of the Irish population was the composition of the dependency ratio. In 2001, Ireland had an age dependency ratio of 48.5%, which was similar to the EU average of 49.5. However, this similarity masks great differences in the composition of the ratio between Ireland and the EU. For the EU as a whole, the dependency ratio in 2001 was driven in roughly equal parts by the number of children under 14 and the number of elderly over 65. In the Irish case, the 48.5% dependency ratio was made composed of 31.9% in the young category, and just 16.6% in the elderly category (CSO, 2003). In other words, Ireland's dependency ratio is far more favourable than that in the EU as whole. Ireland also had in 2001 the lowest proportion of elderly people of any country in the EU. What factors drove this evolution of the structure

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and Barry, Bradley and O'Malley (1999) and Barry (2004) contains an analysis of the characteristics and economic impacts of Irish and foreign industry more generally.

of the population and of the dependency ratio, and what role did these factors play in driving labour market outcomes and hence economic performance?

The argument that demographic effects played an important role in determining the high rate of growth is a powerful one. As O'Connell (1999) makes clear, Ireland is at present undergoing a very significant demographic transition, involving a sharp drop in the dependency ratio. The dependency ratio stood at almost 70% in 1981 and is expected to fall to about 47% by 2006 (O'Connell, 1999). This situation is of course in stark contrast to the situation prevailing at present in most continental European countries. The dependency ratio is simply the ratio of those not at work (primarily children and the elderly, but also the unemployed and women staying in the home and out of the labour market) to those in employment. Each of these factors is examined in return.

The low number of elderly people in Ireland at present is primarily a legacy of the massive exodus of people in the doom-laden era of 1950s. The great majority of these people, most of whom emigrated to the United Kingdom and the United States, did not return. This has had the effect of removing a large cohort of people who, had they stayed in Ireland, would now be reaching retirement age and thereby putting upward pressure of the dependency ratio. Of course the flipside of this favourable effect (or at least favourable to those people currently paying taxes in Ireland) is that Ireland had a very high dependency ratio in the 1960s, when other European countries were enjoying low dependency ratios, the reverse of the current situation.

The falling number of children that are not of working age is a consequence of a decline in fertility that commenced in the seventies. This fertility decline was sharply accelerated by the legalization of contraception in 1979; prior to this date, contraception was extremely difficult to obtain[41] for anything other than certain "medical" purposes. (Bloom and Canning, 2003).

For instance, the initial fertility decline was given a further impetus in the sixties when the use of oral contraceptives by women was permitted for the regulation of the menstrual cycle. The study of Bloom and Canning (2003) is a particularly interesting study of this policy change, and they argue that the introduction of contraception has served to lower the Irish dependency ratio[42].

Increases in labour supply obviously increased as a result of these increases in the adult working age population. Other factors also played a role. Increasing numbers of young people participated in higher education, so much so that the numbers in third level institutions was 70% higher in 1996 compared with 1981 (O'Connell, 1999). As O'Connell makes clear, the initial effect of this increase was initially to reduce the number of young people in the labour force, and the available jobs were increasingly occupied by (older) women, who remained part of the labour force once these cohorts of educated young people began to enter the market.

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41 Between 1979 and 1985, however, a prescription was required in order to purchase male contraception. After this date, anyone over the age of 18 could freely purchase this type of contraception.

42 The Irish dependency ratio and the research of Canning and Bloom (2003) is also discussed by Gladwell (2006).

This is again another example of the lagged effect that two policy changes had on labour markets in future decades: the introduction of free secondary school education in the 1960s, and the removal in the seventies of discriminatory legislation and practices that had prevented women from participating fully in the labour market. Marriage bans on women in the public service and pay discrimination in general were made illegal in the early seventies, and the right to maternity leave was introduced in 1981 (Fahey, Russell and Smyth, 2000). Fahey and Fitzgerald (1997) find the labour force participation of women to be highly correlated with levels of educational attainment; Fahey, Russell and Smyth (2000) note that female completion rates for higher level education are higher than completion rates for males, and this will have a significant influence on female employment in Ireland in the future.

Fahey, Russell and Smyth (2000) also discuss female labour force participation in a comparative context, and find that while female participation rates are still fairly low by European levels, there is evidence of convergence. For instance, in 1983 Ireland had the lowest rate of married female participation, and by 1990 only one-third of all women were in employment. The differential between the employment rates of men and women was 22% in 1999, and although this placed Ireland fifth in a European ranking of this measure, this rate was still only 3% above the EU average (Glyn, 2002). Interestingly, increases in female participation rates also appear to be behind the sharp reduction in unemployment and improved economic performance in

the Netherlands, another country that has outperformed the recent EU unemployment performance (see Tille and Yi, 2001 and van Ark, 2003).

Another component of the increase in Irish labour supply is attributable to the effects of migration. Emigration has long been one of the defining features of Irish society. The late 1950s saw net outward migration of 60,000 a year, while the late 1980s saw this figure reach 40,000 a year. O'Grada and O'Rourke (1995) note that most of the emigration between the 1930s and 1980s was on the part of those with the lowest educational qualifications, so that the average level of measured educational attainment of those remaining in Ireland would have increased, although there is more evidence of a "brain drain" in the late 1980s.

Aside from the direct economic effects of emigration, the case has also been made by Kennedy (1992) that emigration itself removed the pressures to reform a "conservative and conformist social structure"; Mjoset (1992) likewise describes the Irish experience of emigration as a vicious circle whereby the population decline brought on by emigration reinforced certain negative attitudes and social structures that were inimical to progress and innovation.

In the nineties, however, net inward migration prevailed. Barrett and Trace (1998) find that the majority of these new immigrants (half of them being returning Irish emigrants) had received university level education, a situation in contrast to the educational profile of immigrants settling in other European countries (Fitzgerald,

2000). Barrett and O'Connell (2000) study data collected in 1998 on about 800 Irish workers who graduated from college in 1992. They examine the labour market experiences of those migrants who returned to Ireland. They find no evidence of a wage premium for returning females, but find evidence of a 10% premium for returning male migrants over above the wages of similar males who stayed in Ireland, controlling for a number of other influences.

Additionally, they find that male migrants who left for labour market reasons enjoyed a 15% wage premium over males who did not leave. As Fitzgerald (2000) notes, it has not proved difficult to attract skilled workers to Ireland from abroad, either by tapping the considerable base of Irish emigrants or through attracting workers how would otherwise have absolutely no connection with the country. This exceptionally elastic labour supply has served to moderate upward pressure on the wages of skilled labour. Barrett, Bergin and Duffy (2006) find that immigrants who arrived in Ireland between 1993 and 2003 were highly educated, although were not always working in occupations which fully reflected their high level of educational attainment. They find that immigration increased GNP by about 3% to 3.5% over the period by lowering skilled wages (by around 6%) and thereby increasing Ireland's cost competitiveness on international markets.

Having discussed at some length the reasons for increased labour supply, it is helpful to briefly mention some of the influences on labour demand in Ireland over the period 1980 to 2000. One clear influence is the massive expansion of output

in the nineties, and the implications of this expansion in output for labour demand require little further elaboration.

The opening of the economy to world markets, a process begun in the sixties, continued apace during this period. While many indigenous firms in protected sectors shed workers in the initial phase of opening up the economy, it seems reasonable to conclude that many of the structural employment effects induced by the lifting of trade restrictions had run their course by the early nineties, at least with respect the inefficient protected "traditional industries" of the 1930s and 1950s. The increasing openness can perhaps best be summarized in the following way: in 1980 the ratio of the sum of the exports and imports to GDP was 70%; this figure reached 103% by 1990 and an astonishing 190% by 2000.

Lower real interest rates, achieved through a more responsible managing of public finances after 1987 (Honohan, 1999) and the convergence of Irish interest rates to the Eurozone average during the late nineties in the run up to membership of the euro, undoubtedly played a role in increasing labour demand, and the sharp reduction in interest rates displayed above.

Increased technical innovation, falling marginal tax rates of business activities and levels of educational attainment are also seen as boosting labour demand during this period (Fitzgerald, 1999). Labour demand is afforded a prominent position in Blanchard's (2002) assessment of Irish growth. He argues that wage moderation,

brought about by the collective corporatized wage bargaining that has existed in Ireland since 1987, appears to be a driving force in the reduction in unemployment. The wage bargaining agreements were inaugurated in 1987 against a consensus that wage restraint was necessary to help steer the economy away from its fiscal crisis. Blanchard defines wage moderation as wage growth below the rate consistent with technological progress. This moderation helped improve the employment scenario through its positive effects on profits and capital accumulation, as well as through an increase in ratio of employment to capital.

Blanchard suggests that the employment effects of such wage moderation are large in a small open economy where the world real interest rate is given, and where labour is mobile. The labour effect arises through the influence of UK unemployment on Irish unemployment; he suggests that Irish wages are likely to grow at approximately the same rate as in the UK, since labour will migrate to find the best wage, thus establishing this arbitrage relationship. This point is illustrated in the graph below.

However, given that technical progress has been higher in Ireland, wage growth will have been moderated in the sense defined above. As Glyn (2002) notes, real hourly wage growth was only 1.1% between 1990 and 1999, compared to trend growth in labour productivity (as calculated by Glyn) of 3.2%.

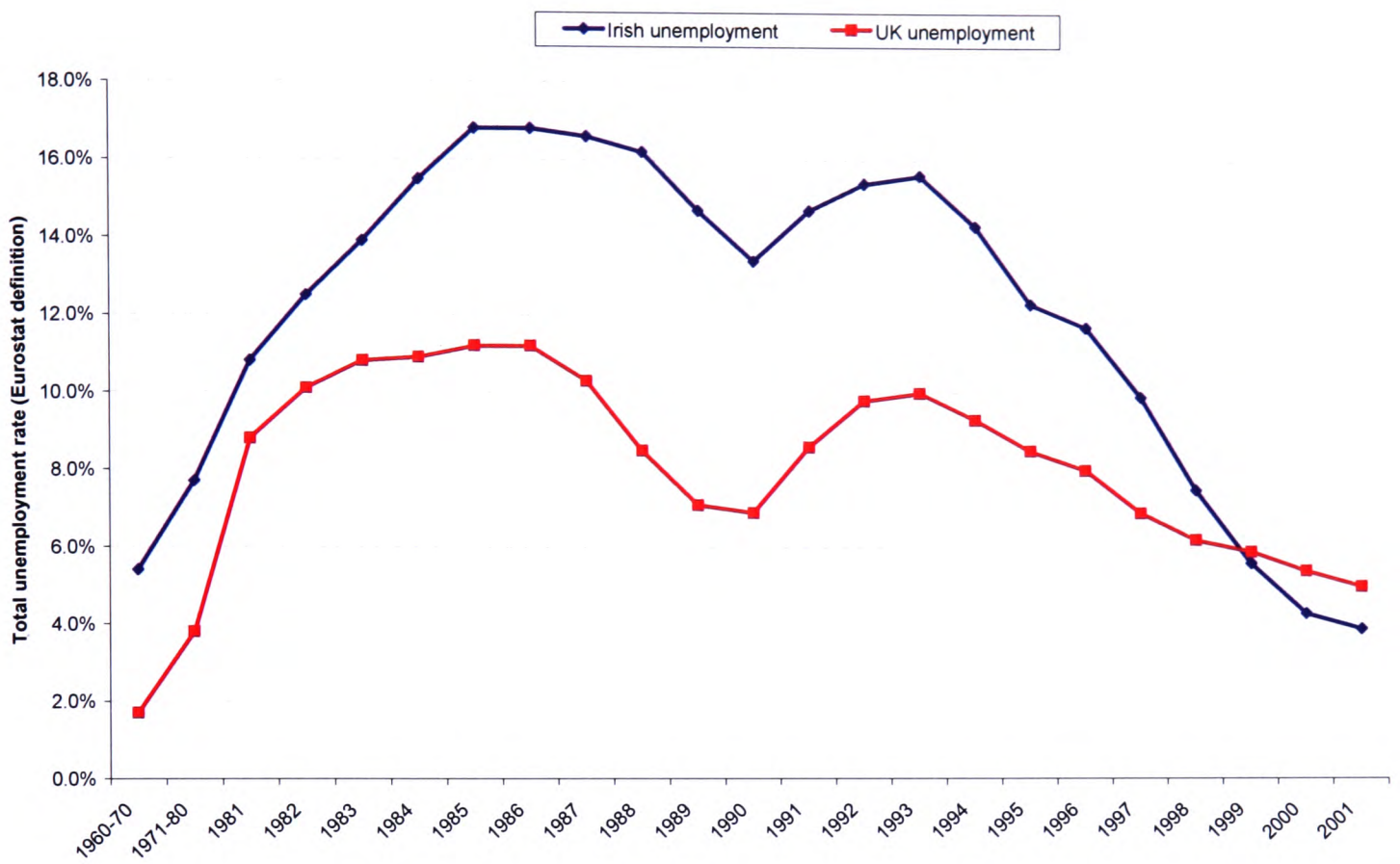

Figure 1.19: UK and Irish unemployment.

The foregoing discussion has touched on a number of important and interlinked issues, which are unified in what may be called the Krugman-Barry hypothesis. This hypothesis also provides an elegant explanation for why productivity and labour have together been so important for recent Irish growth. Below it is explained how this hypothesis links together many seemingly disparate threads in the Irish growth story, such as labour demand and supply, FDI, and the outward orientation of Irish economic development. It is argued that the results of the growth accounting in this exercise provide a good measure of support in favour of this hypothesis, and therefore this chapter provides some independent and new evidence in favour of the Krugman-Barry hypothesis.

An important early contribution to this research area was Krugman (1997), who noted that there were many compelling reasons for viewing Ireland not as a *national* economy, but rather as a *regional* economy. The distinction is important because in a national economy, productivity determines (long-run) economic well-being, whereas the fate of a regional economy is crucially determined by its export performance: regional income is closely linked to regional exports, so if exports fall, expenditure on non-tradeables declines and workers emigrate. This is one reason why the high Irish productivity rates from 1973 did not give rise to convergence in living standards.

Barry (1999b) elaborated on this theory in his accounts of Irish growth. He defines the long standing economic problem in Irish development as the need to become competitive in internationally traded sectors other than agriculture. As a regional economy, Irish workers readily emigrated to other economies (most notably to Britain and to the US) if wages fell or unemployment rose[43]. This ruled out the path to economic development taken by other late industrialisers, which was to develop through lower wages, which allowed a manufacturing sector to develop, which in turn gave rise to beneficial indirect effects such as learning by doing, human capital accumulation, and reverse engineering. In the Irish case, the willingness of Irish men and women to emigrate following the Act of Union of 1800 with Great Britain placed a floor on wages below which wages would not adjust. This ruled out the low-wage development path.

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[43] Productivity growth in non-tradeables displaces workers, and if, as seems likely, agriculture cannot employ these workers, then they are likely to emigrate.

How did this situation arise? Barry relies on Krugman (1991a, b) to argue that, after the Act of Union[44], the formerly prosperous Irish economy became a rural hinterland of Britain (with the exception of some industrialization around Belfast in Northern Ireland). Krugman argues that, prior to the industrial revolution, high transport costs and insignificant economies of scale meant that suppliers to the agricultural sector (this being the most important economic sector by a considerable distance) were obliged to locate close to their markets, with the result that any industrial activity was distributed rather uniformly across economies.

Rapid technical progress in transport, and the rise of factories and mass production and new economies of scale in production associated with the Industrial Revolution, broke this link. Agglomeration economies became increasingly important as the industrial revolution progressed, and production was increasingly concentrated in regions with large city-based populations. Technological externalities, the result of the manufacturing and technical progress in these newly industrializing cities, gave rise to further agglomeration (see David, 1990). Ireland became, or rather remained, an agricultural backwater of Britain, even as Britain fostered, and greatly benefited from, the Industrial Revolution.

This is why Barry (1999b) defined the Irish development problem as being one of becoming competitive in the non-agricultural sector, because capital accumulation

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[44] The Act of Union 1800 merged Ireland and the Kingdom of Great Britain to create the United Kingdom of Great Britain and Ireland on 1 January 1801. The act received the Royal Assent on 1 August 1800.

and productivity tend to displace labour in a regional and agricultural economy. In a regional economy, this is problematic because wages will not adjust downwards when labour is displaced; instead the displaced labour will emigrate. In this light, it is not difficult to see why the protectionist policies of the thirties, forties and fifties were so disastrous for economic development.

Given this complex problem, how did Ireland escape from this situation? Barry (1999b) sees the sources of the economic transformation of the 1990s in the changes in industrial policy in the 1960s. The extensive and generous incentives provided to foreign capital since the 1960s encouraged substantial FDI flows to Ireland, particularly in the 1990s. This greatly contributed to expanding the Irish export base, which, as a regional economy, is a vital. In turn, this supported domestic demand which increased expenditure on non-tradeables. The increased presence of high-tech manufacturing centers facilitated learning-by-doing and indirect human capital accumulation, which improved the performance of both the foreign and the indigenous sector. As Barry, Bradley and O'Malley (1999) point out, indigenous industry employed 8% more people in 1997 than it did ten years previously, which was especially impressive as it was contrary to prevailing EU and OECD trends.

Were labour market reallocations important for growth? A shift-share analysis

One fruitful means of examining labour market evolutions in a growing economy, and examining in more detail some of the implications of the Krugman-Barry

hypothesis, is to examine if growth in productivity is being driven by reallocations of employment from sectors with low productivity growth to those with higher growth, or whether productivity growth is attributable to growth in productivity within sectors. The level of productivity level should also be taken into account, since gains to employment shifts to high productivity growth sectors may be diminished if the level of productivity is low in such sectors (van Ark, 1996). This type of analysis is often referred to as "shift-share" analysis and expositions and recent applications are available in Syrquin (1984), Timmer and Szirmai (2000), van Ark (1996, 2000) and Jalava, Heikkinen, and Hjerppe (2002). Shift-share analysis is thus a means of examining the impact of structural changes on labour productivity. If the Krugman/Barry hypothesis is correct, evidence should be found of reallocation away from low productivity sectors, especially agriculture, to higher productivity industries.

Productivity for the economy as a whole may be written as the sum of sectoral productivity levels weighted by sectoral employment shares (van Ark, 1996):

$$P_m = \frac{Y_m}{L_m} = \sum_{k=1}^{n}(\frac{Y_k}{L_k})(\frac{L_k}{L_m}) = \sum_{k=1}^{n}(P_k S_k) \tag{1.27}$$

Here, Y is output and L is employment and thus P is productivity ($\frac{Y}{L}$); the m subscripts refer to the total economy, and the k subscripts index the sectors ($k = 1, ..., n$). S is the sectoral employment share ($\frac{L_k}{L_m}$). Taking differences, this expression may be written as:

$$\Delta P_m = \sum(\Delta P_k * S_k) + \sum(P_k * \Delta S_k) \tag{1.28}$$

In a discrete time setting, this equation can be rewritten in the following form:

$$\frac{P_m^t - P_m^0}{P_m^0} = \frac{\sum_{k=1}^n (P_k^t - P_k^0) * S_k^0}{\sum_{k=1}^n P_k^0} + \frac{\sum_{k=1}^n P_k^0 * (S_k^t - S_k^0)}{\sum_{k=1}^n P_k^0} + \frac{\sum_{k=1}^n (P_k^t - P_k^0) * (S_k^t - S_k^0)}{\sum_{k=1}^n P_k^0} \tag{1.29}$$

The t superscript indicates time period, while the 0 superscript indicates a base year. The first term on the right hand side of the above expression is a measure of productivity growth within sectors, and is referred to as the intrasectoral effect. The second term is the net shift effect and represents the effect of the change in sectoral employment shares on overall growth. This "static" effect is positive if labour moves from low to high productivity sectors, and is negative if labour moves from sectors with high productivity to those sectors with low productivity. The third term is an interaction term that captures the joint effect of changes in employment shares and sectoral productivity. As van Ark (2000) notes, this effect is usually small since sectors with fast productivity growth generally display an offsetting decline in their employment shares. This term will be positive if sectors with an increasing employment share show increasing productivity, and likewise it is negative if sectors with a falling share display falling productivity. The results of this analysis are shown below, which shows the percentage of the total re-allocation effect that is attributable to each component.

Year	Intrasectoral effect	Net shift effect	Interaction effect
1980	100.68%	-1.05%	0.37%
1981	101.69%	-0.86%	-0.83%
1982	102.63%	-0.88%	-1.75%
1983	103.03%	-0.84%	-2.19%
1984	102.21%	-0.67%	-1.55%
1985	103.44%	-0.66%	-2.78%
1986	102.61%	-0.76%	-1.85%
1987	103.80%	-0.78%	-3.02%
1988	102.91%	-0.74%	-2.17%
1989	100.59%	-0.61%	0.02%
1990	101.39%	-0.55%	-0.84%
1991	101.92%	-0.58%	-1.34%
1992	102.13%	-0.56%	-1.57%
1993	102.56%	-0.52%	-2.04%
1994	103.34%	-0.47%	-2.87%
1995	101.55%	-0.44%	-1.11%
1996	100.55%	-0.47%	-0.07%
1997	97.99%	-0.39%	2.41%
1998	99.25%	-0.40%	1.14%
1999	97.11%	-0.41%	3.30%
2000	97.71%	-0.34%	2.63%
2001	98.40%	-0.31%	1.92%

Figure 1.20: Results of shift share analysis.

In common with many other exercises of this nature (see, for example, the references listed above), the analysis reveals that by far the most important source of productivity growth occurs through the intrasectoral effect. Interestingly, there is a small but significant decrease in the role played by the net shift effect over the period. It is also negative in every year, suggesting that productivity has not increased due to a dynamic reallocation of labour resources away from "low tech" to "high tech" industries which exhibited higher productivity. However, the trend of the the value of this variable indicates that this effect is diminshing over time. This is likely to reflect the increasing importance of services in the economy, and the decline and collapse of many sheltered industries before the beginning of the sample period studied in this chapter.

Given that this number declines over the period, it suggests that a good deal of re-allocation happened either in the seventies or early eighties; that is, before the sample period studied in this chapter. Reallocation towards higher productivity sectors is likely to impact on the wider economy with a lag. The opening-up of the economy to international trade in the 1960s exposed many inefficient domestic firms to international competition for the first time, and therefore it is likely that labour re-allocation may have undergone its most significant developments in the sixties and seventies. In fact, this is precisely the finding of O'Leary (2003). He found that aggregate productivity converged across Irish regions between 1960 and 1979, due to the "convergent effect" of this structural change and to converging service

sectors. Therefore, the decline in the net shift effect over this period is perhaps to be expected[45].

Conclusion on labour input

This section of the chapter examined the role of labour in the Irish boom. The starting point was the set of main results above, which pointed to a large positive contribution of labour services generally, both in respect of the quantity and the quality of this flow of services. The reasons for this large positive contribution were then assessed. Perhaps unsurprisingly, the fundamental basis of labour contributions appears to be deep seated and rooted in the rather complicated history of Irish economic development. A full quantitative assessment of the relative roles of labour demand and labour supply is outside the scope of this chapter. However, it seems likely that the analytical narrative presented covers the main contributions of supply and demand. In particular, the emphasis of recent research on fertility and changes in policy concerning fertility seems especially well placed. Likewise, the removal of large cohorts of individuals through migration served to drastically reduce the dependency ratio.

The demand for labour is a more complicated story, encompassing as it does the research on the economic geography of Ireland (as represented by Krugman and Barry) as well as the more conventional macroeconomic accounts of Blanchard (2002) and Honohan and Walsh (2002). However, perhaps the most compelling ac-

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[45] Interestingly, forthcoming research by Temple and Woeesmann (2006) finds that the reallocation of labour is an important determinant of international variation in productivity growth.

count of the role of labour is suggested by the Krugman/Barry hypothesis. The basic growth accounting results provided a measure of support in favour of this explanation of Irish growth. This was investigated further in some new shareshift analysis, which provided a helpful perspective on labour market evolutions over the sample period.

1.9 Conclusion

This chapter has studied productivity and economic growth in Ireland over the period 1980 to 2001 by decomposing growth in GDP into its constituent components in order to assess which of the proximate growth determinants, in the form of capital and labour inputs, accounted for the greater part of growth in the period. The first part of the paper consisted of a detailed review of methodologies and data sources (more information relating to methodology is included in the Appendix to this chapter). There it was observed that the relative paucity of economic data on Ireland, especially with respect to labour services, rendered the task of creating appropriate index measures more difficult. The available data was used to carefully construct series for value added, labour and capital services, and factor shares.

Applying these growth accounting techniques to this data suggested an important role for productivity and increases in the quality and quantity of labour in determining the dramatic recent growth rates. A notable feature of the results was the relatively small role accorded to capital services, one implication of which is that there appears be a quantitatively significant difference between recent Irish growth and that of the Asian "tiger" economies during the boom years of those economies. As such, this chapter has demonstrated that accumulation of capital and labour inputs support growth, but that the fundamental causes of this growth are more deep-rooted. It seems most unlikely that the quantity and quality of Irish labour input will continue to grow as rapidly as it has done in the recent past, whereas the finding that capital is

relatively unimportant during the boom years suggests that the cause for future Irish growth will be found in other sources. This is consistent with emerging lessons from the empirical growth literature, which is increasingly turning its attention towards the deep determinants of growth.

Returning to the growth accounting analysis, the possibility that reports of rapid economic growth were overstated was also investigated. This involved a critical review of the relevant literature, and some new analysis based on alternative weights for the growth accounting. This new analysis demonstrated that concerns over the statistical reliability of Irish value added data were overstated by some commentators. Whilst acknowledging the presence and importance of transfer pricing and other related practices, the dramatic increase in Irish value added and TFP is mostly real, and reflects the underlying economic circumstances. One topic that was not investigated in great detail in this chapter was the reason for the TFP boom. Again, econometric investigations of the determinants of TFP are hampered by data inadequacies. Unfortunately, econometric models of TFP do not appear to be feasible in the Irish context given the yearly frequency of much of the important data and the resultant difficulty of estimating a time series model with a number of parameters on a data set with less than 25 observations. Moreover, much of this data is either not available at all or not available with an appropriate degree of coverage[46].

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[46] As an adjunct to this discussion, it is worth noting that constant-price gross domestic expenditure on R&D was almost eight times higher in 2001 than in 1981 (OECD, 2006). Inward foreign direct investment constituted 9.1% of gross domestic fixed capital formation per year on average from 1985 to 1995. At the height of the Irish and global technology boom, this figure had reached 112.5% in

The result that labour services and TFP were both important for growth suggested instead a measure of support for the Krugman/Barry hypothesis on Ireland's economic geography. This line of research argues that labour re-allocation should be important, and this prediction was examined using shareshift analysis. A number of influences powerfully affected the Irish labour market since the sixties, and the importance of these factors was discussed. Policy decisions which (perhaps unwittingly) changed fertility, and the role of migration, were particularly important in this regard. However, while these serendipitous outcomes may have been important, conscious policy decisions with respect to education (which greatly improved the quality of supply of human capital) and with respect to industrial policy, in particular the policy to pursue a low corporate tax rate and to attract foreign capital with generous subsidies, yielded tangible benefits for the economy.

What lessons can be drawn from this analysis? One powerful lesson is that luck and history can important determinants of economic outcomes. The migration of the fifties and sixties, and the changes in fertility patterns in the seventies and subsequently, were not consciously designed policies intended to deliver a massive spurt of growth at some future stage. Instead, they were reactions to previous failures in economic policy (the migration of the post war era), and from the interaction of complex social and economic phenomena (in the case of fertility and labour supply changes). The role of history manifested itself under the Krugman/Barry hypothesis,

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2000! This figure was 40% in 2001 and 75% in 2003 (UNCTAD, 2005).

which argued that the relatively prosperous Irish economy of the 18th century became a rural hinterland of the United Kingdom. These hypotheses were not tested directly, but the results of the growth accounting do provide a measure of evidence that is consistent with they Krugman/Barry hypothesis. Irish policy makers struggled to overcome this legacy following independence in 1922.

What final conclusions can be reached on the sources of Irish growth? A combination of fortuitous circumstances in the form of a benign external macroeconomic environment in the 1990s, allied with a favourable demographic scenario, interacted with a progressive policy environment that encouraged both human and physical capital accumulation and openness to international markets. Ireland's rapid convergence should therefore not be interpreted as being due to a single cause, or purely to luck, or exclusively to exceptional foresight on the part of the policymakers. It was a process of delayed convergence by an economy that had grossly underperformed the European average for much of the twentieth century, albeit a convergence that was given a great deal of impetus by forward-looking policies.

1.A Appendix 1 - A Review of the basic growth accounting methodologies used in the paper

1.A.1 Introduction

This section introduces, in general terms, the basic approaches that are used in the main part of this chapter to explain recent Irish economic growth. The goal of growth accounting is to provide a consistent decomposition of GDP, founded on index number theory and neoclassical production theory, among its component elements with a view to describing the sources of (aggregate) output growth. The approach examines how much of the rate of change of output in a particular economic entity, such as an industry, sector or economy, can be explained by the rate of change in labour and capital factor inputs. That part of output growth that is not attributable to growth in capital and labour is referred to as total- or multi-factor productivity (henceforth TFP), which implies that the TFP variable is measured in a residual fashion in this framework. In the words of the OECD (2001a) "Multifactor productivity measurement helps disentangle the growth contributions of labour, capital, intermediate inputs and technology. This is an important tool for reviewing growth patterns and assessing the potential for future economic growth".

A clear explanation of the TFP residual appears in Hulten (2001): "The TFP residual captures changes in the amount of output that can be produced by a given quantity of inputs. Intuitively, it measures the shift in the production function...Many

factors may cause this shift: technical innovations, organizational and institutional changes, shifts in societal attitudes, fluctuations in demand, changes in factor shares, omitted variables, and measurement errors. The residual should not be equated with technical change, although it often is".

Standard primal neoclassical growth accounting does not make any assumptions about the underlying model of growth in the economy, which may cause the results of growth accounting exercises to be viewed with a certain degree of skepticism because of a real or perceived problem of permissiveness, in that the results can potentially be interpreted in more ways than is legitimate (Prescott, 2002).

However, there does exist in the literature a successful body of work that carefully uses established and new theories of economic growth to interpret growth accounting results, suggesting that a sensibly cautious approach can be a useful exercise. In any case, the real point of growth accounting is not to immediately identify the deep structure of the economy and the fundamental causes of growth, but rather to suggest proximate sources of growth as a first step towards further analysis of these sources or as a means of testing hypotheses as to the sources of growth. In the words of Barro (1999) "Generally, it is seen as a preliminary step".

In the case of the accounting in this chapter, the accounting is both a preliminary step to more detailed analysis, and an end in itself. The growth accounting results are useful on their own terms, since they serve a useful purpose in allowing

comparison between the results of such accounting exercise for other countries. This helps to classify Irish growth according to whether or not it was, for example, capital intensive or instead driven by productivity. In turn, this has important implications for future growth in Ireland. Additionally, as noted above, the results of growth accounting provide measures of evidence which help adjudicate between competing explanations of the Irish boom.

Moreover, given the enormous number of papers in existence that have sought to understand the growth experience of countries and group of countries though the lens of growth accounting, conducting the first detailed growth accounting study for Ireland allows useful comparisons to be made between the nature of growth in Ireland with the experiences of other countries, and more particularly for testing the some of hypotheses discussed above. The results section of this chapter includes some comparative analysis. One can also modify the basic growth accounting framework to investigate interesting auxiliary issues. Modifications and extensions to the basic model presented below will be presented and explained at appropriate junctures of the chapter.

1.A.2 Methodology

This section introduces and the basic concepts of growth accounting and presents and discusses the specific methods used in this chapter of the thesis. The methodology used is in essence a version of the analysis that appears in Jorgenson (1990) and

OECD (2001a), which is in turn based on methodologies whose initial development is associated with, inter alia, Tinbergen (1942), Kendrick (1956), Solow (1957) and Denison (1961, 1962), and subsequently improved upon by numerous others. In this approach, output is expressed at the aggregate level in terms of value added and as a function of labour, capital and productivity. Aggregate level variables are calculated on the basis of an appropriate aggregation technique that is to be applied to sectoral values. Sectoral value added is again a function of productivity and the capital and labour inputs in that sector, and the productivity contribution of an input is its value share times its growth rate.

This approach assumes the existence of an aggregate production function; in turn, this requires the further assumptions that the sectoral value added function is the same for all sectors; that the functions relating labour and capital inputs are the same in every sector, that the sectoral production functions are the same as the aggregate production functions and that the different components of the inputs receive the same price in every sector (Jorgenson, 1990). How reasonable are these assumptions?

Jorgenson (1990) provides an intuitive defense of these restrictions, based on the observation that measured real world reallocations of labour and capital across sectors implies a violation of these assumptions. If these reallocations are significant for economic growth and productivity, then one may question the usefulness of assuming labour and capital inputs are the same in every sector, since inputs presumably only move between sectors because of different rates of return. Jorgenson

notes that the aggregate productivity growth rate will depend in part on reallocations between sectors of value added, capital and labour and that such reallocations may be obtained by calculating the difference between growth rates of aggregates indexes of value added, capital and labour and the related indexes found by weighting the components of these aggregate indexes by prices specific to the sector of the component. Jorgenson finds that reallocation has a small but not entirely negligible effect on productivity over the period 1947 to 1985 for the US economy. His conclusion is that the assumptions required to implement the sectoral analysis that were mentioned above appear reasonable over the long-run, but are very likely not to hold in particular periods, such as during recessions. This would appear to suggest that the time period used in this chapter (over twenty years) is of an appropriate duration.

Growth accounting is based on index number theory and the neoclassical theory of production, and hence rests on a number of assumptions. Here, some of the more important assumptions are briefly presented; the list of assumption and the discussion below is based closely on OECD (2001a). The most basic assumption is that a production function may be used to represent the existence of a production technology, which relates gross output to inputs of labour, capital and intermediate inputs. This production function is homogenous of degree one. There are N and M types, respectively, of labour services and capital services.

The representative firm operates in a competitive environment and minimizes the costs of inputs subject to the production technology mentioned above. Labour

and intermediate inputs can be hired at the market rates, while the user cost of capital (explained in detail in the section on capital input) represents the price of capital services that arises from the (productive) stock of a particular type of capital asset. Note that the aggregate value added TFP analysis described above and used in this chapter implies the existence of the value added function which combines capital and labour together in an efficient way and in a way that is independent of intermediate inputs (ONS, 2003). It should be noted here that the approach adopted is not, in the words of Barro (1999), a "dual" approach but is rather a "primal approach".

The distinction relates to the fact that this paper computes TFP on the basis of factor quantities instead of factor prices. Hsieh (2002) is a leading example of the use of factor prices in a growth accounting exercise. The intuition for using factor prices (Barro, 1999) is that factor prices may only increase if output is increasing for given inputs, so the correctly weighted average of the growth of the factor prices measures the rate of TFP growth. This approach requires no assumptions about the equivalence of factor prices to marginal products or about the nature of the production function. However, the data requirements needed to implement this type of analysis are extremely onerous. Very detailed data is required on factor prices for different varieties, vintages and qualities of inputs, and complex assumptions frequently need to be made to overcome data unavailability. These data problems alone probably explain why this approach has featured so rarely in the literature.

Assume the existence of a production function Q, relating gross output to labour inputs (L) and capital inputs (K). There are N different types of labour ($L_1, L_2, L_3....L_N$) and K types of capital ($K_1, K_2, K_3....K_M$). Productivity changes are Hicks neutral so we may write:

$$Q = A \cdot F(L_1, L_2, L_3....L_N, K_1, K_2, K_3....K_M) \tag{1.30}$$

The representative firm minimizes cost, subject to this production technology, and it can hire labour at (market) wage rate

$$w_i(i = 1, 2, ...N) \tag{1.31}$$

The price at which a firm can hire capital is slightly more involved, and this was discussed in more detail in the main body of the chapter, but the user cost of capital is the price of capital and is a function of, inter alia, the way in which an asset loses efficiency as it ages, changes in the market price for a new asset, asset retirement, required rates of return etc. All of these influences are picked up by user cost of capital term $\mu_i(i = 1, 2, ...N)$.

We may now express the representative firm's problem as the standard optimization problem:

$$\text{Min } C = \sum_{i=1}^{N} w_i L_i + \sum_{i=1}^{M} \mu_i K \tag{1.32}$$

subject to

$$Q = A \cdot F(L_1, L_2, L_3 .... L_N, K_1, K_2, K_3 .... K_M)$$

The solution to this optimization problem gives rise to the usual marginal conditions:

$$w_i = P \cdot A \frac{\delta F}{\delta L_i} \tag{1.33}$$

$$\mu_i = P \cdot A \frac{\delta F}{\delta K_i} \tag{1.34}$$

Where P is the price of output. These two equations simply state respectively that labour is hired up the point where the wage rate equals the marginal revenue of labour, and capital is hired up to the point where the marginal revenue it generates is equal to its users costs. The important thing to note here is that each type (or quality) i of labour and capital is weighted by its respective marginal productivity.

Now differentiate production function with respect to time

$$\frac{d \ln Q}{dt} = \sum_{i=1}^{N} \frac{F_{L_i} L_i}{F} \frac{d \ln L_i}{dt} + \sum_{i=1}^{M} \frac{F_{K_i} K_i}{F} \frac{d \ln K_i}{dt} + \frac{d \ln A}{dt} \tag{1.35}$$

Note the weights attached to the inputs are the output elasticities, which are not directly observable. One could estimate these elasticities empirically, and indeed a number of authors have attempted to do this. However, the econometric problems that attend such exercises are severe. The most significant problem is that labour

and capital are not determined separately from output, so least squares type techniques will give rise to biased estimates of these coefficients (on this see Barro, 1999 and Sarel, 1997). Hulten (2001) also discusses the problems that numerous parameters may impose on limited data sets and the demanding and usually non-linear econometric techniques that are often required to overcome the endogeneity issue mentioned previously.

The more common procedure is to assume that factor markets are competitive and to insert the optimality conditions in place of the output elasticities, which is acceptable since the two entities are obviously equivalent in a competitive market. Nevertheless, this practice is not without its own problems, the most obvious being the point that factor markets may not be competitive. This is a reasonable criticism, but one would perhaps expect factor markets in most advanced economies to be fairly competitive and responsive to market pressures when viewed over a sufficiently long time period. Hall (1988) demonstrated that if imperfect competition leads to prices above marginal cost, then the Solow residual will contain a biased estimate of the Hicksian technological shift parameter, A. Roeger (1995) demonstrated how the assumption of imperfect competition can reconcile conflicting estimates of dual and primal TFP estimates.

Sarel (1997) also discusses potential biases that may arise in relation to the treatment of self employed workers. The treatment of the self employed above in

the main body of the chapter. In any case, the practice of assuming competitive markets is well established in the literature, and the use of this assumption here at least supplies a degree of comparability with existing results, even if it does not conclusively address the objections that can be made against it.

Nevertheless, a literature does exist which drops the competitive markets assumption and decomposes output growth into its component parts in the presence of imperfect competition. The main effect of introducing imperfect competition in this context is that the shares of labour and capital found under competitive assumptions will differ from those when market imperfections are considered. The consequences of incorrectly measuring factor shares can have very significant effects on a growth accounting exercise, since under- or overestimating the shares of a particular input will lead to different conclusions as to the sources of growth.

Young (1995) sums up the issue as follows: "The absence of perfect competition, in the context of a constant returns to scale production function, could lead to mismeasurement of the elasticity of output with respect to each input, as factor shares need no longer reflect output elasticities. In particular, to the degree that monopoly profits are reflected in capital income, capital's income share will tend to overstate the elasticity of output with respect to capital." This chapter follows the standard practice in the literature, which is to assume competitive markets. Nevertheless, these qualifications regarding imperfect markets must be kept in mind when interpreting the results.

Now, assuming competitive factor markets once again, substitute the optimality conditions for the output elasticities:

$$\text{Plug } PAF_{L_i} = w_i \text{ into } \frac{F_{L_i}L_i}{F} \Rightarrow \frac{F_{L_i}L_i}{F} = \frac{w_iL_i}{PAF} = \frac{w_iL_i}{PQ} \tag{1.36}$$

$$\text{Plug } PAF_{K_i} = \mu_i \text{ into } \frac{F_{K_i}K_i}{F} \Rightarrow \frac{F_{K_i}K_i}{F} = \frac{\mu_iK_i}{PAF} = \frac{\mu_iK_i}{PQ} \tag{1.37}$$

The expressions $\frac{w_iL_i}{PQ}$ and $\frac{\mu_iK_i}{PQ}$ represent, respectively, the share of labour of type i in the total value of production, and the share of capital of type i in the total value of production.

$$\frac{d\ln Q}{dt} = \sum_{i=1}^{N} \frac{w_iL_i}{PQ}\frac{d\ln L_i}{dt} + \sum_{i=1}^{M} \frac{\mu_iK_i}{PQ}\frac{d\ln K_i}{dt} + \frac{d\ln A}{dt} \tag{1.38}$$

Re-arranging this expression allows for the residual calculation of the rate of change of total factor productivity (TFP):

$$\frac{d\ln A}{dt} = \frac{d\ln Q}{dt} - \sum_{i=1}^{N} \frac{w_iL_i}{PQ}\frac{d\ln L_i}{dt} - \sum_{i=1}^{M} \frac{\mu_iK_i}{PQ}\frac{d\ln K_i}{dt} \tag{1.39}$$

One can simplify this expression by weighting the rate of change of each type of input by marginal productivity or share in total outlays:

$$\frac{d\ln L}{dt} = \sum_{i=1}^{N} \frac{w_iL_i}{wL}\frac{d\ln L_i}{dt} \text{ where } wL = \sum_{i=1}^{N} w_iL_i \tag{1.40}$$

$$\frac{d\ln K}{dt} = \sum_{i=1}^{M} \frac{\mu_iK_i}{\mu L}\frac{d\ln K_i}{dt} \text{ where } \mu K = \sum_{i=1}^{M} \mu_iK_i \tag{1.41}$$

Writing the current price share of labour and capital as $s_L = \frac{wL}{PQ}$ and $s_K = \frac{\mu K}{PQ}$, the notation above means we can rewrite the expression for TFP as:

$$\frac{d\ln A}{dt} = \frac{d\ln Q}{dt} - s_L\frac{d\ln L}{dt} - s_K\frac{d\ln K}{dt} \tag{1.42}$$

1.A.3 Implementing the Growth Accounting Model

The equation below is expressed in continuous time, but macroeconomic data are obviously only available in discrete time.

$$\frac{d\ln A}{dt} = \frac{d\ln Q}{dt} - s_L\frac{d\ln L}{dt} - s_K\frac{d\ln K}{dt} \tag{1.43}$$

Therefore, one needs to use an appropriate index to approximate and empirically implement this equation.

People have in the past used econometric techniques but Diewert (1976) demonstrated that if a particular type of production function is assumed, specifically the transcendental logarithmic or translog index that was developed by Christensen, Jorgenson and Lau (1973), then the continuous Divisia index can be approximated in an exact way using the discrete Tornqvist index. The Tornqvist index is the average value of a Divisia index at two points in time; a Divisia index is an index that allows shares of an aggregate to change over time. Translog production functions are a very general and very flexible type of production function, in that they impose no a priori restrictions elasticities of substitution and returns to scale and they may be

interpreted in certain contexts as more general forms of other production functions, such as, for instance, the Cobb-Douglas production function.

Diewert's (1976) work was important because he demonstrated that the Tornqvist index was not just an approximation to the Divisia index, but instead was an exact index when the underlying production technology was translog. Since the translog production function can be regarded as a reasonably good approximation to many other production functions, then even if the underlying production function isn't translog, then using the Tornqvist index won't necessarily lead to any particularly significant loss of accuracy. In the words of Hulten (2001), "the discrete time Tornqvist index was a sensible choice even if the "world" was not translog". In this event, the degree of exactness in the index number depends on the closeness of translog function to the true production function.

Diewert (1976) used the term 'superlative' to characterize this aspect of an index. What Diewert showed, in effect, was that the translog specification of the production function served as a potential function for the discrete Tornqvist index in the same way that the continuous production function served as a potential function for the continuous Divisia index..."the value of "inessential" parameters of the translog - that is, those other than the Hicksian efficient parameter - need not be estimated if the Solow residual is used".

Consider the following translog value added production function:

$$Q = \exp(\alpha_0 + \alpha_K \ln K + \alpha_L \ln L + \alpha_t t + \frac{1}{2} B_{KK} (\ln K)^2 \quad (1.44)$$

$$+ B_{KL} (\ln K)(\ln L) + B_{Kt} \ln K \cdot t + \frac{1}{2} B_{LL} (\ln L)^2 \quad (1.45)$$

$$+ B_{Lt} \ln L \cdot t + \frac{1}{2} B_{tt} t^2 \quad (1.46)$$

Note that this may be considered (Diewert, 1987) as a simple second order Taylor expansion of some general production function of the form below, relating the log of output y to a vector of n different types of x-inputs:

$$\ln y = f(\ln x. \ln x, \ln x ... \ln x) \quad (1.47)$$

Under the assumption of CRS, the following restrictions hold

$$\alpha_K + \alpha_L = 1 \text{ and } B_{KK} + B_{KL} = B_{LL} + B_{KL} = B_{Lt} + B_{Kt} = 0 \quad (1.48)$$

Take first differences of the production function to get a measure of growth over discrete periods:

$$\ln(\frac{Q(t)}{Q(t-1)}) = \tilde{O}_L \ln(\frac{L(t)}{L(t-1)}) + \tilde{O}_K \ln(\frac{K(t)}{K(t-1)}) + TFP_{T-1,T} \quad (1.49)$$

$$\text{Where } \tilde{O}_i = \frac{O_i(T) - O_i(T-1)}{2} \quad (1.50)$$

Where the O_i terms represent shares in factor payments.

To allow K and L to be made up of different aggregates, we can assume, as is standard (see for instance Young (1995) and OECD (2001a), that K and L are CRS translog functions of differentiated sub-inputs.

$$K = \exp[\alpha_1^K \ln K_1 + \alpha_2^K \ln K_2 + ... + \alpha_m^K \ln K_m + \frac{1}{2} B_{11}^K \ln(K_1)^2 + \quad (1.51)$$

$$\frac{1}{2} B_{12}^K \ln(K_2)^2 ... \frac{1}{2} B_{mm}^K \ln(K_m)^2 \quad (1.52)$$

$$L = \exp[\alpha_1^L \ln L_1 + \alpha_2^L \ln L_2 + ... + \alpha_n^L \ln K_n + \frac{1}{2} B_{11}^L \ln(L_1)^2 + \quad (1.53)$$

$$\frac{1}{2} B_{12}^L \ln(L_2)^2 ... \frac{1}{2} B_{nn}^L \ln(L_n)^2 \quad (1.54)$$

Again, first difference the logarithms to provide a measure of growth rates and to find the Tornqvist indices for the input:

$$\ln(\frac{K(t)}{K(t-1)}) = \sum_{i=1}^{m} \tilde{O}_{Ki} \ln(\frac{K(t)}{K(t-1)}) \quad (1.55)$$

$$\ln(\frac{L(t)}{L(t-1)}) = \sum_{i=1}^{n} \tilde{O}_{Li} \ln(\frac{L(t)}{L(t-1)}) \quad (1.56)$$

$$\tilde{O}_i = \frac{O_i(T) + O_i(T-1)}{2} \quad (1.57)$$

Again, the O_i terms represent the share of sub-inputs.

One should also note that these indices provide a type of adjustment for quality by weighting the growth of each sub-input by its marginal product. In other words, if a particular category or type of input becomes more highly rewarded than other types of input, it is presumably because its marginal product has increased. Therefore, using marginal productivity in this way is an implicit way of accounting for changes in quality.

In conclusion, this appendix has presented the basic methodologies and techniques that underpin neoclassical attempts at decomposing output growth into its component parts.

1.B Appendix 2 - A non-parametric cross-country perspective on Irish productivity

This section presents the results of an alternative means of calculating TFP to the parametric Tornqvist indices presented in the main part of the chapter. Specifically, this section of the chapter calculates cross-country Malmquist TFP indices; a Malmquist index is obtained by non-parametric methods and does not require, for example, data on prices or assumptions about the form of the production function, nor does it assume efficient production. Instead, the Malmquist index is generated using data envelopment methods that construct a frontier from observations in a dataset; this frontier is generated using linear programming techniques that create a "best-practice" set of observations based on high average productivity (Grosskopf, Hayes

and Taylor, 2001). The productivity performance of individual observational units, such as countries in the case of this chapter, are then compared to this frontier. The precise way in which these indices are constructed and estimated is the subject of the next subsection. This non-parametric exercise is useful for a number of reasons. It provides an alternative to the Tornqvist measures of productivity produced above. It also allows estimated TFP to be decomposed into various subcomponents, including efficiency change and technical change, which should provide further information as to Irish productivity performance.

1.B.1 The Malmquist Index

The fundamental component of the Malmquist index is the distance function. Distance functions are used in the context of productivity measurement to examine the maximal level of output that may be produced by a given set of outputs and a given production technology relative to observed output levels. Distance functions are helpful in this regard since their use does not require any behavioral assumptions such as profit maximization or cost minimization (Coelli, Rao, and Battesse (1998). The (output) distance function is due to Shepherd (1970) and is concerned with finding reciprocal of the greatest proportional increase of output, given the inputs, such that output is still feasible. This measure is the reciprocal of Farrell's (1957) measure of output technical efficiency, which assess the distance between an observation and the frontier of technology; in practice, as noted above, the frontier represents

"best practice" productivity and is determined using techniques from data envelopment analysis and linear programming.

The work of Fare,Grosskopf, Norris, and Zhang (1994) was important in synthesizing much of the literature on this topic and for presenting new techniques to derive the index, and much of what follows is based on that paper. Derivations and explanations of some of the main methods are also available in Caselli, Rao, and Battesse (1998) and Fare, Grosskopf and Lovell (1994).

Defining the Malmquist index involves defining distance functions for different time periods (Fare,Grosskopf, Norris, and Zhang, 1994). Formally, the output set $S(x)$ is defined as the set of all output vectors, y, which may be produced using the input vector, x (Coelli, Rao and Battesse, 1998):

$$S^t(x) = \{(x^t, y^t) : x^t \text{ can produce } y^t\} \tag{1.58}$$

Distance functions measure the greatest proportional change in outputs necessary to make (x^{t+1}, y^{t+1}) relative to the technology of time period t.

$$D_0^t(x^t, y^t) = \inf\left\{\delta : (x^t, y^t/\delta)\epsilon S^t(x)\right\} \tag{1.59}$$

Defining two distance function with respect to different time periods, as required to generate the Malmquist index is written as:

$$D_0^t(x^{t+1}, y^{t+1}) = \inf\left\{\delta : (x^{t+1}, y^{t+1}/\delta)\epsilon S^t(x)\right\} \tag{1.60}$$

This distance function simply measures the largest proportional change in outputs required the make the $t+1$ outputs feasible for technology at time t. Caves, Christensen and Diewert (1982) define the Malmquist productivity index as

$$M_0^t = \frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \tag{1.61}$$

Fare, Grosskopf, Norris and Zhang (1994) take the geometric mean of two of these Caves, Christensen and Diewert indices so as to avoid problems connected with the choice of an arbitrary time period as a reference rule:

$$M_0(x^{t+1}, y^{t+1}, x^t, y) = \left[\left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)}\right)\left(\frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)}\right)\right]^{\frac{1}{2}} \tag{1.62}$$

This can be decomposed into the product of two terms that have a useful economic interpretation:

$$M_0 = \left(\frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)}\right) * \left[\left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})}\right)\left(\frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)}\right)\right]^{\frac{1}{2}} \tag{1.63}$$

The first term (outside the square brackets) is commonly understood as measuring efficiency change; it measures how far production is from maximum potential production. Since it captures how much closer an observation gets to the best practice frontier, it can also be interpreted as a measure of diffusion and the concomitant absorption of best practices, and it will also pick up changes in capital utilisation.

This term is essentially an index that compares actual output with technologically feasible level of output.

The term in the square brackets is a technical change component and is a measure of the geometric mean of shifts in technology at x^t and x^{t+1} input levels; in other words, it measures the extent to which the frontier shifts at each level of observed input, and thus can be interpreted as a measure of innovation. As Fare, Grosskopf, Norris and Zhang (1994) make clear, it is the geometric mean of the (vertical) distances between the frontiers of the different production sets, evaluated with the inputs of adjacent time periods. As one can see from the formula above the product of the technical change component and the efficiency change component yield a measure of frontier productivity change: $M_0(x^{t+1}, y^{t+1}, x^t, y) = TECH * EFFCH$. Here, $TECH$ is technical change and $EFFCH$ is efficiency change. Hulten (2001) provides a helpful and intuitive summary of the Malmquist approach: "If, for example, the output of country A would be cut in half if it were forced to use the other country's technology, while output in country B would double, then Malmquist index would show that A's technology is twice as productive".

Finally, one should note that the Malmquist may be calculated relative to any production technology, so that different types of returns to scale may be embodied in the production process. Fare, Grosskopf and Lovell (1994) present a further decomposition of the index that allows for variable returns to scale. The index is calculated relative to a constant returns to scale production process that further decomposes the

efficiency change index into components that are based on pure efficiency change and a residual component which is based on deviations of variable and constant returns to scale technologies. In this case, the index may be represented schematically as $M_0(x^{t+1}, y^{t+1}, x^t, y) = TECH * PEFFCH * SCH$. Here, $TECH$ is technical change, $PEFFCH$ is pure efficiency change and SCH is scale change. All of these measures are reported below.

1.B.2 Calculating the Index

Caves, Christensen and Diewert (1982) demonstrated that one could compute the Malmquist index as a Tornqvist index if the distance functions were of the translog form with identical second order forms. There are other ways to compute the index, but Fare, Grosskopf, Norris and Zhang (1994) developed and used much more general methods based on data envelopment analysis and linear programming techniques. The following example of this approach to calculating the index is taken from Grosskopf, Hayes and Taylor (2001).

For each country, distance functions are calculated using data on inputs (capital and labour) and outputs (this may be, for example, GDP or value added). Distance functions are obtained as the solutions to linear programming problems, and Grosskopf, Hayes and Taylor provide the following example of such a program for country $k' = 1, ..., K$, inputs $x_n^{k,t}$, $n = 1, ..., N$ and outputs $y_m^{k,t}, m = 1, ..., M$. The program for observation k' is then:

$$
\begin{aligned}
\left[D_0^t(x^{k,t}, y^{k,t})\right] &= \max \delta \\
&\quad \text{subject to } \sum_{k=1}^{K} z^{k,t}, y^{k,t} \geqq \delta y_m^{k',t}, \quad m = 1, ..., M, \\
&\quad \sum_{k=1}^{K} z^{k,t} x^{k,t} \leqq x^{k',t}, \qquad n = 1, ..., N, \\
z^{k,t} &\geqq 0, \qquad\qquad k = 1, ..., K. \qquad\qquad (1.64)
\end{aligned}
$$

The $z^{k,t}$ are variables that form convex combinations of inputs and outputs that form the technology and its frontier on the basis of the observed data. The δ acts to scale the observation towards the frontier; the program would be solved once for each observation, making the appropriate changes to the variables and on the right hand side. The three other distance functions are calculated in a similar manner, although calculating the distance functions and Malmquist functions over periods t and $t+1$ involves making related changes to the right hand side of the inequalities. Scale and VRS efficiency changes are calculated by adding the further constraint $\sum_{k=1}^{K} z^{k,t} = 1$ to the system above. See Fare, Grosskopf, Norris and Zhang (1994) and Fare, Grosskopf, and Lovell (1994) for more detail.

1.B.3 Results

Data for the construction of the cross- country Malmquist indices was taken from OECD national accounts data from 1970 to 2001. The data were converted to constant price international dollar values (since the data are only published in local cur-

rencies). Value added was used as the output variable, and the numbers employed in the labour force and capital stocks (generated using the perpetual inventory method applied to constant price national GFCF) provided the inputs. While it is appreciated that the lengthy discussion on methodology above decried the use of crude input measures for productivity analysis, a compromise was required for the case of a wide-ranging cross-country comparative analysis. These inputs and outputs are widely used in cross-country Malmquist calculations and their use here therefore provides a degree of comparability with the results of other studies, such as the seminal work by Fare, Grosskopf, Norris and Zhang (1994), as well as more recent work such as the studies by Grosskopf, Hayes and Taylor (2001) and Hsiao and Park (2001). The results of the Malmquist analysis[47] are presented below.

As noted above, values in the columns in this table are geometric means of yearly figures for each variable. Values below unity in a column indicate a deterioration in economic performance. One immediate conclusion that may be drawn is that estimated Malmquist TFP for Ireland appears to be below the Tornqvist estimates. The reasons for this difference in the estimates is discussed at some length below, but it is nevertheless worth noting the relatively high ranking of Irish (Malmquist) TFP compared to other countries, an outcome that is not wholly inconsistent with the high relative placing of Ireland by the Tornqvist estimates presented above.

---

[47] The calculations were performed using Coelli's (1996) DEAP program.

Country	Effch	Techch	Pech	Sech	TFPch
Australia	0.933	1.078	0.938	0.995	1.005
Austria	0.938	1.078	0.947	0.99	1.012
Belgium	0.938	1.076	0.946	0.992	1.01
Denmark	0.936	1.081	0.948	0.988	1.012
Finland	1.016	1.082	1.015	1.001	1.099
France	0.936	1.081	0.937	0.999	1.012
Germany	0.936	1.082	0.93	1.007	1.013
Greece	0.947	1.068	0.959	0.987	1.01
Iceland	0.941	1.078	1	0.941	1.014
Ireland	0.943	1.074	0.957	0.985	1.013
Italy	0.941	1.076	0.943	0.998	1.013
Japan	0.949	1.08	0.939	1.011	1.024
Netherlands	0.936	1.081	0.94	0.995	1.012
New Zealand	0.929	1.073	0.951	0.977	0.997
Norway	0.948	1.075	0.961	0.986	1.019
Portugal	0.938	1.068	0.95	0.988	1.001
Canada	0.927	1.07	0.93	0.997	0.992
Spain	0.952	1.077	0.953	0.999	1.025
Sweden	0.938	1.073	0.945	0.992	1.006
Switzerland	0.934	1.077	0.942	0.992	1.006
UK	0.936	1.069	0.934	1.002	1
US	1	1.079	1	1	1.079

Figure 1.21: Results of Malmquist analysis.

One somewhat unusual aspect of these results is that the estimated level of TFP growth appears to be very high for the US. One might interpret this result as implying that the US is much more efficient than the rest of the world, which seems plausible. Data envelopment techniques of this type are sensitive to outliers because the frontier must necessarily envelop all data points, so extreme points can potentially have a large effect on the analysis. In a wide ranging cross country analysis covering twenty rather different countries, it is not implausible that the superior efficiency of the United States has manifested itself in this way.

The most important positive contribution to Malmquist productivity growth in Ireland (and indeed for most of the other countries) has come from the $techch$ variable. This variable captures technical change and innovation and suggests that Irish growth over the period was driven by the increasing adoption of frontier technology. This result accords well with the discussion above that emphasized the increasing quality and participation rates in Irish education, which has helped the domestic economy absorb world class practices both directly through knowledge assimilation and indirectly through effects associated with spillovers from foreign direct investment (FDI), such as increased R&D, and the business and organizational practices absorbed abroad by returning Irish migrants. The less-than-unity figure for the efficiency change variable ($effch$) is perhaps not surprising for an economy that was converging to world and EU standards for much of this period.

This result of the Malmquist analysis - that the main impulse to growth has come from the technical change variable - is suggestive, and appears to confirm the finding that productivity, as measured by the primal growth accounting TFP results, has been very important. This is further evidence in support of the Krugman/Barry hypothesis, inasmuch as these results are consistent with an important impulse to growth coming from TFP (which is in part comprised of technical change), and improvements in the quality of labour. Again, this evidence is somewhat circumstantial in that it is rather indirect, but it is not inconsistent with the findings of the parametric Tornqvist results and their emphasis on labour and productivity.

An important exercise to be performed in respect of these Malmquist results is to account for their apparent divergence from the conventional residual Tornqvist TFP results. One immediate point of departure is the different time periods and different data used to construct the respective productivity estimates. The time period used to construct the Malmquist figures was chosen so as to take advantage of the longest possible time period that the available data permitted, so as to give as broad a perspective as possible. As noted above in the data section of the chapter, the Malmquist figures are based on OECD national accounts data. Possible differences between the Malmquist and Tornqvist indices are potentially explainable by the fact that the Tornqvist figures, being based on two different comprehensive datasets, are inevitably and unavoidably somewhat more accurate than the Malmquist figures. Conversion of the OECD national accounts figures into common currencies (US dollars) at particular exchange rates perhaps also explains part of the divergence in estimates.

Aside from these data issues, there are more technical reasons for differences in Malmquist and Tornqvist estimates. The seminal Fare, Grosskopf, Norris and Zhang (1994) paper computed the two indices for the period 1979-1988 for 17 OECD countries, and they also found a fairly large divergence in estimates for all of the countries. They note that the results would coincide in a world with no inefficiency (and presumably with perfect data), and also note that traditional neoclassical growth accounting calculates a national productivity index only by comparing outputs and inputs in one period to outputs and inputs in the next period. By contrast, the Malmquist index

is an explicit multilateral formulation of productivity, and its comparisons involve comparisons with the world frontier.

Related to this point of multilateral comparisons is the point that the choice of comparator countries is to some extent arbitrary. The arbitrariness is to some extent unavoidable, since including countries that are too similar gives a false impression of the world frontier, while including countries that are too dissimilar gives rise to the possibility that outliers will adversely contaminate the results, since the influence of outliers that are due to data problems can badly affect the construction of the enveloping frontier (Hulten, 2001). Hulten also notes that increasing returns to scale technology, or non-Hicks neutral technological progress, will cause the Tornqvist and Malmquist estimates to differ. These differences were studied in a systematic way by Lee (2004). He studies the empirical compatibility between the two indices for the seven largest industrial countries, and, using a variety of non-parametric statistical techniques, finds that for five of the seven countries the two indices to be comparable in value to each other for his sample period. The value of the indices are similarly comparable for certain sub-periods for the remaining countries. Lee's analysis was based on a group of quite similar countries (US, Canada, UK, France, Germany, Italy, and Japan), whereas Fare *et al.* (1994) and this chapter used a much more diverse selection of countries.

An alternative explanation may simply be that the results reflect the fact that the data have been measured with error, which would perhaps explain some of the rather

anomalous results, including the high ranking of certain countries and the fact that the estimates of TFP for most counties are dominated by the contribution from the technical change variable, although Fare *et al.* (1994) also found below unity values for efficiency change for a number of countries (as well as below-unity values for a number of other variables and countries) in their paper. The problems of using labour force headcounts and of cumulating investment flows to generate capital stocks using the perpetual inventory method were discussed in detail in the main body of the chapter, and it is not inconceivable that this has introduced some bias into the results.

Nevertheless, the decision to use and generate data in this manner, was necessarily pragmatic inasmuch as the variety of countries and the relatively long time span of the data required a number of simplifications. Moreover, the wide variety of countries studied increases the possibility that the results were contaminated by the presence of outliers, which can have a major impact on frontier methods like the Malmquist approach. Despite these concerns and qualifications, the results of the analysis are instructive as they provide an alternative perspective on Irish productivity performance, and as noted above, are not inconsistent with the results from the Tornqvist analysis in the main part of the chapter and therefore provide a measure of re-assurance as to the robustness of the parametric estimates.

In conclusion, the non-parametric Malmquist index was calculated for a number of OECD countries. These results provided a useful alternative perspective on Irish economic development and Irish productivity growth, although it was noted that

these results differed from those calculated using the Tornqvist approach. The possible reasons for this difference were explored. The Malmquist results provide some tentative support for the main avenues of inquiry discussed in the body of the paper but there are reasonably significant differences in the rate of productivity growth estimated under the two approaches.

Chapter 2
A dynamic heterogeneous panel approach to the equipment investment-growth nexus

2.1 Introduction

This chapter investigates the effect of equipment investment on income growth in a panel of 49 countries for the period from 1960 to 1990. Following the work of De Long and Summers (1991), a large literature has debated the effects of equipment investment on growth. This chapter contributes to that debate by applying recently developed econometric techniques which allow for both slope and intercept heterogeneity, thereby relaxing an assumption implicit in prior work that the estimated coefficients on equipment investment fall on a common regression response surface for all countries in the sample. Specifically, this approach applies the Pooled Mean Group (henceforth PMG) estimator to allow for such heterogeneity and thereby to investigate whether the conclusions of the earlier literature are altered by allowing the short-run relationship between growth and equipment investment to differ within an Equilibrium Correction Mechanism (henceforth ECM) framework, whilst constraining the long-run coefficients to be the same across countries. This constraint is tested, and the justifications for such a constraint are considered. More conventional estimators, such as fixed effect and dynamic fixed effect specifications, are also es-

timated and their results compared to those obtained from the PMG approach. The results from the new estimation approach indicate that this approach does appear to be reach new conclusions regarding equipment and growth, which has implications for the understanding of equipment in growth and more generally in respect of the role of heterogeneity in econometric growth models.

Empirical work that has focused explicitly on the effects of equipment investment has tended to support the view that there appears to be a robust and statistically significant positive association with growth, whereas studies concerned with analyzing broader definitions of capital have suggested a far less important effect of physical capital on economic growth. Studies directly concerned with the growth effects of equipment investment including, De Long and Summers (1992, 1993, 1994), Temple (1998) and Jalilian and Odedokun (2000), have supported the original findings of De Long and Summers: that equipment investment has much more explanatory power for productivity rates than the other components of investment, and that the social rate of return, especially in developing countries, is much higher than the private rate of return to equipment investment. De Long and Summers (1991) estimated that the "social rate of return to equipment investment in well functioning market economies is of the order of 30% per annum". Empirical papers that have studied variables directly related to equipment investment (such as the price of equipment imports (Lee (1995), Mazumdar (2001)) and the relative price of equipment (Jones 1994) have

also supported these findings of a positive and significant association between equipment and growth.

In contrast, the work of Mankiw, Romer and Weil (1992) has argued that an augmented Solow model that includes the accumulation of human as well as physical capital provides an "excellent" characterization of the cross country data, finding that capital receives approximately its "social return", with no evidence of externalities to the accumulation of physical capital.

This contradiction in the empirical literature is closely related to the lack of consensus in the theoretical literature on growth. Exogenous technological progress and population growth determine the steady state of a neoclassical Solow type growth model, implying that other variables, such as equipment investment, have at most a transitional effect. In the Solow model, a once off increase in the rate of equipment investment temporarily raises growth. When growth returns to its steady state, output and the capital stock have adjusted to levels just sufficient to ensure that gross investment can maintain a constant capital labour ratio. Furthermore, social returns to investment are equated to private returns by virtue of the competitive assumptions of the neoclassical model, implying that, absent distortionary government policies, no externalities will arise.

On the other hand, endogenous growth theory often emphasizes the role that non-decreasing returns to physical capital may have in driving permanent growth.

Arrow (1962) and Romer (1986), for example, introduce externalities to investment in physical capital arising from the effects of knowledge spillovers, leading to a difference between social and private returns. Such externalities give rise to the possibility of permanent growth being driven by activities and processes, such as equipment investment, related to the accumulation of physical capital.

This chapter seeks to address some of these issues and debates by contributing on the existing literature in the following ways. First, this chapter is one of the few pieces of work that studies the effect of equipment investment on growth in a panel data framework. The other papers to study the issue using pooled cross section time series data are papers by Jalilian and Odedokun (2000) and Oulton and Young (1996), which are discussed in more detail below. As noted, the econometric modeling approach followed in this chapter allows for both intercept and slope heterogeneity across countries, while also encompassing the type of fixed-effects analysis of these two papers. Generally speaking, modeling heterogeneity and dynamics should allow for a richer modeling of key relationships. Separately estimating standard fixed effect type specifications introduces the possibility of encompassing the results of the earlier literature. Therefore, a major theme of the chapter is to investigate the consequences of using more realistic models of parameter heterogeneity in a growth context. The findings are compared with those from the more traditional approaches.

The rest of this chapter proceeds as follows. In the next section, the motivation for studying this topic is discussed. In the following section, the literature on

the equipment investment-growth nexus is reviewed, as are the econometric issues involved in studying the relationship.

2.1.1 Motivation for the study

In the Solow model, long-run growth can only be influenced by two factors: exogenous technological change and the evolution of the labour input. In the short-run, however, GDP is permitted to be affected by changes in the rate of capital accumulation resulting from changes in the amount of output committed to the various components and forms of investment. Furthermore, capital is the only factor of production whose productive employment can readily altered at short notice, whereas technical progress can only be influenced in the long-run. Over the medium to long term, as Boskin and Lau point out (1992), the rate of growth of labour is invariably severely constrained by the rate of expansion of population. Even with international migration of labour, population growth rates of more than 2% per annum are very rarely observed in the modern industrialized economies (the case of Ireland, the subject of the previous chapter, being a notable exception).

Equipment investment is an important component of total investment and there are several reasons for suspecting that it plays an influential role in economic growth, and that its influence is over and above the rate of return it receives in the market. One very compelling reason is the relationship between capital goods and the productive technologies they embody. Capital is central to technological progress, and

increases in capital intensity are important for improvements in total factor productivity. Reflections such as this led Landes (1969) to declare "the machine is at the heart of the new economic civilization". Greenwood, Hercowitz and Krusell (1997) estimate that 60% of technical progress is embodied in equipment. Indeed, several theoretical models, which are discussed in the literature review section, are supported and obtain their motivation from these observations, and these papers suggest a strong correlation between equipment related variables and per capita growth rates.

Another reason for speculating that there is a relationship between equipment investment and economic growth is that the equipment sector typically accounts for half of the overall manufacturing sector in the advanced industrial economies, and it is the manufacturing sector which tends to be the sector most heavily engaged in innovative Research and Development (R & D) activity. In the US, for example, the manufacturing sector conducts roughly 95% of private sector R & D (De Long and Summers, 1991). Hence, as De Long and Summers argue, it is possible that equipment investment may give rise to significant external economies, such as learning by doing and knowledge spillovers. Such externalities occupy a central role in many endogenous growth theories in explaining permanent growth, as noted above.

Endogenous growth theory also emphasizes the potentially significant effects of learning-by-doing, which may be described as the positive effect of experience on productivity (see Barro and Sala-i-Martin, 1995). For example, Arrow (1962) and Romer (1986) assume that an increase in a firm's capital stock results in an increase

in its knowledge or technological know-how. De Long (1992) argues that workers and their employers gain particularly valuable experience from learning how to install, use and adapt to sophisticated equipment. These effects describe benefits internal to the organization that installs and uses the new equipment, but there are compelling reasons for believing that, consistent with endogenous growth theory, the firm will not be able to completely internalize all of these benefits. Other firms wishing to remain competitive will attempt to reproduce successful operating procedures of the innovating firm, and will attempt to lure away workers with experience of using the new equipment to their own firms with the promise of higher wages stemming from the superior worker productivity of these workers. As De Long and Summers (1991) note "Such a view leads naturally to an expectation of high social returns from equipment investment, for equipment investment is a necessary precondition for this process of learning and experience to begin".

The positive association between the proximate growth determinant of equipment investment and economic growth that has been identified in this body of work may have powerful implications for economic development and policy, especially given that the returns to equipment investment appear to be very high in developing countries. Temple (1998) suggests that "the return to equipment appears to be so high (in developing countries) that, at the very least, a simple Solow model needs to be extended to include externalities to equipment investment". Of course, bearing in mind the issues raised with respect to the effects of "policy" on growth made in the Intro-

duction to this thesis, a serious qualification must be made with respect to the power of individual policies to induce permanent alterations in long-run growth. Nevertheless, it still would appear to be appropriate to investigate whether the claims made in some parts of the literature on behalf of equipment investment have any legitimacy whatsoever.

A simple scatter plot showing the relationship between real GDP growth and the ratio of equipment investment to GDP is shown below; this shows a positive relationship between the two variable between 1960 and 1990 for most of the 49 countries included in the sample[48].

As noted, it is apparent from the scatter plots below that the relationship between growth and equipment investment differs between countries and therefore it is apposite to consider the econometric motivations for producing a new study of the equipment investment-growth nexus. Existing empirical studies in the growth literature typically assume identical production functions for each country in a cross section. This implies that the same parameter values apply to each country in the sample. Cross section regressions are not ideal environments in which to implement econometric procedures which take into account potential or actual heterogeneity on national economic characteristics, especially when such characteristics are not eas-

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[48] However, it is also apparent that the relationship is not uniform across countries and this suggests that econometric techniques which allow for heterogeneity in output elasticities would be appropriate in this modeling environment. The relationship within countries between growth and the equipment investment ratio is displayed in a graph in the first appendix to this chapter.

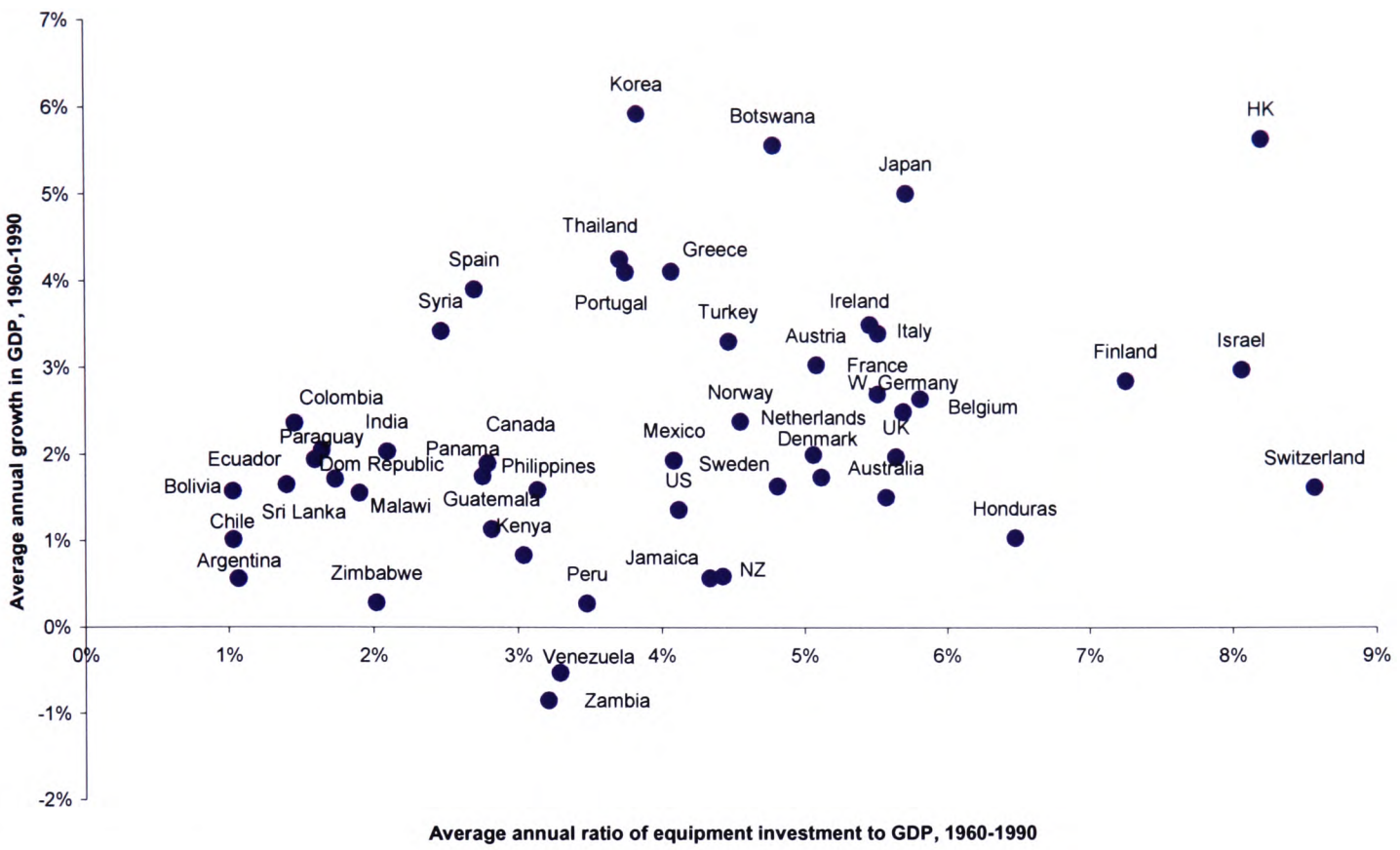

Figure 2.1: The relationship between equipment investment and per capita GDP growth in 49 countries, 1960-1990.

ily observed. As Lee, Pesaran, Smith (1998) argue, there is no reason on a priori theoretical grounds to rule out the possibility of different production functions[49].

Cross-sectional regressions in the growth literature typically suffer from omitted variable bias as well as heterogeneity bias, since the country specific component of the production function is unobservable but correlated with the regressors. A panel framework presents an appealing alternative to cross-sectional approaches, and modern techniques for estimating in a panel context offer the possibility of harmoniz-

[49] In a companion paper, Lee, Pesaran and Smith (1997) find extensive heterogeneity in growth rates and speeds of convergence in the Penn World Tables data. For a 102 country non-oil sample, hypotheses of a common steady state growth rate and of common speeds of convergence are both strongly rejected.

ing the assumptions of many conventional growth model with the need for realistic econometric modeling. In general terms, panel data offers more efficiency and more degrees of freedom and less collinearity, relative to cross-sectional work. As Durlauf and Quah (1998) put it "These instances of greater flexibility (and, thus, reduced possibilities for mis-specification) allowed by panel data analyses unavailable to cross section regression studies account for their broader econometric use more generally, not just in studies of economic growth".

Newly developed techniques can also overcome restrictive and undesirable parameter homogeneity assumptions, and these techniques are applied in this chapter. As noted by Pesaran and Smith (1995) and Lee, Pesaran and Smith (1998) studies that assume incorrectly that certain parameters are common across countries can lead to bias and inconsistency when estimating the variables of interest. This chapter finds strong evidence of considerable heterogeneity among parameter estimates across countries, suggesting that directly pooling such parameters across countries will result in misleading inference. Furthermore, as noted above, the panel data framework can accommodate the presence of unobservable country effects. Another advantage of panel data is that it can capture potentially important dynamic effects. Equipment investment and economic growth are obviously dynamic processes, and therefore static specifications cannot be expected to capture essential features of such processes.

2.1.2 Literature Review

Equipment investment and growth

This review assesses the modern literature that specifically analyses the equipment investment-economic growth nexus. It does not review an earlier qualitative body of economic work, which has long argued that the accumulation of machinery ought to be accorded a prominent role in accounts of economic development. For a small representative sample of such work, see Rostow (1958), Gershenkron (1962), and Mokyr (1990).

As noted earlier, the more recent quantitative interest in the topic began with the publication in 1991 of De Long and Summers' paper "Equipment Investment and Economic Growth". This led to a resurgence of interest in the subject. This type of work involved regressing a measure of per capita income on a number of variables that included equipment investment on a cross-section of countries using data drawn primarily from the Summers-Heston data set. Two papers best exemplify this work, and these are the original paper by De Long and Summers (1991) and the subsequent detailed and careful re-examination by Temple (1998). Both of these papers supported the notion that equipment investment appeared to play a uniquely positive role in economic growth, especially in developing countries. These two key papers are reviewed, as doing so provides a valuable and informative summary of the cross section literature. Subsequent papers by De Long and Summers (1992, 1993,

1994) reviewed the robustness properties of the results, and examined whether the results held as strongly for developing countries.

In their original article, De Long and Summers found that for a large and diverse cross section of countries over the period 1960-1985, every extra one percent of GDP invested in equipment was associated with an increase in GDP growth of one-third of a percentage point per annum, which was a far stronger association than found between growth and any other component of investment that they analyzed. De Long and Summers estimated by OLS a simple equation that related GDP per worker to equipment and non-equipment investment shares of GDP, as well as labour force growth and relative GDP per capita

In their diagnostic testing of this regression, De Long and Summers found that, on the whole, the results appear to be statistically significant and robust to changes in sample period and size, various interactions, alternative measures of equipment investment and the inclusion of additional determinants of growth and that this implies "...a clear, strong and robust statistical relationship between national rates of machinery and equipment investment and productivity growth". A very interesting and important result that also emerged in this and other papers on this topic by these authors is that the (social) returns to equipment are very high in LDCs; much higher, in fact, than in the developing world. As De Long and Summers (1991) put it "...there is a strong growth-equipment investment association even when rich industrialized

countries are not considered: Rapid growth is found where equipment investment is high, and slow growth is found where equipment investment is low".

Other re-assessments of the original De Long and Summers findings have reached a variety of different conclusions. Auerbach, Hassett and Oliner (1994) assessed the robustness of De Long and Summers (1991) and claimed that the original 1991 results were very sensitive to the exclusion of certain countries (in particular Botswana). The rejoinder of De Long and Summers (1994) noted that all of these criticism had been considered and dealt with in their original paper. In a detailed econometric re-examination of these cross-sectional debates, Temple (1998) confirmed these original findings of high rates of return to equipment investment, especially in developing countries. Temple's study differed from the original De Long and Summers in that he explicitly grounded his analysis in the neoclassical empirical growth framework developed in Mankiw, Romer and Weil (1992). This allowed him to make an assessment of whether the estimated return to equipment investment is consistent with a basic Solow type model. This approach has the advantage of placing formal theoretical structure on the De Long and Summers regressions. This helps with matters of interpretation and in controlling for auxiliary variables. Temple was also very careful to consider and take account of a comprehensive list of potential and actual econometric problems[50].

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[50] Some of these problems econometric were discussed in the Introduction to the thesis, and included the problem of endogeneity (which arises when per capita income is regressed on the accumulated factors of production), the problem of outliers (which is a quite serious problem when one considers the diversity of the world's economies), and the presence of initial technical efficiency. Some of these

The only papers to employ a panel framework to study this topic are the papers by Oulton and Young (1996) and Jalilian and Odedokun (2000). Oulton and Young (1996) addressed the issue using a number of different specifications, including ones based on a Mankiw, Romer and Weil (1992) approach as well as a production function approach (similar to that in Benhabib and Spiegel, 1994); they carefully tested these specifications in the context of both the augmented Solow and the production function-type approach based on stock data. The basic De Long and Summers (1991) specification was also estimated using panel data. They find that "...there seems to be no special magic to equipment investment as an engine of growth". This conclusion is based on two findings: the first is that the elasticity of output with respect to the total capital stock is approximately the same as the share of capital in national income. The second particularly significant finding is that the elasticity of output with respect to the ratio of equipment investment to GDP is approximately the same as the net private cost of capital plus the depreciation rate; in rich countries the elasticity was estimated to be *lower* than the cost of capital.

The approach of the Oulton and Young paper is similar in many respects to this chapter: it estimates a variety of models and specifications using panel data, and compares its results to those of the literature. Many of the variable definitions

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themes are revisited in the econometric section of the chapter below. Temple's (1998) study shows that although the positive association between equipment and growth is slightly weaker in developed countries than that found by De Long and Summers, the rate of return in developing countries again appears to be very high, and that these results are robust with respect to a variety of respecifications and sample sizes.

are also same in that paper and this chapter. This chapter is also careful to follow the distinction, first introduced into the literature on equipment investment by these authors, between net and gross rates of return to investment. This distinction is particularly important in interpreting findings from the production function approach to equipment investment.

Whereas Oulton and Young (1996) tested a variety of different econometric specifications, Jalilian and Odedokun (1996) base their empirical work entirely upon a generalized augmented Solow model. Their empirical model was estimated using fixed effects panel data regressions on five-year data from the Penn World Tables (version 5.6) on their 55 country panel. The model estimated is a Solow model based on a linearly homogenous Cobb-Douglas specification of the production function, with several categories of capital, which enter their empirical model in the form of investment-to-GDP ratios: business investment, machinery investment, transport equipment, residential investment, and other (unspecified) durable private investment. These authors find that equipment investment has a significantly positive effect of growth for the sample as a whole, but the authors did not compare the estimated effect for developed and LDC subsamples. Rates of return are not reported. The greatest effects of these investment ratios come from machinery investment, miscellaneous investment and transport equipment; they do not find a significant association between business investment and growth.

Equipment investment and growth: Indirect linkages

As noted above, an established line of research beginning with Arrow (1962) has suggested there may be important positive externalities from accumulating capital, and this is a powerful rationale for studying the topic to investigate whether the data reveal any association between investment and growth. Additionally, a number of have papers have also examined indirect effects of equipment investment on growth. Jones (1994) empirically examines the relationship between economic growth and the relative price of capital. He finds that when the relative price of machinery and non-machinery are included in a Barro type cross-sectional growth regression, a strong negative relationship is observed between growth and the relative price of machinery, while the relative price of non-machinery enters insignificantly. This suggest that equipment is the most important component of capital for growth, or at least as suggested by these types of growth regressions. In one of his regressions, he shows that much investment may in fact be driven by machinery investment. Holding fixed the relative price of total investment or the share of machinery investment, a higher relative price of machinery investment reduces the total investment share.

The relative price of machinery is crucial for determining not only the share of investment devoted to machinery, but also for determining the total share of investment within an economy. However, one should bear in mind the role that price distortions (perhaps induced by government intervention) may have in influencing

the results in this paper, so that conclusions about the effect of equipment on growth should be only be cautiously drawn. In related work, Jovanovic and Rob (1997) show that differences in equipment prices can generate large income dispersions in a Solow model if technology is embodied in capital instead of being disembodied.

Imports of capital goods and machinery are examined by Lee(1995) and Mazumdar (2001). Lee's paper examines the role played by capital imports on economic growth. He finds that the growth rate is higher in a country that uses relatively more imported equipment for the production of capital stock than other countries at the same stage of development, and he highlights the importance of the composition of investment in addition to the size of total investment in determining growth. Mazumdar's (2001) paper extends and clarifies these results by considering their relation to De Long and Summers' stress on the overall importance of equipment investment. He argues that Lee's paper cannot be used to distinguish between the importance of imported equipment and the importance of overall equipment (that is, both imported and domestically produced). Mazumdar distinguishes between domestically produced equipment and that which is imported. He finds evidence that domestically produced equipment actually reduces the growth rate in LDCs, but that all countries benefit from imported equipment. Since LDCs typically import around 80% of their equipment, it is not surprising that the overall effect is positive. Since Mazumdar's data appear to show that rich nations gain more, relative to LDCs, from equipment investment, this is probably evidence of comparative advantage in the production of

equipment. Domestically produced equipment is LDCs therefore constitutes a misallocation of resources.

Finally, another notable contribution to the debate on the channels by which equipment investment may affect growth is provided by Rodriguez-Clare (1996). He developed a model in which equipment investment occupies centre stage in explaining the differential growth performance of poor and rich countries. New technologies are embodied in equipment and firms in his model pay a fixed cost to use these new technologies. Higher equipment prices allow monopolists to charge higher markups, and technology upgrading is then less frequent, which results in the technological gap between rich and poor countries growing larger.

Automatic general-to-specific modeling algorithms have also supported the idea that equipment investment is important for growth; Hendry and Krolzig (2004) and Hoover and Perez (2004) both find the rate of equipment investment to be a significant and robust growth determinant out of the possible universe of linear models[51]. Levine and Renelt's (1992) wide ranging study of growth and its correlates also supported the idea that investment in physical capital is robust and significant in growth regressions.

Against these optimistic findings concerning machinery and its positive relationship with growth, a number of papers have suggested a different and more subtle

[51] In addition to the rate of equipment investment, both papers also found that growth is determined by years an economy is open, political stability, and the percentage of the population that is Confucian and the percentage that is Protestant.

relationship. A paper by Temple and Voth (1998) with a slightly different orientation to the studies just cited argues that the apparently robust correlation between equipment and growth is the result of prior industrialization, and suggest that large positive coefficients on equipment variables may not be evidence of externalities if concomitant and prior industrialization is important. In other words, the positive and significant relationship between equipment and growth is actually due to the influence of other variables which tend not to be included in econometric growth models.

Temple and Voth do, however, accept the idea that rapid economic growth is likely to be accompanied by high levels of productive equipment investment, and find some evidence of high social returns to this type of investment. Blomstrom, Lipsey and Zejan (1996) find that, dividing the post war period into five-year subperiods, per capita GDP growth is more closely related to subsequent capital formation than current or past capital formation. Both of these papers suggest a degree of caution in interpreting positive coefficients on equipment variables in regressions as strong evidence of a strong effect of equipment on growth. Finally, and in a different but related vein, Easterly's (2002) review of the aid and development policies of the last fifty years is a powerful voice of caution against assuming that increased investment automatically translates into improved growth performance.

In conclusion, this literature review began by reviewing the key pieces of cross sectional work on the equipment investment-growth nexus, both because this strand of work represents almost all of the empirical work in this area, and because its

conclusions have proved influential in the literature in framing the debate on the relationship between equipment and growth. Theoretical research inspired by the empirical work has lent support to the original conclusions of De Long and Summers (1991) and has led to the development of persuasive and sophisticated theoretical models to explain the observed equipment correlations. Representative research in the cross-sectional literature suggests a high positive and significant correlation between equipment investment and economic growth, and that the return to equipment is very high in developing countries. However, such cross-country regression studies suffer from certain econometric limitations and are discussed in somewhat more detail in the next section. This review of the literature has shown that is the debate on equipment investment has not been decisively concluded in favour of one view or another. This chapter is another empirical contribution to the debate; the goal of the chapter is to examine how the results of the substantial body of empirical literature are altered by the application of new econometric modeling approaches.

2.2 Growth economics in theory and in practice: Implications for modeling the equipment investment-growth nexus

The discussion in this section is informed by a desire to apply best practice techniques from the empirical growth literature, while still attempting to retain a degree of continuity and comparability with existing work. It discusses the econometric con-

siderations involved in formulating, studying and implementing empirical studies of the equipment investment-growth nexus To this end, it very selectively reviews, from the perspective of jointly modeling equipment investment and growth, the growing body of work which critically assesses existing empirical work on economic growth.

Where does the study of equipment investment and growth fit into the framework of empirical growth economics? The original work of De Long and Summers (1991) was very clearly located in the first stage of the literature, in that these authors estimated a simple linear regression to determine the effect of equipment investment on growth without deriving this equation from any particular theoretical model. How might one improve on this simple specification?

Relaxing the assumption of parameter heterogeneity, or at least testing for heterogeneity that is implicit in cross-sectional work starting with De Long and Summers (1991), is likely to deliver an improvement in the accuracy and robustness of any estimates. As Levine and Renelt (1992) and Brock and Durlauf (2001) argue, the assumption of parameter homogeneity is very problematic when studying cross sectional growth performance given that the subjects of such a study are highly complex, heterogeneous national economies. It is hard to defend the some of the implications of the cross-sectional work that all countries in the world fall on a common regression response surface, so that a 1% change in the level of a variable on the right hand side of that equation has the same effect in the United States as it does in any coun-

try in, say, sub-saharan Africa. This line of thinking therefore suggests testing for, and possibly incorporating, parameter heterogeneity into empirical growth models[52].

The Introduction to the thesis also noted another problematic characteristic of much of the early growth literature was a tendency to perform econometrics in a "model-free" environment, giving rise to the problem of "open-endedness". This is defined by Brock and Durlauf (2001) as giving rise to the problem that "the validity of one causal theory does not imply the falsity of another". This is a particular problem for an equation of the type of equation estimated by De Long and Summers (1991), since it was not derived from any particular model of economic growth. It is also a problem when one considers the results of Temple and Voth (1998), who demonstrate that equipment investment may just be a sideshow to the more important phenomenon of industrialization. This suggests the De Long and Summers (1991) could be improved upon by explicitly basing empirical models on internally consistent theoretical models. The estimated equations in this chapter are derived on the one hand from a neoclassical augmented Solow-type growth model, and on the other from a related neoclassical production function. The problem that presenting the results of any one empirical model can be misleading is acknowledged (due to the problem of model uncertainty), and hence two different but related specifications

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[52] It is also worth noting that some researchers have argued against the automatic use of panels, arguing that such methods often "make unjustifiable assumptions about parameter heterogeneity" (Temple (1998), and instead advocate the use of time series methods. However this chapter employs techniques that do not impose any "unjustifiable" or untestable assumptions about parameter heterogeneity; all such assumptions are tested.

are presented. Finally, a variety of robustness tests are conducted on the baseline specifications to determine the fragility of the results.

2.2.1 The Mean Group and Pooled Mean Group Estimators

The issue of parameter heterogeneity has been discussed. The second appendix to this chapter provides an example of how inconsistent estimates may be generated in a panel context of heterogeneity is overlooked. How should heterogeneity be dealt with? One starting point for panel data is simply to use fixed effect estimation. As mentioned above, Islam's (1995) paper took MRW's cross-sectional work as a benchmark on which to base a panel study of the growth process. Islam's approach modeled cross-country heterogeneity through the use of fixed effects for each country, and estimated the model using standard fixed effects techniques. However, as noted in the literature cited above on parameter heterogeneity, especially the Durlauf, Kourtellos Minkin (2001) paper, there are no particular empirical or theoretical reasons why panel estimation should be restricted to modeling intercept heterogeneity. Indeed as shown in Pesaran and Smith (1995) and Pesaran, Smith and Im (1996) in the presence of slope heterogeneity (and dynamics), standard panel techniques such as the fixed effect estimator, lead to inconsistent estimates even for panels of large dimensions (long time dimensions and many cross-sections). This fixed effect procedure imposes homogeneity of slope coefficients, and it is sometimes argued that such an approach is valid if the gain in precision from pooling heterogeneous objects

is greater than the cost of potential bias (Baltagi and Griffin (1995). In a growth context, this would typically involve assuming, as Bassanini and Scarpetta (2000) point out, common technology and common convergence parameters, which in turn depends on common technological change and population growth across countries.

One way of avoiding this rather extreme argument is to adopt the approach of Pesaran, Shin and Smith (1999), who have developed the pooled mean group (hence-forth PMG) estimator for heterogeneous dynamic panels. This approach is interme-diate between a dynamic fixed effect estimator and the mean-group estimator, which involves estimating separate regressions for each country and calculating averages of the country specific coefficients. The PMG approach involves both pooling and averaging methods; it constrains long-run coefficients to be the same, but allows short-run responses to differ from country to country, to capture the effect of, say, different economic institutional structures across countries.

As Bassanini and Scarpetta (2001) note, long-run slope homogeneity may in-crease the efficiency of PMG parameter estimates with respect to the corresponding mean group (MG) estimators since the MG estimator does not take into account the fact that some parameters may be the same across groups; see Pesaran, Shin and Smith (1999) for details. Note that the assumption of long-run parameter homogene-ity cannot be defended a priori, and must be tested empirically in all specifications and the results of such tests are presented below.

The Estimators

Pesaran and Smith (1995) introduced the mean group (MG) estimator. This estimator may be used when the parameter of interest is the average effect of some exogenous variable and involves estimating separate regressions for each group by ordinary least squares (OLS) and then arithmetically averaging the coefficients across groups. It is consistent when both N and T are reasonably large. The MG estimators of λ and β (see the Appendix to this chapter for the definition of these variables) are given by:

$$\hat{\lambda_{MG}} = \frac{1}{N}\sum_{i=1}^{N}\hat{\lambda_i} \tag{2.1}$$

$$\hat{\beta_{MG}} = \frac{1}{N}\sum_{i=1}^{N}\hat{\beta_i} \tag{2.2}$$

MG estimation may be used when the slope coefficients are random in a sense defined by Swamy (1970). Swamy considered what is now known as a random coefficients model, where it is assumed that η_i (group-specific fixed effects) are identically independently distributed and are distributed independently of x_{it} and u_{it} for all i and t, with zero mean and a constant variance. Such a model does not allow for heterogeneity that arises from, for example, possibly systematic relationships that may exist between the β_i terms and sample means or sample variances of the process governing the x_{it} terms. To allow for such possibilities, the MG can also be used where the slope coefficients are treated as fixed, in the same way that intercepts are treated in a fixed effects model (Ul Haque, Pesaran, and Sharma, 1999). There-

fore, MG estimation is applicable if the slopes are random (as in the sense of Swamy (1970) , or if the slopes are fixed. The MG estimator is consistent, but suffers from bias in small samples in dynamic panel models. This bias results from the well-known lagged dependent variable bias, causing the estimates to be lower than their true values (Nickell, 1981)[53].

Another source of bias is the non-linearity inherent in estimating in estimation of the long-run coefficients from the short-run coefficients (Pesaran and Zhao, 1999). Pesaran, Smith and Im (1995) studied this bias using Monte Carlo simulations for a dynamic heterogeneous panel and found that the MG estimator performs reasonably when T is large. Serious biases do exist, however, when T is small and when N is large relative to T. The dimensions of the panel used in this chapter are $T = 31$ and $N = 49$ so the chance of such bias seriously affecting the MG results is material. The estimates of the long-run coefficients using the correction to this problem studied and proposed by Pesaran and Zhao (1999) have not been applied in this chapter but one should still bear in mind the possibility that some amount of bias may present in the results for MG estimation.

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[53] As is well known, estimating a panel that contains a lagged value of the dependent variable on the right hand side with LSDV results in a bias that is asymptotically decreasing as the time dimension goes to infinity (Nickell, 1981). Judson and Owen (1996) suggest the bias on the lagged dependent variable may be up to 50% for panels with small time dimensions (T=5). They test the fixed effect estimator in the autoregressive case using Monte Carlo simulations and find that its performance compares favourably with, if not better than, many alternatives, when the time dimension is 30, which is a dimension very similar to the one used in this chapter.

An additional issue of MG estimation is that the estimator ignores the possibility that some parameters may be the same across groups. This is in direct contrast to the pooled estimators described above, which allow intercepts to differ across groups but constrain all slope coefficients to be the same across groups. The assumption made by the MG estimator that all parameters differ across all groups implies that an estimator which did not ignore this possibility would be more efficient than MG estimates.

Indeed, Pesaran, Smith, Shin (1999) developed the Pooled Mean Group (PMG) estimator to allow for an intermediate choice between the pooled estimators, which force all slope coefficients to be the same, and the MG estimator, which forces all parameters to be different. As Loayza and Ranciere (2001) note, the choice between the MG and PMG in general involves a trade-off between consistency and efficiency considerations. If constraints which impose cross-country restrictions are in fact valid in practice, then an estimator which imposes such constraints will clearly be more efficient.

The PMG estimator allows intercepts, short-run coefficients and error variances to differ across groups, but imposes the equality of one or more of the long-run coefficients across groups. In a cross-country growth context, such an assumption of a common long-run production function could perhaps be justified by appealing to access to common "public good" technologies, the impact of trade, or some type of arbitrage relationship. While this may be a rather strong assumption given the

very diverse and heterogeneous sample of countries studied in this chapter, it does seem reasonable to test for the presence of common long-run coefficients, rather than assume, without testing the data, that such commonality is contrary to prior intuition. Furthermore, it is seems reasonable and sensible to econometrically model output or per capita output as responding similarly to equipment investment across countries in the long-run, while allowing the effect of historical and institutional factors to cause the short-run dynamics and speeds of adjustment to differ across groups.

The PMG estimator may also be adapted to allow only a subset of the long-run coefficients to be the same while allowing the others differ. However, like the MG estimator, the PMG estimator is affected by downward bias on the coefficient of the lagged dependent variable. Pesaran, Shin, and Smith (1999) discuss some possible bias correction techniques that may be used, such as those proposed by Kiviet and Phillips (1993), but as Pesaran *et al.* (1999) note, these correction techniques apply to the estimates of the short-run coefficients. This means that since the long-run coefficients are non-linear functions of the short-run coefficients, techniques which correct or attempt to correct the bias in the short-run coefficients can still leave the more important long-run coefficients biased.

Another issue to consider is the stationarity of the data. An important feature of the types of Autoregressive Distributed Lag Model (ARDL) considered by Pesaran and coauthors (see especially Pesaran and Smith, 1995 and Pesaran and Shin, 1999) is that standard estimation and inference can be used for the PMG estimator regardless

of whether the regressors are stationary or non-stationary. These methods mean that there is no need for pre-testing and order-of-integration conformability since the estimators are valid whether the variables are stationary or integrated. This result is based on a key assumption that there exists a single long-run relationship between the dependent variable and the right hand side regressors. As Loayza and Ranciere (2001) point out, such an assumption is implicit in many single-equation estimators of long-run relationships in the cointegration literature. Absent this assumption, such estimators would at best simply identify some linear combination of long-run relationships in the data. In the context of a dynamic panel the existence of a long-run relationship requires that the absolute value of coefficient on the lagged dependent variable be less than one, and such a relationship is demonstrated in the results below.

The finding that standard methods of inference and estimation can be used in this context is also based on the requirement that the regressors be strictly exogenous and the resulting error term be serially uncorrelated. The requirement that the regressors be strictly exogenous requires the regressors to be independent of the error term at all leads and lags. Pesaran and Shin (1999) suggest that to ensure strict exogeneity of the regressors, the lag order of the regressors should be adjusted so that there is no correlation between leads and lags of the regressors and error term. Augmenting the lag order of the dynamic regression to ensure that the residuals are serially uncorrelated to the extent permitted by the data, and a negative estimated coefficient on the

lagged dependent variable are therefore sufficient to permit use of these estimating techniques.

In the next section of this chapter, the results of estimating the model derived in the last section are presented and discussed. As well as the MG and PMG estimators, Fixed Effect (FE) and a Dynamic Fixed Effect (DFE) specification are also estimated. These specifications provide a measure of comparison with the earlier literature. This comparison has the potential to yield useful information concerning the bias which arises when traditional pooled approaches are used, as well as hopefully pointing to the extent of the improvement which the new estimators are likely to bring to the study of dynamic heterogeneous panels. It will also be instructive to compare the results of my DFE estimation with the methods and conclusions of Jalilian and Odedokun (2000) and Oulton and Young (1996), the only other works to study equipment investment in a panel framework.

Finally, it is instructive to briefly review and compare some of the distinguishing features of the estimation techniques employed in this chapter against other popular estimators commonly used in the growth literature. One estimation technique that could conceivably have been employed, but has not actually been used in this chapter, is the seemingly unrelated regression estimation (SUR) approach introduced by Zellner(1962). SUR is useful in contexts where several equations are connected through the contemporaneous correlation of their error term, so that estimating all of the equations together as system using SUR should enhance efficiency (since the

contemporaneous error covariances can be freely estimated) relative to a situation where each particular equation is estimated individually(Kennedy, 1998).

However, it would not be practical to implement a SUR approach in the context of this chapter for two reasons. The first is that SUR is more suited to cases where N is rather small. This is because SUR involves, as Bassanini and Scarpetta (2001) point out, the estimation of $N * K$ coefficients (where the panel is of dimension $N * K$) as well as $\frac{1}{2}N(N+1)$ elements of the covariance matrix. When the system of equations is nearly square (that is, when the number of individual cross sectional observations is comparable to the number of time series observations) there is a problem of degrees of freedom. The second problem with SUR in this context, as noted by Pesaran, Shin, and Smith (1999), is that SUR is typically concerned with estimating linear cross country restrictions, whereas the approach adopted by the Pooled Mean Group estimator is concerned with common long-run coefficients and therefore implies non-linear restrictions across the different equations and countries. Therefore, approaches other than SUR must be sought[54].

Alternative methods of estimating dynamic panels include familiar techniques such as least squares dummy variables (LSDV), the Anderson-Hsiao estimator and the related Generalized Method of Moments (GMM) estimator. The LSDV estimator does not allow slope heterogeneity, and may suffer badly from Nickell (1981) bias. The first response to the Nickell bias was the work Anderson and Hsiao (1982) who

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[54] SUR estimation is however used in the next chapter.

derived a consistent instrumental variable estimator. Arellano and Bond (1991) improved on the Anderson-Hsiao estimator with a GMM estimator which also produced consistent estimates but achieved much greater efficiency gains relative to Anderson-Hsiao by exploiting additional moment restrictions. Kiviet (1995) has argued that the AH technique compares favourably with the GMM estimator, and addresses the problem of finite sample bias by proposing and estimating a small sample correction to the standard within-groups estimator.

For the type of relatively large time dimension (T=31) used in this chapter, Pesaran and Smith (1995) have shown that such procedures will produce inconsistent estimates of the average parameter values unless the slope coefficients are in fact identical across the individual units of observation. As Pesaran, Shin, and Smith (1999) point out, in almost all cross-country macroeconomic panels, tests indicate that this requirement is almost never met, implying that slope coefficients differ significantly across groups. The problem comes about because when regressors are serially correlated, ignoring heterogeneity results in serially correlated disturbances, which generates inconsistency for regression with lagged dependent variables even as the time dimension goes to infinity. This means that the solutions to the problem of the Nickell bias discussed are not necessarily helpful for dealing with heterogeneity of this type. The next section introduces the theoretical models to which the FE, DFE, MG and PMG estimators are applied.

2.3 Theoretical modeling and empirical specification.

This section introduces the two main specifications which are estimated in this chapter. Consider an aggregate linearly homogenous production that at time t is given by:

$$Y(t) = K(t)^{\varphi} H(t)^{\beta} (A(t)L(t))^{1-\varphi-\beta} \tag{2.3}$$

Where Y, K, L and H are output, physical capital, labor and human capital respectively; φ and β are the partial elasticities of output with respect to physical capital and human capital respectively. This type of production function is common in the growth literature.

Since this chapter is interested in the relative contribution of equipment to economic growth, it is useful to apply the simple generalization of the Solow model due to Nonneman and Vanhoudt (1996) and to consider the subcomponents of overall capital, K. We can extend equation (4) above by decomposing capital into terms related to equipment (E) and structures (S) as follows:

$$Y(t) = E(t)^{\alpha} S(t)^{\gamma} H(t)^{\beta} (A(t)L(t))^{1-\alpha-\beta-\gamma} \tag{2.4}$$

From this point, one can follow a Mankiw, Romer and Weil (1992) approach and study steady-state and out of steady-state relationships to reach a an augmented Solow Equilibrium Correction Mechanism (ECM) specification which is suitable for estimation. For the augmented Solow approach, one needs to describe the evolution

of the right hand side variables in the above equation, where the lower case letters denote the intensive form:

$$\frac{de}{dt} = s_e(t)y(t) - (n(t) + d)e(t)) \tag{2.5}$$

$$\frac{ds}{dt} = s_s(t)y(t) - (n(t) + d)s(t)) \tag{2.6}$$

$$\frac{dh}{dt} = s_h(t)y(t) - (n(t) + d)h(t)) \tag{2.7}$$

$$\frac{dA}{dt} = g(t)A(t) \tag{2.8}$$

$$\frac{dL}{dt} = n(t)L(t) \tag{2.9}$$

In the above equations, $y = \frac{Y}{L}$ is output per effective labor unit and e is equipment stock per effective labor unit and s is structures stock per effective labor unit. $h = \frac{H}{L}$ represents average human capital, s_e and s_s stand for the investment rate in equipment and in structures respectively. n is the growth rate of labor, g is the rate of change in technology and d is a common time-invariant depreciation rate.

Under the assumption that $\alpha + \beta + \gamma < 1$ (that is, decreasing returns to reproducible factors[55]) this system can be solved to obtain the steady state values e^*, s^* and h^* by setting the above equations to zero. Substituting these steady state relations into the production function and taking logs yields an expression for steady state output in per capita or intensive form:

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[55] If we assume constant returns at this point, the model has no steady state.

$$\ln y^*(t) = \ln A(t) + \frac{\alpha}{1-\alpha-\beta-\gamma}\ln s_e + \frac{\gamma}{1-\alpha-\beta-\gamma}\ln s_s + \frac{\beta}{1-\alpha-\beta-\gamma}\ln s_h - \frac{(\alpha+\beta+\gamma)}{1-\alpha-\beta-\gamma}\ln(n(t)+g(t)+d) \quad (2.10)$$

MRW present a similar equation for output in intensive form which is a function of the accumulation of physical and human capital. They proxy the accumulation of human capital by using data on the percentage of the working-age population that is in secondary school. As they note "When testing the augmented Solow model, a primary question is whether the available data on human capital correspond more closely to the rate of accumulation or the level of human capital". This is because the equation above can also be readily expressed as a function of steady state human capital as follows:

$$\ln y^*(t) = \ln A(t) + \frac{\alpha}{1-\alpha-\beta-\gamma}\ln s_e + \frac{\gamma}{1-\alpha-\beta-\gamma}\ln s_s + \frac{\beta}{1-\alpha-\beta-\gamma}\ln h^* - \frac{(\alpha+\beta+\gamma)}{1-\alpha-\beta-\gamma}\ln(n(t)+g(t)+d) \quad (2.11)$$

This is convenient because stock data on human capital is more readily obtainable than is data on the accumulation of human capital, and the use of stock data on human capital has been much more widely used by researchers in the growth literature. Moreover, the recent availability of improved stock data on human capital in the OECD (discussed in the data section below) also makes the use of a stock measure more desirable. This is a stock variable and therefore estimating a coefficient

for $\ln s_h$, the share of total saving devoted to the accumulation of human capital, will result in biased estimates. Therefore, the final empirical specification should take into account the nature of the human capital data and estimate a model that includes the level of human capital.

However, a problem with this equation is that it is a function of the steady state stock of human capital $(\ln h^*)$, which is not observable. Bassanini and Scarpetta (2001) provide a means of expressing the output equation as a function of the relationship between the steady state value of human capital and its actual level. Bassanini and Scarpetta express the three equations of motions above in growth rates and substituting out the respective investment rates into the equation for steady state output, yielding a linearized solution for $\ln h^*$ of the form:

$$\ln(h(t)/A(t)) = \psi(\ln h^*(t)/A(t)) + (1-\psi)\ln(h(t-1)/A(t-1)) \qquad (2.12)$$

where ψ is a function of (α, β) and $(n+g+d)$. Rearranging this equation results in the following expression for $\ln h^*$:

$$\ln h^*(t) = \ln h(t) + \frac{1-\psi}{\psi}\Delta \ln(h(t)/A(t)) \qquad (2.13)$$

By replacing the $\ln h^*$ term with its expression in this equation, we now have an expression for steady state growth as a function of investment ratios and the stock of human capital.

As is often stressed in the literature, this would be a valid specification of growth equation only if all countries in a sample are in their steady state, or if deviations from steady state were independent and identically distributed. If countries are not in their steady state or deviations are not i.i.d., as is very likely, then transitional dynamics must be modeled.

A linear approximation to the transitional dynamics of this model can be described as follows. Approximating around the steady state, the pace of convergence is given by:

$$\frac{d\ln(y(t)/A(t))}{dt} \approx \lambda\left[\ln(y^*(t)/A(t)) - \ln y(t)\right] \tag{2.14}$$

Where

$$\lambda \approx [(1-\alpha-\beta-\gamma)(n(t)+g(t)+d)] \tag{2.15}$$

The solution of this differential equation implies that:

$$\ln(y(t)/A(t)) - \ln(y(t-1)/A(t-1)) \tag{2.16}$$

$$= \phi(\lambda)(\ln(y^*(t)/A(t)) - (\ln(y^*(t-1)/A(t-1)) \tag{2.17}$$

Where $\phi(\lambda) = 1 - e^{-\lambda t}$. Inserting the expressions for y^* and h^* into this equation gives:

$$\begin{aligned}\Delta \ln y(t) &= -\phi(\lambda)\ln(y(t-1)) - \phi(\lambda)\frac{\alpha}{1-\alpha-\beta-\gamma}\ln s_e \\ &+\phi(\lambda)\frac{\gamma}{1-\alpha-\beta-\gamma}\ln s_s \\ &+\phi(\lambda)\frac{\beta}{1-\alpha-\beta-\gamma}\ln h(t) + \frac{1-\psi}{\psi}\frac{\beta}{1-\alpha-\beta-\gamma}\Delta \ln h(t) \\ &-\phi(\lambda)\frac{(\alpha+\beta+\gamma)}{1-\alpha-\beta-\gamma}\ln(n(t)+g(t)+d) \\ &+\left(1-\frac{\phi(\lambda)}{\psi}\right)g + \phi(\lambda)\ln A(0) + \phi(\lambda)g(t)\end{aligned} \tag{2.18}$$

One econometric issue with this specification is that growth is a linear function of a depreciation rate which is common to both equipment and structures (this point is also made by Oulton and Young, 1996 and Temple, 1998). In a panel data context the country-specific fixed effects will capture the effects of this variable, and therefore the depreciation rate doesn't enter the model directly, thereby avoiding any multicollinearity problems. A baseline econometric panel data specification suitable for estimating this equation is set out below.

$$\begin{aligned}\Delta \ln y_{i,t} &= a_{0,i} - \phi_i \ln y_{i,t-1} + \beta_{1,i}\ln s^e_{i,t} + \beta_{2,i}\ln s^s_{i,t} \\ &+\beta_{3,i}\ln h_{i,t} - \beta_{4,i}n_{i,t} + a_5 t + b_{1,i}\Delta \ln s^e_{i,t} \\ &+b_{2,i}\Delta \ln s^s_{i,t} + b_{3,i}\ln \Delta h_{i,t} + b_{4,i}\Delta n_{i,t} + \varepsilon_{i,t}\end{aligned} \tag{2.19}$$

This is model is in equilibrium correction model (ECM) form, which includes differences in they key variables. This is necessary as this chapter uses annual data, which is likely to contain short term business cycle effects. Much work in growth

econometrics does not use annual data, but instead uses periodic data averaged over a number of years which results in panels with very short time dimensions. For example, the Oulton and Young (1996) and Jalilian and Odedokun (2000) papers on equipment investment and growth, use quinquennial data over a twenty five year period. This practice has the effect of insulating the econometric results from short term business cycle factors which constitute unwanted influences in studies concerned with medium to long-run growth performance. However, using periodic averaged data may involve a loss of information. The approach adopted in this chapter is to use annual data in order to use as much information as the data contains, but this means the panel specification above needs to be modified to take into account any possible business cycle influences, and the short term component of the ECM is an ideal way to deal with this problem; hence differences of the long-run (levels variables) are included as above.

Now, if the long-run variables (these are the levels variables in the equation above) are grouped into $x_{i,t}$, a vector of weakly exogenous explanatory variables for group i, and group the coefficients into β_i, then there exists

$$\Delta y_{i,t} = \phi_i y_{i,t-1} + \beta_i' x_{i,t-1} + \sum_{j=1}^{p-1} \lambda_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij}' \Delta x_{i,t-j} + \mu_i + \epsilon_{it} \qquad (2.20)$$

Again, $y_{i,t}$ is a dependent variable, and μ_i represents country-specific fixed effects. The ϵ_{it} is a vector of disturbances that are independently and identically

distributed across i and t with zero mean and positive and finite variance. There exists a long-run relationship between $y_{i,t}$ and $x_{i,t}$ if

$$y_{i,t} = \theta'_{it} x_{i,t} + \eta_{it} \text{ where } \theta'_{it} = \frac{\beta'_i}{\phi_i} \tag{2.21}$$

In this equation, θ'_{it} is a vector of long-run coefficients, and the components of η_{it} are stationary and include fixed effects. Given that $\eta_{it} = y_{i,t} - \theta'_{it} x_{i,t}$, one may write the following equilibrium correction specification:

$$\Delta y_{i,t} = \phi_i \eta_{it-1} + \sum_{j=1}^{p-1} \lambda_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \delta'_{ij} \Delta x_{i,t-j} + \mu_i + \epsilon_{it} \tag{2.22}$$

In this formulation, ϕ_i is the equilibrium correction coefficient and measures the speed of adjustment towards equilibrium. For a long-run relationship to exist, the estimated coefficient needs to lie between -1 and 0. The PMG model, which constrains the coefficients on the long-run variables to be the same across groups, is expressed as follows.

$$\begin{aligned} \Delta \ln y_{i,t} \;=\; & -\phi_i(\ln y_{i,t-1} - \theta_1 \ln s^e_{i,t} - \theta_2 \ln s^s_{i,t} - \theta_3 \ln h_{i,t} \\ & +\theta_4 n_{i,t} + a_5 t + \theta_{0,i}) + b_{1,i} \Delta \ln s^e_{i,t} \\ & +b_{2,i} \Delta \ln s^s_{i,t} + b_{3,i} \ln \Delta h_{i,t} + b_{4,i} \Delta n_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{2.23}$$

This type of specification also has the advantage that it differentiates between short-run and long-run effects. This highlights the potential for heterogeneity across

countries of the response of the dependent variable to possible differences in the long-run and short-run parameters. Again, the PMG ECM formulation that is applied to both approaches solves this problem. The time trend has dropped out of this specification because the data used is demeaned to remove the effect of any common time trend - this is discussed in much more detail in the results section.

A similar ECM specification can also be obtained from a different conceptualization of the same production function. This specification starts by analyzing the production function as a stock relationship, following, for example, the work of Benhabib and Spiegel (1994). In this approach, the capital and labour inputs are measured, not by ratios, but by capital and labour stocks. Human capital is again measured as a stock in this approach. This type of stock production function model was also estimated for equipment investment in Oulton and Young (1996) and Temple (1998). In Oulton and Young, the stocks were expressed in intensive form; that is, in per capita terms; on the other hand, Temple (1998) did not measure the stock variables in this form. This chapter does not use the intensive form to study the stock relationship; the procedure taken is simply to directly take logs of the original production function. Expressing it in ECM form (including short-run variables to allow for business cycle effects which are likely to be present in the high frequency annual data used in this chapter and also including terms for fixed effects) yields the

following specification:

$$\begin{aligned}\Delta \ln Y_{i,t} &= -\phi_i(\ln Y_{i,t-1} - \theta_1 \ln E_{i,t} - \theta_2 \ln S_{i,t} \\ &\quad -\theta_3 \ln H_{i,t} + \theta_{0,i}) + b_{1,i}\Delta \ln E_{i,t} \\ &\quad +b_{2,i}\Delta \ln S_{i,t} + b_{3,i} \ln \Delta H_{i,t} + \varepsilon_{i,t}\end{aligned} \tag{2.24}$$

It is perhaps worth emphasising that although this specification is similar in form to that derived for the augmented Solow MRW approach, and is estimated in a similar fashion, this equation involves the calculation of different variables and the estimation is distinct from the augmented Solow approach and therefore the two sets of results are presented separately below. This is therefore the second theoretical model which is estimated in the PMG environment.

2.4 Empirical analysis

This section presents and discusses the results of the panel data estimation of some of the types of models presented above. It also discusses relevant data and sample issues.

2.4.1 Data and measurement issues

A discussion of the Penn World Tables data

This most important data source used in this chapter is the Penn World Tables (PWT). See Summers and Heston (1988, 1991, 1996) for discussions. PWT version

5.6 contains sets of national accounts on economic time series for almost all countries in the world for the period 1950 to 1992[56] and national expenditures of various types and details relative prices (purchasing power parities (PPP).

The United Nations International Comparison Project (ICP) was set up in the late 1960s (see Temple, 1998) to allow cross country comparisons of GDP and its subaggregates in real terms (UN, 2001). PPP conversions are used to facilitate cross country comparisons of key economic aggregates, such as real income and expenditures, free of price and exchange rate distortions. The estimates from the UN ICP have been combined with countries' national accounts to form the PWT.

This section of the chapter is concerned with identifying the potential problems that may arise from using this data set. Fortunately, Summers and Heston have written a number of papers discussing the difficulties of the benchmark quantity and price data. These results suggest that a good degree of caution should attend inferences made on the basis of this data. While it would be unrealistic to suppose that such a complex undertaking as making cross country macroeconomic comparisons would be without its flaws, it is still important to understand and address key problematic features. Perhaps the most serious problem relates to the quality of data collection, which is a very severe problem when looking at developing country data.

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[56] The most recent version of the Penn World Tables, 6.2, updates most of the data to 2004. However, the data series underlying the investment figures have not been updated, so PWT 5.6 data has been used for the growth and investment series.

Summers and Heston (1996) note a positive association between per capita income and the quality of statistics.

Srinivasan (1995) regards this, quite rightly, as a very serious drawback to this data. He notes that the international agencies who publish such data do not collect the primary data themselves, and are obliged instead to rely on the efforts of national statistical agencies. This leads to difficulties in that many developing countries employ different concepts and methods of data collection, and differ widely in their social, administrative and political conditions. This results in "serious conceptual problems, measurement biases and lack of comparability over time and within countries and across countries at a point in time".

Temple (1999) describes one response to these conclusions "Those instinctively suspicious of the literature sometimes fall back on measurement error to avoid engaging with it". Perhaps the appropriate response to this problem is not to regard it is as fatal to the entire exercise, but instead to acknowledge it, to examine its wider implications and to treat inferences drawn on the basis of this data with a good degree of skepticism. The same can be said of the more general problems described below by Summers and Heston.

The first problem with the benchmark quantity and price data is that its quality is determined by the quality of both the individual countries national accounts and the benchmark study's price surveys This is a problem if unregistered economic

activities comprise a significant proportion of GDP. Another problem is the difficulty of making comparisons of services across different countries, and as Summers and Heston (1988) note, several studies have shown that the failure to match good and services adequately across countries raises important practical difficulties.

The choice of aggregation method is also problematic, as one may not wish to build in a simplifying but dangerous assumption of, for example, common worldwide tastes. Depreciation rates are often determined on the basis of national tax laws rather than studies of countries' actual experience (Summers and Heston, 1996). Another quite serious problem for growth studies is the lack of good data on labour force participation. As these authors say "They vary enough to make GDP per capita a very unsatisfactory proxy of GDP per worker"[57]. This has implications for the calculation of labour force participation variables used in the two specifications considered here.

Formal tests of measurement error in growth regressions are rare. Leading techniques to deal with the problem include instrumental variables, but this approach is obviously difficult, as noted above, because of the lack of suitable instruments. Summers and Heston (1988) suggest a useful benchmark for thinking about the extent of measurement error and hence the degree of caution one should bring to a reading of results based on their data: they find that "By and large, among rich countries, comparisons are likely to be correct within say 5-10%; comparisons of poor countries

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[57] This point has also been taken up by Scarpetta, Bassanini, Pilat and Schreyer (2000), who demonstrate how employment rates have changed significantly over time in OECD countries.

with rich ones may be subject to errors twice as great". This perhaps suggests using slightly more generous confidence intervals for regressions involving the use of data from these countries.

Human capital data

The human capital data on LDC countries is taken from the Barro-Lee dataset, available from the Center for International Development at Harvard and the NBER. The particular measure used in this study is the average years of schooling in the population over 15. The data are available quinquennially and have been interpolated to create a yearly series for all countries. Human capital data for twenty OECD countries are taken from De la Fuente and Domenech (2001). Rogers (2003a) provides a very helpful discussion of the issues involved in studying international human capital data.

One problem with this measure of human capital is that it is a measure of the quantity of education and therefore does not capture differences in the quality of education. Internationally comparable measures of educational quality for the very diverse sample of countries included in this and other empirical growth studies are very difficult to generate for a number of reasons. As discussed in the previous chapter at some length, one way to determine the quality of schooling is to compare labor market outcomes such as wage premiums attributable to additional education or to reduced likelihood of entering employment due to extra education. An obvious

problem with this measure is that labor market performance is influenced by variables other than schooling such as parental background, innate ability, average income levels in the economy as a whole, and so on.

Controlling for all of these influences in a consistent and comparable manner for the world as a whole is very challenging. An alternative approach, and one used in recent work on the determinants of school quality by Barro and Lee (2001), is attempt to compare educational quality across countries using cognate tests of performance in knowledge, skills, behaviour and attitudes. However, important questions remain concerning the actual comparability of such tests, and the extent to which such measures accurately reflect fundamental differences in outcomes solely attributable to education. [58]

In any event, the stock measure of human capital that is used in this chapter is similar or identical to the human capital measure used in most empirical growth research. Stock measures of human capital are also, as Temple(2000) notes, more helpful than flow measures in avoiding reverse causality problems. The other variables are measured using data as follows.

Other regression data

The dependent variables for the stock/production function approach is GDP, while for the augmented Solow/MRW approach it is GDP per worker. The GDP used

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[58] Other problems with measuring human capital are discussed in MRW(1992).

in each case is expressed in constant 1985 purchasing power parities as discussed above. The data on equipment and structures investment is also drawn from the Penn World Tables, and is also expressed in constant 1985 purchasing power parities. The equipment investment and structures investment data were calculated as follows. For the augmented Solow approach, the equipment and non-equipment investment ratios were calculated by dividing the investment data into GDP. These definitions of investment ratios are precisely the same as those found in Oulton and Young (1996). Data on population growth in also drawn from the Penn World Tables.

For the production function/stock approach the investment data were cumulated using the perpetual inventory method to calculate a stock figure. The stock was added to by each year's investment, and reduced by depreciation, which was assumed, in line with the literature, 15% for equipment and 2% for structures. This construction of stock figures is a different approach to that followed by Oulton and Young (1996). In that paper, the authors use the capital stock figures provided in Penn World Tables 5.6; this chapter cumulated the existing investment data to create a new capital stock measure as this allows the stock data to start in 1960, whereas the Penn World Tables capital stock data starts in 1965.

Data availability for the variables considered in this study, especially the availability of the equipment and structures series, limited the final sample of countries to 49. Initially, this chapter began with a subset of the entire range of countries for which data is available in the Penn World Tables. This subset excluded those

countries whose data receive a grade of "D" from Summers and Heston. Countries receive a "D" grade from Summers and Heston if the real income figures are based on extremely little primary data, so that measurement error is likely to be a very serious problem for these countries. This subset comprised 80 countries. The sample was reduced to 49 due to the lack of series on equipment and structures investment for many countries, and data unavailability in the Barro-Lee human capital data set. Similar considerations also influenced restricting the sample period to be 1960 to 1990.

The countries used in the chapter are Botswana, Kenya, Malawi, Zambia, Zimbabwe, Canada, Dominican Republic, Guatemala, Honduras, Jamaica, Mexico, Panama, USA, Argentina, Bolivia, Chile, Colombia, Ecuador, Paraguay, Peru, Venezuela, Hong Kong, India, Israel, Japan, Republic of Korea, Philippines, Sri Lanka, Syria, Thailand, Austria, Belgium, Denmark, Finland, France, West Germany, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, Australia, and New Zealand. By describing the African, South American and South East Asian countries as developing economies, this constitutes a sample of 21 "developed" countries, and 28 "developing" countries (including Israel).

2.4.2 Results

This section presents the results of estimation of the ECM equations specified above. The first set of results are from the augmented Solow/MRW approach and are presented in the table below[59].

	FE	DFE	PMG	MG
Diff y				
Long run coefficients				
Log(h)	0.1705	0.0129	0.064	-0.003
	(0.0362)***	(0.2902)	(0.080)	(0.381)
log(Sm)	0.0923	0.4021	0.238	0.22
	(0.0133)***	(0.0908)***	(0.022)***	(0.164)
log(Ss)	0.1493	0.4714	0.353	-0.043
	(0.0159)***	(0.1088)***	(0.044)***	(0.342)
Δlog(n)	-1.9565	-16.899	-5.86	-7.75
	(0.4984)***	(0.3943)***	(1.35)***	(12.645)
Equilbrium Correction coefficient				
φ		-0.052	-0.071	-0.278
		(0.0079)***	(0.012)***	(0.036)***
Joint Hausman test				0.13
No. of observations (NxT)	1470	1470	1470	1470
No. of countries	49	49	49	49
Average adjusted Rbar sq.	0.0941	0.099	0.5443	0.1985

Note: Short run coefficients, fixed effects and constant not reported.

Figure 2.2: Results from estimation of augmented Solow/MRW specification.

As noted in the previous chapter, one asterisk indicates significance at the 10% level, two asterisks indicate significance at the 5% level, and three asterisks indicate

[59] All regressions were estimated using the Gauss code developed by Yongcheol Shin. The code is available at http://www.econ.cam.ac.uk/faculty/pesaran/jasa.exe

significance at the 1% level. For each estimator (except the MG estimator, which appears to be affected by outlying observations to be discussed below), the long-run variables are of the anticipated sign. $Log(h)$ measures the logarithm of the human capital measure, Se and Ss are respectively shares of equipment investment and structures investment and n is the growth rate of population.

For the PMG results, recall that the equilibrium correction coefficient and the (unreported) short-run variables are free to vary across countries, but the long-run coefficients are constrained to be equal across countries. Note that the coefficient on the lagged value of income is negative and statistically significant. This is re-assuring as a negative coefficient on this variable is required to ensure the dynamic stability of the model. The Hausman (1978) test is the familiar test used in settings to compare estimators where one estimator is consistent only under the null hypothesis, whereas the other estimator is inefficient under the null but consistent under the null and an alternative hypothesis. In the context of tests involving the MG and PMG estimators, Smith (2004) points out that the Hausman test is not itself a test for heterogeneity, but a test for the effects of heterogeneity on the consistency of different estimators. The Hausman statistic in this case fails to reject joint homogeneity of all long-run parameters.

Estimating the MRW model using only MG estimates did not produce statistically significant results. This finding is in line with other studies which are based on "groups" with very different characteristics to each other; if outliers are important, the

equal weighting given by MG to each outlier will render the overall average results statistically insignificant. For more on this aspect of MG estimators, see the paper by the Centre for Spatial Economics (2004). In many international samples which use the Penn World Tables, the potential of one country to significantly alter the estimated parameters can often be quite high (Bassanini and Scarpetta, 2001). This represents a particular problem for the Mean Group estimator because it is an unweighted average so that it is excessively sensitive to the presence of outlying country estimates (see Pesaran, Shin, and Smith, 1999 and Nair-Reichert and Weinhold, 2001). The PMG estimator is less sensitive (Loazya and Ranciere, 2001) as it produces estimates that are weighted averages of the country-specific estimates, where the weights are given according to the inverse of their corresponding variance-covariance matrix.

As one would expect, the actual value of the estimated coefficient differs across the different estimators. The DFE results narrowly fail to replicate the relative importance attached to structures and equipment investment, in the sense that the results presented here indicate a slightly higher value for structures than for equipment; however, it is instructive to note that the PMG estimator finds a much large difference in the output elasticity between the two measures, suggesting further that the relative importance of equipment compared to structures is less than has been found in the literature.

Human capital does not enter significantly in this specification (although it does in some of the other specifications); Rogers (2003) provides a comprehensive discus-

sion and tests of why this might be so, arguing persuasively that countries differ in their ability to use schooling productively and therefore a positive correlation between growth and schooling is not automatic; similar points are also discussed at some length in Easterly (2002). Rogers (2003) finds that, after controlling for variables which measure the capacity of an economy to use schooling productively (using variables such as the black market premium and the extent of brain drain), schooling is far more likely to be significantly and positively associated with growth. This is borne out in the results presented below for developing and developed subsamples of countries, whereby the human capital variables are more likely to enter significantly and positively in the developed sample for the production function/stock approach, presumably because of their capacity to use schooling and other types of human capital in a productive manner, although this effect is not present in the augmented Solow/MRW specifications. The very large estimated coefficients estimated on the population growth variable are of very similar dimensions to those of Bassanini and Scarpetta (2001).

These DFE results are presented for their own intrinsic interest as well as for comparative purposes both with the published fixed effect estimations of Jalilian and Odedokun (2000) and Oulton and Young (1996) and with the PMG estimators. The DFE results are useful in this regard because they may be said to represent an opposite extreme to the MG estimators, since the DFE estimator constrains all the slope coefficients to be the same, whereas the MG estimator imposes no such restrictions.

Jalilian and Odedokun's (2000) fixed effect estimation paper had a different focus, motivation and modeling methodology than this chapter. They find that equipment investment is positive and significant in all of their specifications, which is not the case for the other types of investment that they consider in their augmented Solow framework. Oulton and Young's augmented Solow specification delivers a coefficient of 0.146 for equipment, and 0.1319 for structures (noting of course that their data, sample period and specification differ from that employed in this chapter). This finding is interesting as the coefficients are close, just as are the coefficients presented in the results table above. This suggests that panel data specifications of the augmented Solow model greatly reduce the difference, compared to the earlier cross-sectional literature, between the elasticity of output with respect to equipment and structures.

One should also note that the DFE estimates that are presented have not been corrected for Nickell (1981) type biases. As discussed above, models that include a lagged dependent variable will be produce biased estimates in small samples under the application of fixed effect estimation procedures. Kiviet (1995), however, showed that while this estimator suffers from crippling bias in small samples, a bias corrected version of this estimator has a small variance compared to many consistent estimators. Moreover, as Judson and Owen (1997) point out, although the bias in a panel with a time dimension of 30 would be between 3% and 20%, errors of this magnitude would still result in a coefficient with the correct sign and biases of variables

other than the lagged dependent variable are relatively small. In any event, the Kiviet (1995) correction has not been implemented because results based on fixed effect estimators are not the central focus of this chapter for reasons already discussed and also because of the reasonably long time dimension ($T = 31$) of my panel; however, the results of the DFE estimation should still be treated with some (small) degree of caution given all of these considerations.

It is also important to note that these results are based on cross-sectionally demeaned data. Cross-sectional demeaning involves expressing the variables less the cross-sectional mean for the period in each group, which has the same effect mathematically as including year-specific intercepts. Cross-sectional demeaning is important in these types of panels as it removes the effects of any common omitted variables which would otherwise impart bias to the results if they were not addressed in an appropriate economic manner. This is why the time trend does not appear in these results. For instance, assuming for the moment that technology is a public good to which all countries have access (which is debatable but serves the purposes of this example), then the there will be a time specific trend which is common to all countries. The cross-section demeaning removes the influence of any technology trend as well as any other common time specific influence.

Therefore the approach adopted here seems more appropriate than using the raw data (that is, not cross-sectionally demeaned) but including a common time trend, since this trend may not capture all time effects (and in any case would very likely be

collinear with some of the right hand side variables). Moreover, even if technology is not a public good then the inclusion of country specific fixed effects will pick this effect, and will pick up the other omitted effects which are confined to the country in question. In summary, therefore, the demeaning is not in and of itself tantamount to assuming common technology or common access to technology across countries (for example Islam, 1995 and Dowrick and Rogers, 2002, show that technology does indeed differ significantly across countries); instead it captures common movements and allows the fixed effects to pick up other country specific idiosyncratic factors.

Diagnostic performance of regressions

Diagnostic statistics are provided in the Appendix to this chapter for this regression. The model appears to perform relatively well, given the great differences in the structures of the economies included in the sample. An average R-bar squared of 54% suggests the model does a reasonably satisfactory of explaining variation in growth through variation in the independent variables. As argued above in the data section, there is perhaps a case for looking at wider than normal confidence intervals to take into account the quality of some of the data in the Penn World Tables.

Referring to the table in the appendix, and at the 1% level gives evidence of serial correlation in three countries (Chile, Venezuela and Austria), evidence of functional form mis-specification in five countries (Botswana, Panama, India, and Korea), evidence of non-normality of residuals in four countries (Botswana, Kenya,

Jamaica, and Panama), and finally evidence of heteroskedasticity in just one country (Panama). Clearly, the most problematic diagnostics arise from countries in the developing world; the model doesn't seem particularly successful in Botswana and Panama in particular, Botswana having been identified by other authors (including De Long and Summers, 1991) in this literature as rather problematic in equipment-growth regressions. The fact that most of the "problem" countries are in the developing world suggests that using wider than normal confidence bands to interpret regression coefficients is indeed a legitimate strategy.

Clearly, it would be preferable to generate regressions which did not exhibit any diagnostic problems, but in a panel of this size, heterogeneity, and duration, it is perhaps unavoidable that regressions specifications will be more appropriate for some countries than others. The proportion of countries failing diagnostic tests in the different categories actually compares favourably with the number of failed tests in the original Pesaran *et al.* (1998) paper, which suggests that the diagnostic results presented in the appendices to this chapter are not fatal to the exercise being undertaken. One important point connected to the diagnostics was the need to secure exogeneity of the right-hand side regressors as a pre-requisite to the valid use of the mean-group type estimators. Leading causes (Kennedy, 1998) of serial correlation are data manipulation and mis-specification. Data manipulation may involve such practices as interpolation which will tend to average true disturbances over successive time periods. Given that the human capital data were interpolated to annual

figures from quinquennial data, this interpolation could give rise to serial correlation. However, it is more likely that some form of mis-specification is to blame for the serially correlated residuals. An omitted serially correlated variable that is relevant to the regression being studied will cause serial correlation. Misspecified dynamics or functional form are also very likely to give rise to this problem.

Other causes of serial correlation are likely, but it is good econometric practice to check for mis-specification before other possible causes are sought and inappropriate remedies applied (Kennedy, 1998). To this end, different lag selection criteria were examined for the variables on the right hand side of the model. In general, when theory does not suggest a clear guide as to potential empirical lag structures, additional criteria are used to choose from alternative models that are likely to be appropriate or acceptable from an econometric point of view. Since general models will always provide a better fit within the sample for the data (Verbeek, 2000), parsimony is to be preferred as this obviously increases the number of free parameters. The final lag specification was therefore determined empirically by manual lag selection and the lag structure chosen was such that each long-run variable enters the model with a one-period lag[60].

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[60] Another possibility for lag selection length is to choose and rely upon a model selection criterion. For instance, in some applications of the PMG estimator, the Schwarz Bayesian Criterion, Posterior Odds Criterion, or other means to determine lag length are used. However, many of these criteria place different emphasis on either the time or cross-sectional dimensions of the panel, and it is not clear that placing greater or less emphasis on either dimension is justified in the context of the panel studied in this chapter. As such, the manual leg selection approach adopted here seems to constitute a reasonable objective form of compromise.

Results from production function/stock approach

Having presented the results of the augmented Solow/MRW approach, the results for the production function stock estimates are given below.

	FE	DFE	PMG	MG
Diff Y				
Long run coefficients				
Log(H)	0.1662	0.3617	0.215	-0.079
	(0.033)***	(0.1278)**	(0.025)***	(-0.176)
Log(L)	0.2842	0.2557	0.424	0.839
	(0.0393)***	(0.1481)	(0.023)***	(0.432)*
log(M)	0.3069	0.242	0.127	0.477
	(0.0196))***	(0.077)***	(0.019)***	(0.287)*
log(S)	0.1929	0.1003	0.268	-0.196
	(0.0221)***	(0.0869)*	(0.027)***	(0.251)
Equilbrium Correction coefficient				
φ		-0.1774	-0.329	-0.767
		(0.018)***	(0.044)***	(0.046)***
Joint Hausman test p-value				0.12
No. of observations (NxT)	1470	1470	1470	1470
No. of countries	49	49	49	49
Average adjusted Rbar sq.	0.0349	0.127	0.5442	0.1987

Note: Short run coefficients, fixed effects and constant not reported.

Figure 2.3: Results from estimation of production function/stock specification.

These PMG estimates exhibit a number of interesting features. The most striking aspect is more evidence that the conclusions of some of the cross-sectional and fixed effects literature may be incorrect with respect to the relative importance of equipment and structures. Interestingly, the estimates that are generated using

the "traditional" fixed effects estimator replicate the sign and relative importance of equipment and structures; in other words it is consistent with the results of the existing literature on this topic and encompasses the results of that literature. This difference between the more traditional estimators and the PMG approach suggests that the PMG estimated may be picking up and correcting biases that would otherwise have gone undetected in the context of a cross- sectional or fixed effects regression. It must of course be borne in mind that other papers used different specifications and data, so that the encompassing isn't strictly general since those specifications aren't replicated here but nevertheless these new results are very similar to those produced elsewhere in the literature. The Hausman statistic fails to reject long-run homogeneity at the 10% level.

It is also notable that the results appear to imply constant returns in the production function. The PMG coefficients suggest a share of non-physical capital (labour force and education) of about 63%, and correspondingly a share of physical capital in output of approximately 30%. Therefore, another important feature of these results is that they appear to suggest that the elasticity of output with respect to both equipment and structures investment is approximately equal to capital's share in national income. This is consistent with the findings of Oulton and Young (1996), again suggesting that there is nothing "special" about equipment investment in terms of it having an exceptional growth-enhancing character. In fact, the elasticity of output to the equipment stock for the PMG estimates is extremely close to results presented in

Oulton and Young (1996): they also estimated a coefficient of 0.127 for their production function specification (again noting that their finding is obtained from different specifications and different data). However, unlike this chapter, their fixed effects results do not suggest a lower output elasticity of structures compared to equipment investment.

The diagnostics for this regression below show that, like the augmented Solow model, the estimation appears to be reasonably satisfactory, and a comprehensive table of diagnostic statistics for this particular regression appears in the appendix to this chapter. At 1%, there is evidence of serial correlation in four countries, misspecification in five, two cases of non-normality, and evidence of heteroskedasticity in one country. As noted above for the case of the MRW results, these are reasonably satisfactory, and an average R-bar squared of 54% suggests the model is performing reasonably well.

Rates of return

Having considered a variety of models which produced estimates of the elasticity of output to equipment investment and equipment stocks, it still remains to examine use these coefficients to calculate *rates of return* to equipment investment. The coefficients on the investment variables estimated above cannot be directly interpreted as rates of return. This is because, for the production function approach, the rate of return must be calculated by adjusting estimated coefficients by the op-

portunity cost of capital and depreciation. The augmented Solow model estimated coefficients must also be modified; these adjustments for both of the econometric specifications are discussed below.

Under the MRW-type augmented Solow approach, assuming profit maximization, it can be shown (see for example Nonneman and Vanhoudt, 1996, Ishise and Sawada, 2006 and Temple, 1998) that the marginal product of equipment capital, net of depreciation, in the steady state growth path for country i is given by:

$$r_e - d_e = \frac{\alpha(n_i + g_i + d_e)}{s_{e,i}} - d_e \tag{2.25}$$

Where r_e is the return to equipment; the equivalent formula and calculation can be readily performed for structures. The coefficient α is the partial elasticity of output with respect to equipment capital and is estimated by the regressions, while $n, g,$ and s_e can be taken from the data. Data on depreciation is not readily available, so one could follow De Long and Summers (1991) and Temple (1998) in assuming that the depreciation rate of equipment, d_e is 0.15, and the depreciation rate of structures is 0.02. The share of equipment investment data (the denominator in the equation above) were used in the econometric modeling and, as noted, was calculated for each country from Penn World Tables data. The α term was estimated from the PMG regressions.

The results of this calculation are similar to those found in Temple (1998). Like Temple's results, these results are rather puzzling. Using this methodology for the

augmented Solow/MRW results, the average return to structures for the entire sample is 10.7%, while for equipment investment the same procedure delivers an estimate of 99%! Temple (1998) obtained very similar results in his cross-sectional study and using a larger sample size (up to 78 countries): he estimated a return to structures of 12% and a return to equipment of just under 100%, results which are very similar to those estimated here. The results are however very sensitive to assumed depreciation rates. The returns also differ sharply between the developed and developing world (this is discussed in more detail below). Temple notes that "It is hard to believe that private returns of this magnitude could be sustained for the best part of 25 years". While Temple goes to considerable lengths to verify the accuracy of this high return to equipment investment and does indeed conclude that the high estimate is reliable, this return to equipment does seem economically implausible.

Under the production function approach that has been studied in this paper, the estimated coefficient measures the *gross* return to the capital measure (see Oulton and Young, 1996), and therefore depreciation must be taken from these coefficient estimates to arrive a net return; Oulton and Young report a cost of capital of approximately 9% for structures, and 15% for equipment. For the sample as a whole, therefore, subtracting an assumed rate of depreciation of 15% from the estimated coefficient of equipment results in an estimate which less than the cost of capital, whereas structures earn an estimated return (assuming depreciation of 2%) which is roughly 10% above its cost of capital.

Scaling these results by the capital/output ratio further reduces the estimated returns. The average capital output ratio for the sample as a whole is, based on figures the data used in King and Levine (1994)[61]. The average capital output ratio (according to this source) is 1.97, while the median is 1.91; the minimum and maximum figures in the sample are 0.58 and 6.82 respectively. Dividing the estimated coefficients (less depreciation) from the production function/stock approach by the mean capital-output ratio in the sample therefore yields a negative estimated return for equipment investment (approximately -9%), while structures earn approximately 10%.

Clearly, these results are very sensitive to assumed depreciation rates. The estimated coefficient on equipment stocks is 0.127, which, when divided a capital/output ratio of approximately 2, yields an adjusted return of roughly 6%. Therefore, any depreciation rate greater than 6% will reduce the return below zero; clearly, even before subtracting depreciation the estimated return is below the Oulton and Young estimates of the cost of capital. Returns to structures are far less sensitive to assumptions regarding depreciation. Oulton and Young (1996) find a similar result for equipment investment - they found that the rate of return on equipment was approximately equal to the net private cost of capital plus the depreciation rate. Estimated returns do however differ very substantially when developing and developed countries are considered separately. This topic is the subject of the next section.

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[61] Data is available from: http://econ.worldbank.org/

2.4.3 Developed and developing countries.

An important conclusion of the earlier literature was that the returns to equipment investment were higher in developing countries than for developed countries. Indeed, this difference between the developed and developing worlds was emphasized and studied as the one of the most significant features of this field of research by De Long and Summers (1991), Oulton and Young (1996) and by Temple (1998). The results obtained by splitting the sample according to the classification of countries into developing and developed[62] are shown in the tables below for each specification (augmented Solow and production function approach).

This set of results replicates an important part of the literature on equipment investment, which is that returns to equipment investment appear to be higher for LDCs than for developed countries, and that structures are more important in the developed world than in the developing world. Interestingly, the coefficients estimated here for equipment and structures are quite similar to Temple's (1998) cross-sectional sample; he estimates a coefficient for equipment of .25 for developing countries, and a value of .13 for developed countries. Moreover, the rates of return are very similar

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[62] For reference, the classification was as follows: The countries used in the chapter are Botswana, Kenya, Malawi, Zambia, Zimbabwe, Canada, Dominican Republic, Guatemala, Honduras, Jamaica, Mexico, Panama, USA, Argentina, Bolivia, Chile, Colombia, Ecuador, Paraguay, Peru, Venezuela, Hong Kong, India, Israel, Japan, Republic of Korea, Philippines, Sri Lanka, Syria, Thailand, Austria, Belgium, Denmark, Finland, France, West Germany, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, Australia, and New Zealand. By describing the African, South American and South East Asian countries as developing economies, this constitutes a sample of 21 "developed" countries, and 28 "developing" countries (including Israel).

Developed countries	FE	DFE	PMG	MG
Diff y				
Long run coefficients				
Log(h)	0.3913	0.6101	0.174	-0.025
	(0.0607)***	(0.3217)*	(0.1130)	(0.381)
log(Sm)	0.0728	0.1053	0.116	0.421
	(0.0227)***	(0.1233)	(0.034)***	(0.164)**
log(Ss)	0.0754	0.2257	0.487	0.73
	(0.0363)*	(0.2077)	(0.089)***	(0.342)**
Δlog(n)	2.8757	-21.0588	-15.832	-13.151
	(0.5536)***	(6.921)***	(2.759)***	(12.645)
Equilbrium Correction coefficient				
φ		-0.0366	-0.059	-0.157
		(0.0076)***	(0.011)***	(0.036)***
Joint Hausman test p-value				0.00
No. of observations (NxT)	630	630	630	630
No. of countries	21	21	21	21
Average adjusted Rbar sq.	0.534	0.409	0.409	0.508

Note: Short run coefficients, fixed effects and constant not reported.

Figure 2.4: Results of estimation of augmented Solow/MRW specification for developed countries.

to those in Temple. For the developing country subsample, the estimated net rate of return to equipment investment is 135% (compared to 140% calculated by Temple); the net rate of return for developed countries is 27% on equipment, and also 27% for structures.

The diagnostic statistics for these regressions (not reported) are also broadly similar to those for the entire sample; although the average R-bar squared was relatively low at 20%. For the diagnostics for sample as a whole, a 1% level was used, but it may be appropriate to adopt a less strict criterion for developing countries. For

Developing countries	FE	DFE	PMG	MG
Diff y				
Long run coefficients				
Log(h)	0.7708	-0.1501	0.312	1.549
	(0.0258)***	(0.2653)	(.09)***	(.0738)***
log(Sm)	0.113	0.4418	0.245	-0.369
	(-0.185)	(0.1424)***	(.044)**	(0.569)
log(Ss)	0.1842	0.4395	0.212	0.866
	(0.215)	(0.1551)***	(.048)**	(0.65)
Δlog(n)	-4.017	-23.1637	-12.399	-90.888
	(0.7626)***	(6.6398)***	(2.785)***	(85.476)
Equilbrium Correction coefficient				
φ		-0.052	-0.1	-0.313
		(0.116)	(0.015)***	(0.047)***
Joint Hausman test				0.00
No. of observations (NxT)	840	840	840	840
No. of countries	28	28	28	28
Average adjusted Rbar sq.	0.083	0.152	0.205	0.462

Note: Short run coefficients, fixed effects and constant not reported.

Figure 2.5: Results of estimation of augmented Solow/MRW specification for developing countries.

the developing sample, there was evidence of serial correlation at the 5% level in five countries, functional form mis-specification in five , non-normality in two countries, and also evidence of heteroskedasticity in just two countries. The smaller sample of rich countries performs slightly better: evidence of serial correlation in two countries at 5%, mis-specification in one country and non-normality in one country, and no evidence of heteroskedasticity in any country

Developed countries	FE	DFE	PMG	MG
Diff Y				
Long run coefficients				
Log(H)	0.3411	0.4076	0.079	0.651
	(0.0422)***	(0.162)*	(.033)**	(0.454)
Log(L)	0.1483	0.0092	0.184	0.529
	(0.0459)***	(0.1846)	(.028)***	(0.373)
Log(M)	0.2744	-0.1099	0.04	-0.791
	(0.0273)***	-0.1243	(.025)	(0.936)
Log(S)	0.2024	0.0616	0.328	0.323
	(0.0343)***	-0.1374	(0.041)***	(O.343)
Equilbrium Correction coefficient				
φ		-0.0827	-0.291	-0.736
		(0.0127)***	(0.070)***	(0.077)***
Joint Hausman test p-value				0.05
No. of observations (NxT)	630	630	630	630
No. of countries	21	21	21	21
Average adjusted Rbar sq.	0.0743	0.409	0.569	0.243

Note: Short run coefficients, constant and fixed effects not reported

Figure 2.6: Results from estimation of production function/stock specification for developed countries.

The same exercise was performed for the production function/stock approach. Again, these results are not inconsistent with the literature that equipment investment is relatively more important for developing countries. In particular, the low and insignificant PMG estimate on equipment investment for developed countries is close to that estimated by Oulton and Young (1996). The rate of return to equipment stock is also high and positive for developing countries[63], even after adjusting for a capital/output ratio of the developing countries in the sample of 1.65. As for the

[63] However, the Hausman statistic for the developing countries regressions rejects long-run homogeneity.

Developing countries	FE	DFE	PMG	MG
Diff Y				
Long run coefficients				
Log(H)	0.075	0.1876	0.015	-0.196
	(0.0488)	(0.1839)	(0.061)	(0.471)
Log(L)	0.4105	0.1228	0.634	0.848
	(0.0872)***	(0.3338)	(.098)***	(0.698)
Log(M)	0.3188	0.3425	0.462	0.391
	(0.0268)***	(0.1031)***	(.026)***	(0.173)**
Log(S)	0.1882	0.0762	0.087	-0.293
	(0.0294)***	(0.1122)	(0.037)**	(0.306)
Equilbrium Correction coefficient				
φ		-0.1294	-0.354	-0.766
		(0.0172)***	(0.055)***	(0.058)***
Joint Hausman test				0.44
No. of observations (NxT)	840	840	840	840
No. of countries	28	28	28	28
Average adjusted Rbar sq.	0.0342	0.152	0.000	0.204

Note: Short run coefficients, constant and fixed effects not reported

Figure 2.7: Results from estimation of production function/stock specification for developing countries.

results for the entire sample, the returns to equipment investment in the developed world appear to be below the cost of capital and indeed below zero. The DFE results surprisingly deliver a negative coefficient for equipment investment for developed countries. This may be due to the downwards bias of DFE estimators (due to the Nickell bias), but this explanation is unlikely to hold true given the relatively long time dimension of the panel, and the fact the other DFE results for other specifications do not appear to be contaminated by this bias. Another disappointing feature of the

PMG results for the developed sample is that the results appear to indicate evidence of diminishing returns. The reasons for this are not clear.

The diagnostic statistics do not reveal any firm explanation for these findings. For the developing sample, four countries display evidence of serial correlation, eight of mis-specification, two of non-normality and one of heteroskedasticity. For the developed sample, four countries display evidence of serial correlation, one of mis-specification, one of non-normality and no evidence of heteroskedasticity.

This section split the sample according to a classification of countries into developing and developed economies. It replicated the findings of the existing cross-sectional and fixed effects literature that equipment investment appears to enjoy very high returns in developing countries, while structures are more important than equipment in the developed world. It also found, in line with previous work, that rates of return to equipment investment are far lower in the developed world compared to the developing world. Conversely, returns to investment in structures are higher in developed world than in the developing world. This replication is encouraging because it appears to encompass some of the findings of the previous studies on this topic, and suggests the main results (that is, for the entire sample) are reasonably well specified.

2.4.4 Sensitivity analysis

De Long and Summers (1991), and Auerbach, Hassett and Oliner (1994) both noted that the results of the De Long and Summers (1991) were quite sensitive to the inclu-

sion and exclusion of individual countries. In light of this, it is important to analyze the sensitivity of the results presented above to the exclusion of individual countries. Therefore, a further exercise was conducted designed to determine whether or not influential outliers were present in the sample, whereby countries (and groups of countries) were dropped one by one and the effect on coefficients, standard errors and general model fit on the remaining sample examined. This approach to detecting outliers does suffer from drawbacks, however, as Temple (1998) points out. It may fail to pick up a group of outliers (the masking effect) or it may incorrectly identify some observations as outliers, due to the presence of other unrepresentative observations (the so-called swamping effect). To deal with this possibility, the models were also estimated without certain *groups* of countries[64].

The selection of the groups to be excluded is necessarily subjective, since the similarities between countries that could give rise to masking or swamping may not be observable by the econometrician. Therefore, the grouping has been done primarily on a geographic or continent wide basis[65]. The graphs below reveal the effects on the equipment and structures coefficient of dropping individual countries from the econometric specification used to generate the main set of results for the entire sam-

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64 The identification of these groups is necessarily somewhat arbitrary, since the decision as to what countries be included in any particular group is somewhat arbitrary. This issue is explored in more detail below.

65 Some studies also exclude oil-exporting companies from their sample. In the present case, there are few countries which were very heavily dependent on the export of oil throughout this period, although assuredly there were countries for which oil was a significant export.

ple as presented above. The first set of results is for the augmented Solow/MRW regressions.

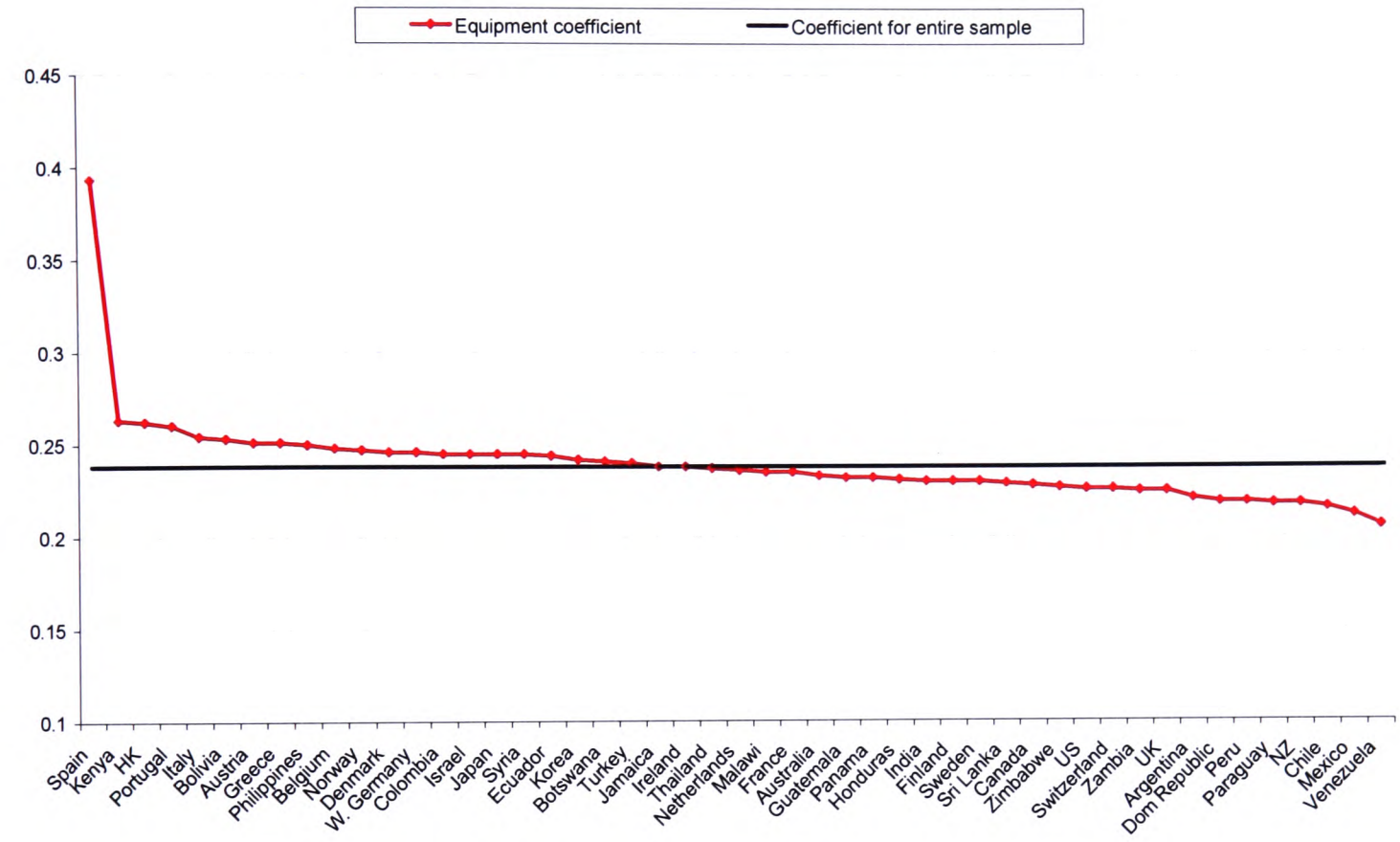

Figure 2.8: Sensitivity of equipment coefficient to exclusion of countries from augmented Solow/MRW specification.

This graph shows that, apart from what appears to be an outlier for Spain, the equipment coefficient as estimated by these regressions is very stable. Apart from the countries at the top of the scale, the coefficient ranges from approximately 0.26 to approximately 0.21. Given the distinct economic character of the countries in the sample, and the nature of the data, this is encouraging. The significance level of the estimated coefficients in these regressions (that is, regressions excluding a

single country) was, unsurprisingly, very similar to that which was estimated for the coefficient for the entire sample.

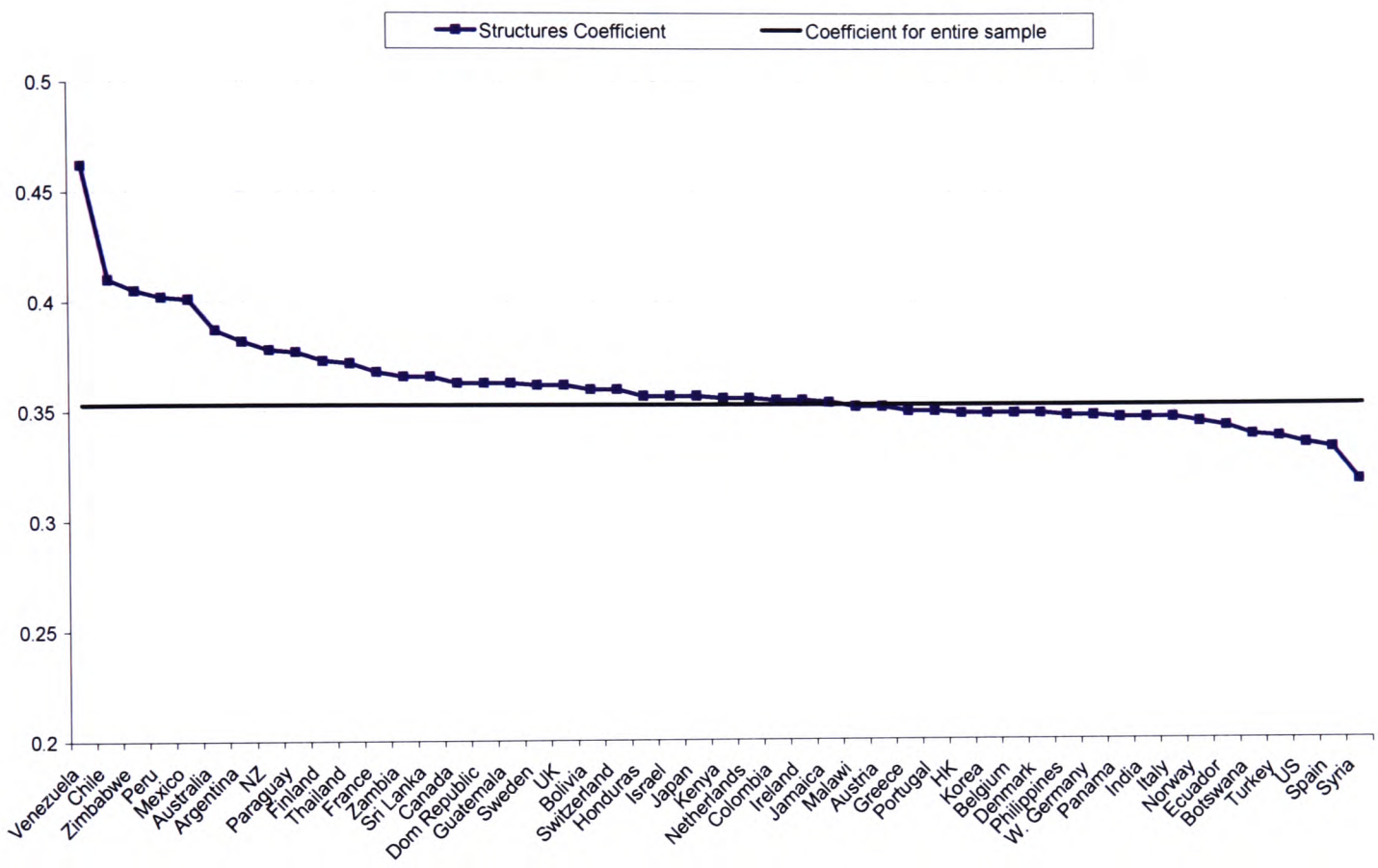

Figure 2.9: Sensitivity of structure coefficient to exclusion of countries from augmented Solow/MRW specification.

The graph above shows the same calculation for the structures coefficient. In this case, the outliers at the higher end of the scale are rather more numerous, but the great majority of countries have little or not effect on the estimates when they are removed from the sample. Excluding all but the top three outlying countries at the left of the scale confines the coefficients to a range between 0.3 and 0.4. Again, Venezuela is an outlier for reasons which are not immediately apparent. The

Venezuelan economy is dominated by the petroleum and agricultural sectors, and it is possible that this resource-rich and rather unbalanced profile may drive some of the results. Paraguay also features as an outlier for both equipment and for structures and Oulton and Young (1996) discuss some unusual features of the Penn World Tables for this particular country which suggest that data problems may be responsible for its effect on coefficient estimates [66].

The graphs below perform the same calculation for the stock regressions.

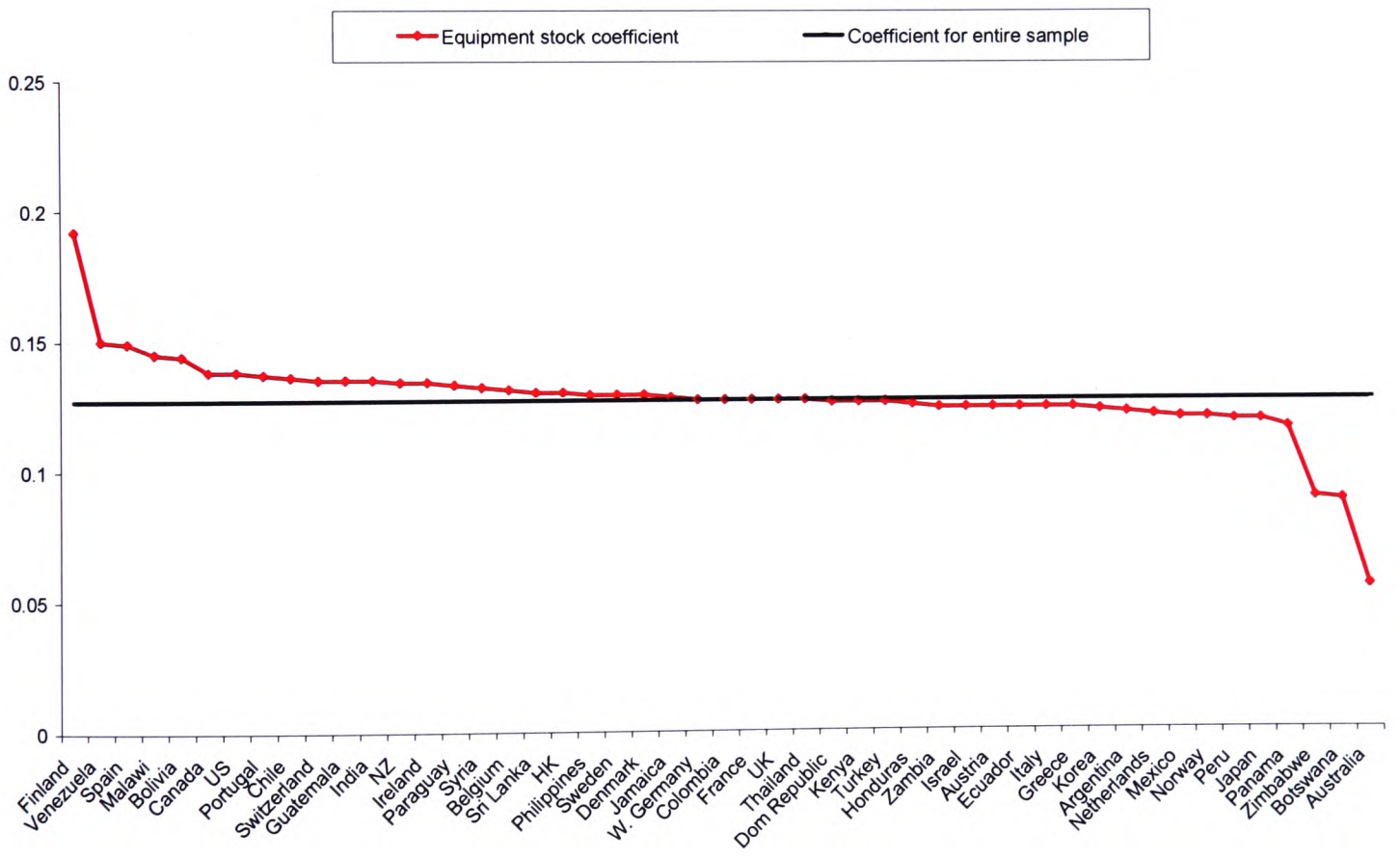

Figure 2.10: Sensitivity of equipment coefficient to exclusion of countries from production function/stock specification.

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66 However, since the definition of capital stocks differs between that of Oulton and Young (1996) and this chapter, the reasons for those authors excluding this country do not automatically apply to this chapter. It is still nevertheless worth noting that the data for Paraguay appears to be of poor quality.

Again, Venezuela is conspicuous as an outlier on this graph, perhaps suggesting some problems with that country's reported data. Likewise, the other outliers on the left side of the scale are not as sharply different from the overall regression coefficient and are therefore perhaps less in need of explanation. However another significant feature of this graph is the precipitous drop in the coefficient that occurs when Australia is removed from the sample. The reasons for this are not clear, especially since the diagnostics for Australia do not indicate any particular issue or suggest any reasons for this effect, although like Venezuela the relatively resource intensive nature of the economy may explain some the discrepancy. Similarly, the economy of Botswana, another outlier, is also heavily dependent on resource intensive activity (notably the diamond sector).

The evidence from the testing on the structures coefficient presents a graph which is very similar to that for equipment, although in this case the "outlying" countries and the country ordering are different, although Turkey Syria, Venezuela and Zimbabwe again appear as outliers. Most of the coefficients are in a very narrow range from approximately 0.25 to approximately 0.28; the lower values to the right of the scale (again including Australia and Botswana) are very close to the .25 limit.

On the basis of these results, the estimated coefficients do not appear to be unduly influenced by the presence of individual countries, although there are some outlying countries which, when excluded appear to reduce the overall coefficient.

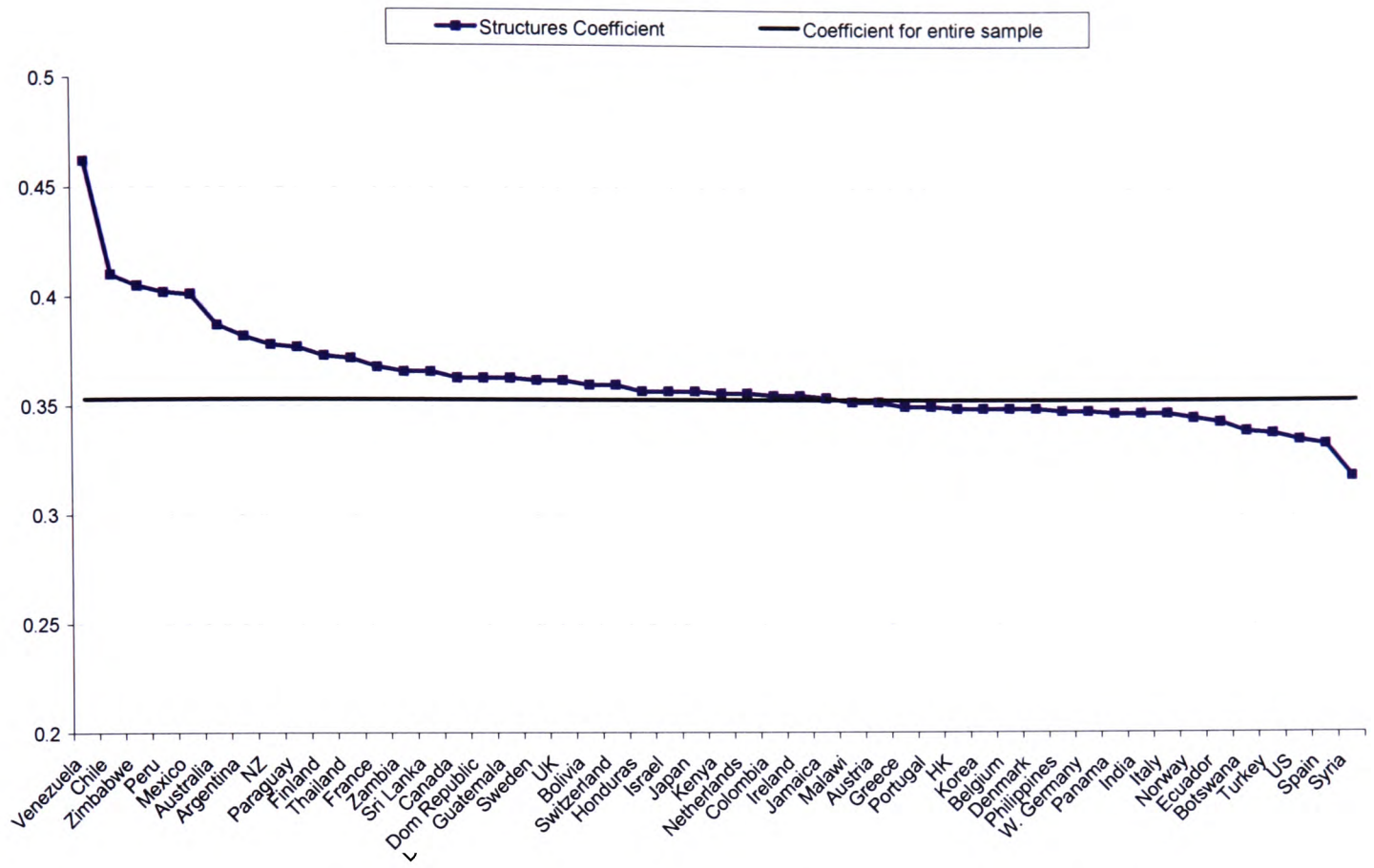

Figure 2.11: Sensitivity of structure coefficient to exclusion of countries from production function/stock specification.

The next steps undertaken to examine the robustness of the regressions examined the effect of excluding groups of countries.

It is entirely possible that there may exist groups of countries which are constituted by links other than those defined by continental location. However, the underlying relationships which determine these linkages may not be apparent to the econometrician undertaking an exercise of this nature, and a pragmatic strategy suggests, in the present case at hand at least, a parsimonious strategy of selecting countries on the basis of geographic classifications. Another reason for selecting groups of the basis of geography is the finding of Koop, Osiewalski and Steel (2000) that variation

in efficiency is much greater between continents than within continents. This supports the intuition that similarities between countries are likely to reflect underlying regional variables, such as the effects of geography, political institutions, trade blocs, and so forth[67]. In other words, splitting the sample along regional lines is likely to be a sensible simple strategy for the purposes of sensitivity analysis.

The tables below summarize the estimated coefficients on both the equipment and the structures variables for both modeling approaches. The first table shows the results from the augmented Solow/MRW approach.

For the purposes of comparison, the last line of the table above shows the estimated coefficient for the entire sample (that is, no countries are excluded). Excluding the Central and South American countries causes the biggest deviation from the entire sample results. It is possible that equipment investment is especially important in this region of the world, and hence excluding them lowers the estimated coefficient. This is at least consistent with the idea that equipment investment is more beneficial in developing countries, although the effect of excluding African countries is so small which somewhat weakens that argument.

The following table shows the results for the production function/stock results:

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[67] Of course, the division of countries into developed and developing contains a certain geographic element, as most of developing countries in the sample are located in Western Europe, and many of the developing countries are located in the Southern hemisphere.

Countries excluded	No. of countries excluded	Machinery	Structures
African	5	0.083	0.263
Central American	6	0.125	0.227
US and Canada	2	0.149	0.278
South American	8	0.168	0.373
Asian	9	0.129	0.061
Australia and NZ	2	0.057	0.247
European	17	0.012	0.094
None; entire sample	0	0.127	0.268

Figure 2.12: The effect of the exclusion of groups of countries from the augmented Solow/MRW specification.

This table reveals that excluding the five African countries and the two antipodean countries approximately halves the coefficient on equipment investment. Australia was identified as something of an outlier in the graphs above, so perhaps this result is not entirely surprising. Excluding the wealthy North American economies of the US and Canada has the anticipated effect of increasing the coefficient on equipment, but the more dramatic and perplexing result is that excluding the European countries greatly reduces the size of the coefficient; in part, this is likely to reflect within-continent heterogeneity, and the presence of apparently outlying countries such as Spain and Finland (the effect of excluding these countries was displayed above) . This effect may also partly explain the coefficient on the antipodean coun-

Countries excluded	No. of countries excluded	Machinery	Structures
African	5	0.237	0.381
Central American	6	0.19	0.396
US and Canada	2	0.217	0.343
South American	8	0.168	0.62
Asian	9	0.27	0.343
Australia and NZ	2	0.21	0.535
European	17	0.36	0.119
None; entire sample	0	0.238	0.353

Figure 2.13: The effect of the exclusion of groups of countries from the production function/stock specification.

tries, but leave unexplained why this effect is not observed for . The structures coefficient is more stable, except when the Asian countries are excluded. This variable also jumps rather sharply when the South American countries are excluded.

These results demonstrate that the results appear to be reasonably robust to the exclusion of individual countries, although the exclusion of some groups had a rather marked effect on the coefficients. This is somewhat encouraging for a sample which contains such a wide variety of countries at different stages of development.

2.5 Conclusion

This chapter sought to contribute to the current literature on growth and equipment investment by being one of the few papers to study the topic in a panel data setting. It was the first paper using panel data analysis to study the equipment investment-growth relationship using annual data instead of five or ten year periods, and it was also the first to use recently developed techniques for modeling both slope and intercept heterogeneity. It studied a proximate growth determinant (equipment being a form of capital input) and demonstrated that the claims made in some of the earlier literature on behalf of the "special" and unique growth-enhancing characteristics of equipment investment may be misplaced. In that sense, the findings of this chapter are consistent with those of Oulton and Young (1996), as well as more generally articles such as King and Levine's (1994) rejection of "capital fundamentalism" and Easterly and Levine's (2001) finding that important stylized growth facts do not depend on factor accumulation.

This chapter found that equipment investment did indeed appear to have explanatory power for growth, but most importantly, the long-run coefficient estimates for structures seemed to be somewhat more important for long-run growth in the sample as a whole than did equipment investment, in the sense that the output elasticity of structures was higher than for equipment in some PMG specifications. This is contrary to what has been found thus far in the cross-sectional and fixed effect panel literature. An encouraging feature of the results in this chapter is that, while

the PMG estimates suggested that structures investment was (relatively) more important for the sample as a whole, this result also encompassed (to a certain extent) the fixed effects literature which found instead that equipment investment was relatively more important. This finding was robust to the exclusion from the sample of both individual countries and groups of countries. This chapter also replicated the finding in the literature that equipment investment appears to be more important for growth in developing than in developed countries. This consistency with earlier results is reassuring.

However, one must exercise caution in drawing strong conclusions (and attendant policy implications) from these findings. A major cause of the difference between this chapter's findings and some of the rest of the literature is probably related to sample selection issues. Both De Long and Summers (1991) and Temple (1998) were able to consider a broader sample of countries (up to 78 in Temple), especially developing countries, because their cross-sectional work did not need to rely on the existence of continuous time series data on equipment and structures investment. Therefore, it is not inconceivable that the developing countries that were selected for my sample shared many of the characteristics of the equipment-growth relationship that developed countries possessed. For example, it is important to bear in mind the qualifications of work such as Temple and Voth (1998), which suggests that the equipment investment-growth correlation may actually reflect a concurrent process of industrialization. In other words, the correlation between growth and

equipment might in fact be driven by a separate underlying process. Estimated returns to equipment investment differed depending on countries included in the calculation, and the econometric specification relied upon to develop coefficient estimates used as an input into these calculations.

Nevertheless, this chapter has contributed to this debate by introducing new and arguably more appropriate econometric techniques to the debate. At a minimum, this chapter has shown that dynamics and heterogeneity should be afforded prominent positions in accounts of economic growth, and it shifts the burden of proof onto future researchers who would otherwise seek to overlook these influences.

2.A Appendix 1: A graphical representation of heterogeneity in the equipment-growth relationship

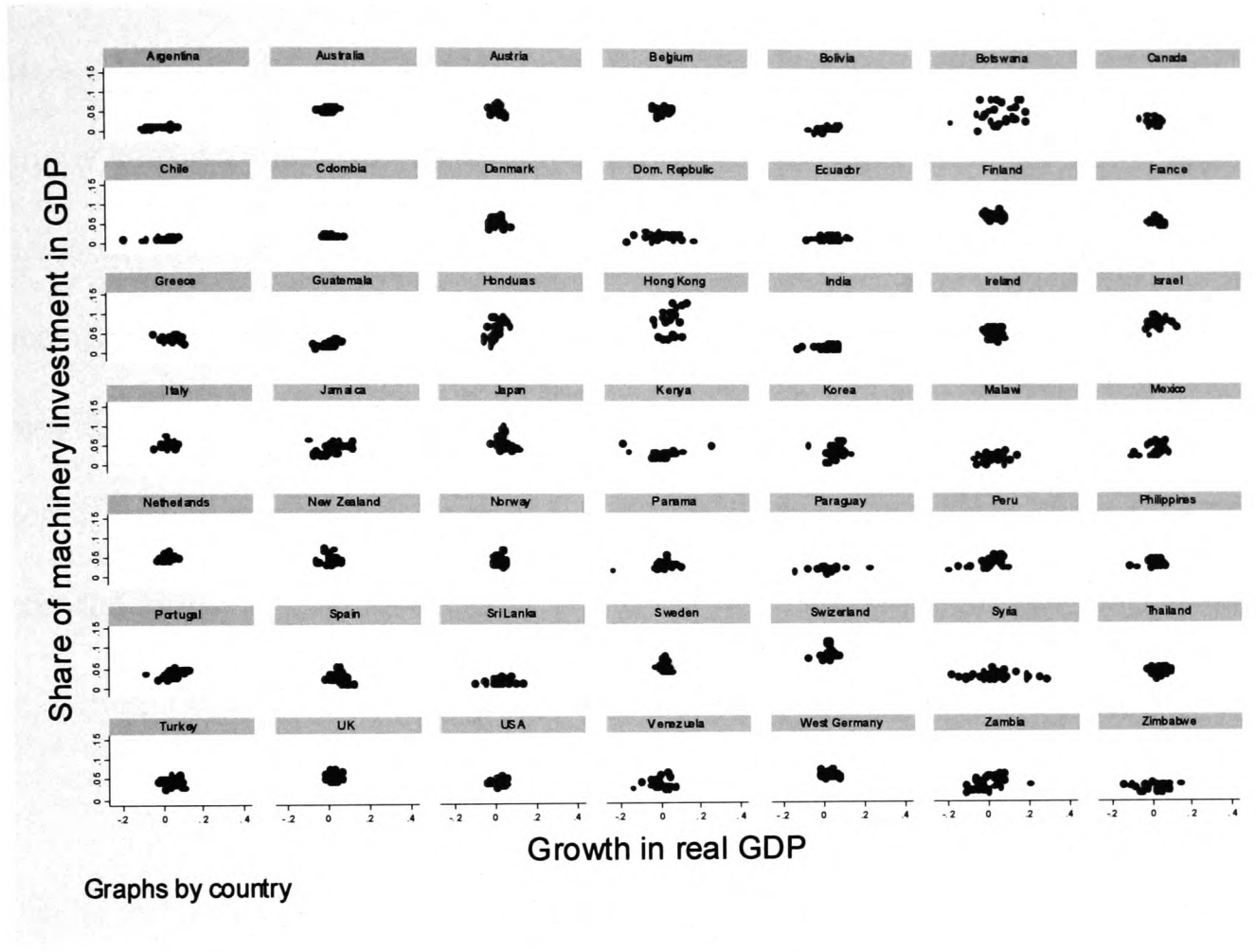

Figure 2.14: The relationship between per capita GDP growth and equipment investment in 49 countries, 1960-1990.

This graph shows, in a simple manner, the variety of relationships which exist in the sample between the share of equipment investment in GDP and GDP growth.

2.B Appendix 2: An example of inconsistency arising from the neglect of heterogeneity.

To see how inconsistencies may arise from ignoring heterogeneity, it is useful to briefly consider the following example arising in the context of a pooled regression, based on the examples in Pesaran and Smith(1995). Suppose data are generated according to a set of micro-relationships which have coefficients that are constant over time but differ randomly across groups. The parameters of interest are the coefficients averaged over groups. A simple dynamic heterogeneous panel could take the form:

$$y_{it} = \lambda_i y_{i,t-1} + \beta_i' x_{it} + \varepsilon_{it} \tag{2.26}$$

$$i = 1, 2, ...N \tag{2.27}$$

$$t = 1, 2, ...T \tag{2.28}$$

where the coefficients λ_i and β_i are permitted to vary across groups through a random coefficient model:

$$\lambda_i = \lambda + \eta_{1i} \tag{2.29}$$

$$\beta_i = \beta + \eta_{2i} \tag{2.30}$$

where it is assumed that η_{2i} and η_{1i} have mean zero and constant covariances. Making certain assumptions, such as covariance stationarity and mean ergodicity of x_{it}, that the support of λ_i lies in the stable range and that the x_{it} are strictly exogenous (that is, x_{it} and ε_{is} are distributed independently for all t and s, the effects of heterogeneity on pooled estimators such as the widely used estimators described above such as LSDV, AH and GMM can be analyzed.

Consider a pooled model based on the micro-relations described above which includes an intercept term α:

$$y_{it} = \alpha_i + \lambda_i y_{i,t-1} + \beta_i' x_{it} + \upsilon_{it} \tag{2.31}$$

$$\upsilon_{it} = \varepsilon_{it} + \eta_{1i} y_{i,t-1} + \eta_{2i} x_{it} \tag{2.32}$$

Given the assumptions described above, it can be seen that $y_{i,t-1}$ and x_{it} are correlated with υ_{it} thus rendering pooled estimators inconsistent. To highlight this point, Pesaran and Smith consider the specific case of x_{it} being a scalar with zero mean and autocovariance $\gamma_i(s)$, we have

$$E(x_{it}\upsilon_{it}) = \sum_{j=0}^{\infty} E(\eta_{1i}\beta_i\lambda_i^j)\gamma_i(|j+1|) \tag{2.33}$$

$$E(y_{i,t-1}\upsilon_{it}) = \sum_{s=0}^{\infty}\sum_{r=0}^{\infty} E(\eta_{1i}\beta_i^2\lambda_i^{r+s})\gamma_i(|r-s|) + \sigma_i^2 \sum_{s=1}^{\infty} E(\eta_{1i}\lambda_i^{2s}) + \sum_{s=0}^{\infty} E(\eta_{2i}\beta_i\lambda_i^s)\gamma_i(|s+1|) \tag{2.34}$$

This implies that even if the x_{it}'s are not serially correlated, $E(y_{i,t-1}\upsilon_{it})$ will still be non-zero because of the second term. Pesaran and Smith (1995) argue that the usual means of correcting for serial correlation are unlikely to work because of the complexity of the process generating υ_{it} and that instrumental variables techniques will not be successful because of a lack of valid instruments. Instrumental variables estimation is not possible because the regressors all appear in υ_{it} so that anything that is correlated with the regressors will also be correlated with the error, leading to biased and consistent estimates of the parameters. The conclusion is that average effects in dynamic models with heterogeneous slopes cannot be estimated consistently even when T and N are large.

To understand the size of the likely biases and what it depends on, assume for simplicity that $\lambda_i = \lambda$, implying that $\eta_{1i} = 0, \forall i$. Suppose that

$$x_{it} = \rho x_{it-1} + u_{it} \tag{2.35}$$

$$u_{it} \sim (0, \tau_j^2) \tag{2.36}$$

Pesaran and Smith show that the inconsistencies arising from use of pooled estimators are potentially large. It can be shown that as

$$\rho \to \infty, plim(\hat{\beta}) \to 0 \tag{2.37}$$

This implies that the effect of the right hand side x variables are biased towards zero, while the coefficient on the lagged dependent variable is biased towards unity. Similarly, the long-run coefficients will be estimated inconsistently, since the long-run effect is $\frac{\hat{\beta}}{1-\hat{\lambda}}$ and both numerator and denominator tend to zero, meaning that the long-run coefficient will be computationally unstable.

2.C Appendix 3: Detailed diagnostic tables for baseline PMG specification for all countries

	Std. error	CH-SC[1]	CH-FF[4]	CH-NO[3]	CH-HE[4]	RBARSQ	LL
Botswana	0.058	1.9	5.54	1.25	0.2	0.49	48.9
Kenya	0.049	0.02	1.25	2.12	0.36	0.56	54.07
Malawi	0.05	0.53	1.39	0.77	1.16	0.05	53.5
Zambia	0.06	0.84	0.06	2.62	1.35	0.06	47.88
Zimbabwe	0.049	1.8	1.27	1.93	0	0.4	53.82
Canada	0.013	3.63	0.32	0.64	0.28	0.69	94.7
Dom. Republic	0.04	0.77	1.26	0.37	0.27	0.61	59.92
Guatemala	0.012	0.66	2.75	1.23	0.31	0.73	96.09
Honduras	0.026	0.42	11.33	1.8	0.51	0.1	73.05
Jamaica	0.042	0.07	4.73	0.5	0.81	0.26	58.38
Mexico	0.02	2.83	0.61	0.88	1.24	0.67	80.33
Panama	0.035	2.78	17.55	10.9	26	0.59	63.79
US	0.013	0.52	0.02	3.31	0.09	0.74	94.82
Argentina	0.029	0.09	1.83	1.62	1.01	0.63	69.97
Bolivia	0.022	9.35	4.85	0.76	0.02	0.37	77.39
Chile	0.046	1.87	5.6	0.52	0.46	0.42	55.97
Colombia	0.014	0.28	4.66	0.05	0.1	0.51	92.65
Ecuador	0.032	0.02	0.08	0.85	0.06	0.48	66.72
Paraguay	0.053	0.03	4.78	16.57	1.54	0.09	51.63
Peru	0.039	1.65	7.62	0.28	1.1	0.62	60.96
Venezuela	0.031	4.58	1.79	0.23	4.36	0.41	67.64
Hong Kong	0.026	8.26	1.55	0.72	0.06	0.55	72.92
India	0.047	0.43	9.68	0.09	2.77	0.27	55.35
Israel	0.024	0.26	1.12	1.41	0.5	0.5	75.64
Japan	0.017	4.05	6.04	2.52	0.3	0.57	84.99
Korea	0.036	1.19	0.02	6.09	4.12	0.35	63.58
Philippines	0.021	0.7	9.97	0.85	0.31	0.64	79.81
Sri Lanka	0.044	0.07	0.28	8.07	0.15	0.29	57.09
Syria	0.107	0.59	4.86	1.48	0.15	0.05	30.64
Thailand	0.028	3.08	0.03	2.18	0.2	0.42	70.81
Austria	0.013	3.05	4.75	1.49	0.3	0.23	92.95
Belgium	0.013	2.46	3.01	0.98	0.48	0.36	93.26
Denmark	0.012	8.37	5.82	0.05	0.7	0.81	97.3
Finland	0.02	1.53	1.03	0.67	3.26	0.53	81.2
France	0.009	0.04	1.82	0.53	0.44	0.43	104.59
W. Germany	0.011	0.8	0.79	4.34	0.97	0.69	99.29
Greece	0.021	5.86	0.04	0.56	0.56	0.59	79.93
Ireland	0.018	1.68	3.23	0.41	0.1	0.42	83.72
Italy	0.014	1.65	0.42	3.81	1.28	0.6	91.36
Netherlands	0.011	0.1	0.83	0.01	1.3	0.48	99.71
Norway	0.015	0.19	0.03	0.41	5.64	0.46	89.08
Portugal	0.028	7.35	3.81	1.55	2.25	0.52	71
Spain	0.012	0.21	0.81	1.15	0.46	0.82	96.42
Sweden	0.011	6.07	0.76	0.94	0.37	0.65	97.49
Switzerland	0.013	7.8	1.91	0.58	0.39	0.64	94.02
Turkey	0.032	1.19	0.06	6.65	1.49	0.25	66.74
UK	0.015	13.3	0.16	0.1	1.03	0.63	89
Australia	0.012	8.6	0.15	1.13	0.56	0.78	95.79
NZ	0.017	0.09	0.06	12.61	1.41	0.62	84.88

1 Godfrey's test of residual serial correlation. The statistic is asymptotically distributed as Chi^2 with one degree of freedom under the null hypothesis of no serial correlation. Critical value is 3.84 at 5% and 6.3 at 1%

2 Ramsey's test of functional form. The statistic is asymptotically distributed as Chi^2 with one degree of freedom under the null hypothesis of no misspecification. Critical value is 3.84 at 5% and 6.3 at 1%

3 Jarque-Bera test of normality. The statistic is asymptotically distributed as Chi^2 with two degrees of freedom under the null hypothesis of no non-normality. Critical value is 5.99 at 5% and 9.21 at 1%

4 Lagrange multiplier test of homoskedasticity. The statistic is asymptotically distributed as Chi^2 with one degree of freedom under the null hypothesis of no heterodkeasticity. Critical value is 3.84 at 5% and 6.3 at 1%

Figure 2.15: Regression diagnostics for PMG estimates of augmented Solow/MRW specification for entire sample.

	Std. error	CH-SC[1]	CH-FF[2]	CH-NO[3]	CH-HE[4]	RBARSQ	LL
Botswana	0.121	1.58	20.59	9.55	1.31	0.53	26.92
Kenya	0.048	1.19	0.55	34.28	0.02	0.59	54.62
Malawi	0.047	2.57	0.26	2.16	0.45	0.16	55.08
Zambia	0.046	0.99	5.29	9.07	0.11	0.45	55.81
Zimbabwe	0.042	5.82	1.18	0.63	1.21	0.49	58.92
Canada	0.014	0.26	4.64	0.25	0.08	0.53	90.62
Dom. Republic	0.036	0.31	4.79	0.72	0.25	0.69	62.98
Guatemal	0.015	0.27	0.34	0.46	0.15	0.56	89.67
Honduras	0.023	0.2	3.9	1.1	0.56	0.36	77.31
Jamaica	0.036	4.04	0.12	13.66	0.02	0.42	63.48
Mexico	0.024	0.45	5.57	1.24	0.7	0.59	75.88
Panama	0.047	1.99	18.42	24.72	18.69	0.26	54.96
US	0.015	0.83	0.26	1.98	0.24	0.62	90.41
Argentina	0.028	1.02	7.19	1.13	0.09	0.65	70.65
Bolivia	0.018	4.24	0.85	1.45	0.46	0.56	83.99
Chile	0.048	14.3	5.38	4.18	0.75	0.38	54.59
Colombia	0.015	2.64	1.73	0.24	0.05	0.16	89.4
Ecuador	0.027	0.13	1.01	1.04	0.12	0.63	72.35
Paraguay	0.032	2.44	4.94	3.32	5.12	0.68	66.81
Peru	0.034	6.08	7.75	0.94	0.08	0.7	65.21
Venezuela	0.023	7.68	0.53	16.3	1.15	0.65	77.11
Hong Kong	0.028	0.09	0.17	2.33	0.88	0.44	70.35
India	0.041	0.01	10.75	0	5.02	0.46	59.45
Israel	0.015	4.22	0	0.08	0.04	0.81	89.95
Japan	0.014	1.61	1.4	0.65	0.28	0.76	91.21
Korea	0.024	0.69	12.07	0.03	1.13	0.67	75.39
Philippines	0.022	1.33	5.61	0.16	0.04	0.59	78.41
Sri Lanka	0.034	0.04	0.62	0.69	0.09	0.54	64.57
Syria	0.065	0.52	0.21	1.24	1.07	0.65	45.56
Thailand	0.02	3.52	0.61	1.39	0	0.67	80.46
Austria	0.013	7.64	5.25	1.34	0.84	0.3	94.4
Belgium	0.011	4.96	0.62	0.53	0.52	0.52	97.61
Denmark	0.009	0.32	10.41	2.23	2.4	0.88	104.45
Finland	0.012	0.31	1.23	5.9	1.39	0.84	97.26
France	0.009	0.72	0.37	1.32	1.5	0.61	105.97
West Germany	0.011	0.06	3.01	1.53	0.44	0.69	97.68
Greece	0.018	0.29	2.63	0.27	0.11	0.68	83.32
Ireland	0.022	0.02	2.81	1.77	1.2	0.12	78.06
Italy	0.014	6.08	0.88	0.35	0.68	0.63	92.43
Netherlands	0.012	4.01	0.91	0.18	1.4	0.37	95.2
Norway	0.013	0.07	3.52	1.62	0.45	0.52	92.75
Portugal	0.025	2.35	0.13	0.24	0.07	0.34	74.23
Spain	0.012	0.14	3.51	0.01	1.32	0.8	96.34
Sweden	0.016	0.08	2.52	1.19	0.18	0.21	86.88
Switzerland	0.012	0.23	0	4.35	0.3	0.8	97.17
Turkey	0.027	0.5	0.32	1.72	1.27	0.49	72.25
UK	0.019	0.27	0.02	1.8	3.27	0.46	83.08
Australia	0.013	0.49	0.02	1.55	2.08	0.73	93.04
NZ	0.023	0.74	1.39	0.44	6.07	0.43	76.71

1 Godfrey's test of residual serial correlation. The statistic is asymptotically distributed as Chi^2 with one degree of freedom under the null hypothesis of no serial correlation. Critical value is 3.84 at 5% and 6.3 at 1%

2 Ramsey's test of functional form. The statistic is asymptotically distributed as Chi^2 with one degree of freedom under the null hypothesis of no misspecification. Critical value is 3.84 at 5% and 6.3 at 1%

3 Jarque-Bera test of normality. The statistic is asymptotically distributed as Chi^2 with two degrees of freedom under the null hypothesis of no non-normality. Critical value is 5.99 at 5% and 9.21 at 1%

4 Lagrange multiplier test of homoskedasticity. The statistic is asymptotically distributed as Chi^2 with one degree of freedom under the null hypothesis of no heterodkeasticity. Critical value is 3.84 at 5% and 6.3 at 1%

Figure 2.16: Regression diagnostics for PMG estimates of augmented stock/production function specification for entire sample.

Chapter 3
Did Labour Institutions Contribute to the Golden Age of Economic Growth?

3.1 Introduction

This chapter studies the so-called "Golden Age" of economic growth, an episode that is seen as having taken place in many developed economies over the period from the end of the second World War until the first oil price shock in 1973. More specifically, this chapter contributes to the literature on this important topic by using a new dataset, encompassing twenty countries[68] and spanning the years from 1960 to 1998, relating to labour institutions and macroeconomic shocks to test the hypothesis that domestic labour institutions played an important role in creating and sustaining the rapid growth witnessed in many of the economies of the industrial world after the war. In particular, the game-theoretic contribution of Cameron and Wallace (2002) and narrative and empirical contributions due to Eichengreen (see for example, Eichengreen,1996 and 2004 and Eichengreen and Iversen, 1999) are used as a basis to jointly model labour institutions and growth in a twenty country panel which spans the years from 1960 and 1998[69]. The work of Cameron and Wallace

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[68] Australia, Austria, Belgium, Canada, Denmark, Finland, France, West Germany, Ireland, Italy, Japan, Netherlands, Norway, New Zealand, Portugal, Spain, Sweden, Switzerland, UK, and US.

[69] For two countries, Germany and Portugal, the data does not include all of the years from 1960 to 1998, and therefore the panel is unbalanced. This is discussed in more detail in the data appendix at

and of Eichengreen is used to identify variables suitable for inclusion in the empirical model, to develop and test hypotheses concerning the relationship between these institutions and growth, and to interpret the outcome of the results from the empirical modeling.

Below, basic macroeconomic features that are conventionally seen has having defined this era are introduced, and the arguments for regarding this period as being a unique episode in the economic history of the industrialized economies of Western Europe, North America and Japan are examined. The literature concerned with finding explanations for this period of exceptional growth and development is then reviewed. The following section then describes the approach of this chapter to the understanding of economic growth during this period, after which results from the estimation of theoretical models are presented and analysed.

3.1.1 The Idea of the Golden Age

Macroeconomic performance throughout the OECD was exceptional in the thirty year period following the cessation of hostilities in continental Europe. Inflation was low, economic growth was rapid, investment rates high, and total factor productivity advanced at unprecedented rates. Data from Maddison (1995) shows that the period from 1950 to 1973 was characterized by growth rates that were neither observed before this period or repeated subsequently. Output expanded in Western Europe by

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the end of this chapter.

0.9% per annum on average over the period from 1820 to 1870, by 1.3% on average from 1870-1913, 1.2% from 1913 to 1950, 3.8% from 1950 to 1973, and finally 1.8% from 1973 to 1992.

Crafts and Toniolo (1996) characterize the period from 1913 to 1973 as being exceptional in the history of "modern economic growth" because of the prolonged underperformance from 1913 to 1945, which was followed by a period of sustained overperformance (1945-1973). Unsurprisingly, economists and historians have christened this period with names that indicate its unique character, such as the aforementioned Golden Age of economic growth, *les Trente Glorieuses*, and *Das Wirtschaftswunder*. Crafts and Toniolo (1996) also make clear that the "conventional periodization" of the Golden Age that is based on these dates does not precisely conform with the distinct experiences of individual countries. Moreover, there was a fair degree of variability in macroeconomic performance between economies. Despite these qualifications, it still seems legitimate to identify this period as being a unique and important episode in modern economic history and accordingly one that deserves close scrutiny.

This stellar growth performance must have seemed extremely unlikely to observers assessing economic prospects from the viewpoint of 1945. Aside from the considerable political uncertainty engendered by the collapse of pre-war domestic and international political structures, and the menacing presence of the Red Army in continental Europe, production was stagnant and trade had all but collapsed. Indus-

trial production stood at 40% of prewar levels in Belgium, France and the Netherlands and less than 20% in Germany and Italy.

By 1947, there were signs of recovery throughout the continent in industrial and agricultural production. This gradual recovery in economic growth was seen by the Allied countries as giving western Europe the necessary economic and political power to deal with the burgeoning problem of an increasingly influential Soviet Union, as well as playing an essential role in resurrecting normal social relations within and between countries (Eichengreen and Iversen, 1999). However, the nascent recovery of 1947 soon faltered, and the hitherto rapid rise in production slowed and the major economies suffered from open and repressed inflation, raw material shortages and a lack of foreign exchange (Eichengreen, 1995). Economists writing on the 1947 recovery and slump began to revisit the pessimistic themes of Samuelson (1943) and other economists writing during the war, who had predicted that the destabilizing forces which manifested themselves after the first World War would re-appear, and that the prospects for economic growth and recovery were poor (Temin, 2002).

Yet in 1948 recovery and structural adjustment commenced once again, and were to continue for the next twenty years in a fashion that was "...unmatched in its prior or subsequent history" (Eichengreen, 1995). There have been no shortage of accounts seeking to explain this post-1948 growth, and the next section of the chapter reviews the existing approaches.

3.2 Explanations of the Golden Age - A Review of the Literature

3.2.1 Introduction

Broadly speaking, in the literature one may identify four main approaches to the study of the Golden Age. These approaches may be distinguished by their different explanations for the rise and fall of the Golden Age, and can be conveniently summarized as being based on theories of :

- the advent and success of Keynesian style demand management policies, including the effects of export led growth and activist government policy in a number of spheres of economic life. This was a popular explanation for the high growth rates during the Golden Age, reflecting the wide spread acceptance of what may be called conventional Keynesian orthodoxy.

- the expansionary effect of postwar reconstruction, a view based on the belief that growth was induced in war-damaged economies by a recovery of human and physical capital levels to more "normal" prewar levels.

- the enhanced opportunities for the redeployment of factor resources, especially the availability of a large supply of labour, and the concomitant structural change which this redeployment induced in national economies. Other supply influences such as, inter alia, the exhaustion of catch up

potential and the impact of increases in the price of oil, often figure in these commentaries.

- the effect of both domestic and international institutions, especially new institutional arrangements in domestic labour markets which are perceived as being influential in solving commitment problems between the owners of capital and labour. Internationally, the existence of the Bretton Woods exchange rate system coincided closely with the dates bracketing the beginning and end of the Golden Age, while the European Payments Union and Marshall Plan seen as playing a critical role in restoring stability and boosting growth in postwar Europe, while the General Agreement on Trade and Tariffs (GATT) was an ongoing support to the recovering world economy.

It should be noted that theories described under individual headings contain elements, to a greater or lesser extent, of complementary explanations. Before reviewing these theories, it is useful to consider the criteria upon which one should rely in evaluating any explanation for the exceptional economic performance that characterized the Golden Age. As Eichengreen (1996), Temple (2001) and Temin (2002) make clear, any theory of post-war growth must be capable of describing not only the remarkable expansionary phase of that era, but also the differences between countries in their own individual experiences, as well as the subsequent slowdown and failure to recover to Golden Age growth rates. As will be clear from the review below, not

all of the approaches listed above can be regarded as being satisfactory when assessed against these criteria.

On the other hand, it is likely to be the case that elements of different theories contain valid explanations for the rise and fall of the Golden Age, and therefore it is likely to be very difficult to construct an empirical model which allows for and encompasses all of these contributory factors. Accordingly, the criteria for assessing the merits of different explanations listed above may be too severe in a context in which the object of the investigation is not to advance the case for one particular theory over all others, but merely to examine whether any particular theory itself possesses any merit when assessed on its own terms. This chapter is a contribution which does not purport to provide an all-encompassing explanation for the Golden Age; instead, it has the more limited aim of examining whether the theories of Cameron and Wallace and of Eichengreen are capable of explaining any part of the growth performance of the Golden Age, and thereby to further advance knowledge in this area by being the first contribution to this literature to apply a systems estimator approach to a new panel dataset of institutions and macroeconomic shocks.

3.2.2 Demand management and Keynesian policy

The success of activist Keynesian style demand policies were long a popular and widely endorsed explanation for the economic success of the postwar period; indeed, De Long (1996) refers to this period as the "Great Keynesian Boom". The rapid and

apparently complete adoption in a number of diverse countries of the central tenets of Keynesian orthodoxy, as embodied in the adoption of fixed exchange rates under Bretton Woods, and the stated desire of many governments to overcome unwanted fluctuations in economic circumstances by fine-tuning various policy instruments, persuaded many observers that enlightened government intervention was responsible for the exceptional economic success of this era.

This type of argument is well summarized by the claim of Boltho (1982) that "...it was government policies that bore an important responsibility for the acceleration in growth that took place...what launched Europe on to a higher growth trend were primarily new economic policies, domestic as well as international". Bispham and Boltho (1982) argue that the implementation of demand management policies in the 1950s and 1960s was characterized by three major differences between the prewar and the postwar period. The first major break with the past was the greater level and significance of government spending and revenues, which, they argued, increased the importance of automatic stabilizers. The second difference with interwar policies was the acceptance by governments that budget deficits were an acceptable policy tool and not an indication of irresponsible public excess. The final change, according to Bispham and Boltho (1982), was the willingness of governments to engage in discretionary counter-cyclical fine tuning[70].

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[70] Needless to say, there are several studies which support contrary arguments. Griliches (1992) suggests that the increased economic significance of the services sector in the postwar period contributed to reduced postwar macroeconomic volatility, whereas Romer (1986) argued that the reduction in relative volatility is in some measure due to data mismeasurement. Romer's (1986) thesis is that the

The work of Boltho (1982) is particularly closely associated with the Keynesian explanation for the Golden Age, so it is worth examining his arguments in more detail. The success of governments in adhering to Keynesian policies, especially the advent of the Bretton Woods fixed exchange rate system, and the use of the three novel policy measures described above and the successful management of interest rates played, according to Bispham and Boltho (1982), "a key role in avoiding for a quarter century any major setback". Once growth was started, confidence grew and positive expectations about future prospects became self-fulfilling. Boltho attributes the high investment rates of this era to the success of the innovative Keynesian policies described above in reinforcing those expectations, and these high investment rates in turn boosted growth. Geroski and Walters (1995) find that between 1948 and 1983 economic activity Granger caused innovative activity (rather than vice versa) and this lends a measure of support to the idea that "momentum" was important for economic performance in that period.

However, the precise contribution of these new activist policies to rapid growth is highly contentious. Econometrically identifying the effect of such policies and simultaneously accounting for the influence of other macroeconomic conditions and the critical role of the expectations that features so prominently in Boltho's account is an extremely difficult endeavour, and the analysis in Boltho (1982) and Boltho and

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apparent greater success of post-war policies in stabilizing the US economic cycle, compared to the period from 1914 to the second world war, was actually a figment of the data; in other words, the post war period was not necessarily any more successful in terms of stabilization than was the interwar period.

Bispham (1982) does little to conclusively settle this issue. For instance, Norway and Sweden, both long seen as exemplar embodiments of Keynesian doctrine, both ran budget surpluses of over 3% during their most rapid growth phases, although it is true that the share of public expenditure as a percentage of GDP also rose sharply in both countries. Boltho's (1982) explanation for the end of the Golden Age is that the gradual attainment of full employment meant that labour was increasingly in a position to exploit its "monopolistic" position.

It is unclear why the Keynesian policies that were so successful in generating rapid growth in the fifties and sixties failed to continue to be successful in the new macroeconomic environment of the 1970s (on this point, see Eichengreen, 1996 and De Long, 1996). Cameron and Wallace (2002) argue that demand side explanations for the Golden Age fail because they do not explain why the fall of the price of oil in the mid-1980s and the more appropriate (that is, appropriate to the circumstances) demand management policies of the 80s and 90s did not lead to a revival of Golden Age macroeconomic performance.

Crafts and Toniolo (1996) also argue that the demand approach ignores the supply side developments that are normally a prominent feature of theories of economic growth. They argue that important supply side influences are ignored in this account, such as the much greater ease with which technology could be diffused from the leading industrial nations to those countries away from the technological frontier in the post-war era as compared to the interwar period. Indeed, Boltho (1996) read-

ily admits that seeking an explanation for long-run growth in demand management policies is "heretical" since neoclassical growth models, which are typically relied upon to explain growth, are almost exclusively supply side explanations.

Moreover, the increasingly open nature of the world economy during this period may indeed have been the result of farsighted government policy in establishing institutional arrangements that facilitated trade and global macroeconomic stability, but such policies were distinct from the activist fine tuning approach which Keynesian economists emphasized as being important in this period. Eichengreen (1996) also argues that Boltho overstated the prevalence of Keynesian policies in the 1950s in Europe, and again asserts that the major defect of the demand approach is that it is unable to account for the subsequent failure of Keynesian doctrine to overcome the 1970s slowdown.

In relation to the export hypothesis, one observes that the role of exports features prominently in another related Keynesian demand-side explanation for the rise of the Golden Age. Beckerman (1962), Lamfalussy (1963), and Thirlwall (1979) argue that, during this period, virtuous circles of increasing exports increased investment, which in turn boosted growth. Exports are accorded a special position within these Keynesian explanations of economic growth because exports are regarded here as being the element of demand with the highest "multiplier" effect on national income. Exports are also seen as beneficial because they have the lowest "import content" of all elements of demand and therefore may be used to finance the pur-

chase of those imports that are essential for growth. Exports are regarded as being a source of demand that is independent of domestic market conditions; they have special significance for countries overcoming the disadvantages of a small or stagnant domestic market[71].

This line of reasoning relates to Hicks (1950) notion of the "supermultiplier", in which the growth rate is closely connected to the growth rate of the largest element of autonomous demand, which, in the case of an open economy, would be exports (see the discussion in Thirlwall, 2000, and Cardoso and Soukiazis, 2003).

This line of argument is heavily influenced by the work of Kaldor (1966), who argued that an increase in exports boosts industrial output, which, through the operation of Verdoorn's Law[72], increases labour productivity. This improved labour productivity enhances export competitiveness, creates a virtuous circle and reinforces the favorable positions of regions and countries with initial competitive advantages. Thirwall (1979) built on these ideas by developing a more rigorous model of balance-of-payments constrained growth, starting from the position that no country can grow faster than the rate consistent with balance-of payments equilibrium on the current account, unless countries can finance ever increasing current account deficits.

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[71] Although not directly related to the Golden Age literature, Ben David (1993) demonstrates that episodes of post-war trade liberalization in the EEC were associated with income convergence across countries.

[72] Verdoorn's Law (which was stated for the first time in1949, an English translation of the original article is Verdoorn, 1993), postulates a positive relationship between the rate of growth of productivity and the rate of growth of output

Boltho (1996) also considers another and related example of interventionist policy from this period: the role of undervalued exchange rates in the Bretton Woods system. The flexibility of the Bretton Woods system is contrasted with the inflexibility and overvaluations that characterized the interwar return to the gold standard. The commitment to the gold standard made external adjustment impossible, and placed an excessive burden on local citizens to bear the politically destabilizing internal costs of adjustment. Conversely, undervalued exchange rates existed for long periods under Bretton Woods because of the special conditions associated with the Bretton Woods system, such as the hegemonic position of the US and the impulse to create institutional arrangements that would help avoid the chaos of the interwar period. Boltho studies the extent to which devaluations and undervaluations had long term as well as short term impacts on growth.

Again, this account relies on the familiar Keynesian mechanism of the creation of virtuous circles, in which undervalued or devalued exchange rates boosted exports, and increased investment and growth. Boltho suggests that these positive demand side developments could have induced favorable responses on the supply side, such as the creation and exploitation of scale economies and higher labour productivity levels. However, Boltho's case studies on Germany and Italy in the 1950s and France and Spain in the 1960s, do not, as the author acknowledges, provide any clear cut answers.

The export-led growth hypothesis has been criticized on a number of grounds. Crafts and Toniolo (1996) point out that the balance-of-payments disequilibria that feature prominently in the explanations of Beckerman (1962) and Thirlwall(1979) depend on the absence of the price effects that correct disequilibria in neoclassical models, as well as on the existence of real wage rigidity. The export-led hypothesis does not suggest any explanations for the end of the Golden Age era. Since the growth of exports in unexplained (except as being a consequence of growth in foreign demand, which is itself unexplained), the theory fails to encompass the rise and decline of the exceptional growth rates of the postwar era. Moreover, Verdoorn's Law has been extensively investigated and tested, but definitive conclusions as to its generality and importance have been lacking.

Returning to the more general export-led growth story, Krugman's (1980) model suggests a radically different role for exports in growth, in which it is output growth that causes exports, rather than vice versa, and therefore Krugman's model reverses the direction of causation found in Thirlwall (1979, and 2000). Krugman argues that trade among industrial countries does not necessarily reflect country specific comparative advantages, but is instead due to countries taking advantage of scale economies along different dimensions. Growing countries are in a position to expand the range of their outputs and therefore their exports, and this is the way in which countries capture world market share. If all the Golden Age countries were growing because of exports, then their terms of trade would fall (assuming a Hecksher-Olin

type world). The fact that the terms of trade in these countries didn't fall suggests that quality and market size effects arising in a world of imperfect competition were actually the primary driving force behind positive correlations between exports and growth[73].

3.2.3 The war reconstruction hypothesis

The war reconstruction thesis has been advanced by a number of authors, such as Janossy (1971), Dumke (1990), Craft and Mills (1996) and Smolny (2000) and others but is perhaps most associated with the work of Janossy (1971) and Dumke (1990) and it is therefore worth reviewing in more detail the contributions made by these two authors.

Janossy's (1971) influential work argued that human capital and physical capital formation is responsible for long-run growth, so that individual countries face a growth path determined by stable growth in human and physical capital. A major shock to capital accumulation, such as a war, need not have major consequences for long-run growth since levels of knowledge and technological innovations made elsewhere are available for exploitation once growth begins to re-attain its normal growth path. More formally, when the ratio of human to physical capital is disproportionately high according to the historical experience of a particular country, then

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[73] Houthakker and Magee (1969), a seminal piece of research in this area showed how, even if all countries were growing and inflating at the same rate, there would still be disparities in trade balances because of differences in the income elasticity in demand for exports.

one can expect a rapid movement back to the long-run growth path after a major shock. In this view, the long-run growth rate is seen as a trend stationary process, so that shocks only cause temporary and not permanent deviations in trend growth. The rise and fall of the Golden Age is therefore nothing other than the exploitation and ultimate exhaustion of reconstruction growth.

Two papers by Crafts and Mills (1996 and 2000) investigated these claims using modern time series techniques. The findings of Crafts and Mills (1996) provide only a limited degree of support for the Janossy hypothesis. They find no evidence of a constant, historically normal growth rate that is a merely a simple function of growth in physical and human capital. For instance, in only two out of the seventeen countries in the Maddison (1991) dataset which Crafts and Mills (1996) use do these authors find evidence that post World War II growth returned to the rate observed in the pre-1914 period. On the other hand, four countries in this sample did emerge from the second World War with higher growth rates than those enjoyed before the first World War. However, they do support the notion that the effect of reconstruction efforts was to speed the transition of national economies back to a more familiar growth rate, although this reconstruction effect was less important than the convergence and catch-up effects familiar from standard neoclassical growth accounts. Nevertheless, Crafts and Mills (1996) do argue that the contribution of reconstruction growth influences should be included in any analysis of postwar growth.

Simple trend stationarity is rejected in Crafts and Mills (2000), but they do find evidence that OECD output can be well characterized as a segmented trend stationary process with several important turning points, with the Golden Age being an example of one such break. Using a dataset of sixteen countries updated from their 1996 paper, they find evidence for the Janossy hypothesis in only three OECD countries. St. Aubyn (1999) does however find evidence of a structural break after World War Two in GDP per head across 16 industrialised countries by examining date from 1890 to 1989. Overall, the simple form of the Janossy hypothesis has not received a great deal of unambiguous support under careful econometric testing, but it has been influential in pointing the way to future researchers to elaborate and improve upon the basic reconstruction story.

Dumke (1990) was another important contribution to the debate on the importance of reconstruction effects in postwar OECD growth. Dumke focused mainly on West Germany, but also studied, in less detail, the growth of 16 other OECD economies. Dumke places a great deal of emphasis on "potential output", which, as in Janossy (1971), is defined by the historical growth experience of a country. International trade plays a role by helping to spread technological innovations from the US, a country which is seen as not having a significant gap between potential and actual output, and this diffusion of international best practices is absorbed by high levels of complementary domestic human capital, and thereby creates a virtuous circle of increasing investment in physical capital and of growth. He studied the time

series evidence for this thesis by estimating a regression model which models the growth in real GDP as being a function of real GDP in 1950, the difference between GDP in 1948 and 1938, this difference squared, and the share of labour in agriculture, and his results lend support to his thesis. The ability of this theory to explain cross-country differences in national growth rates is questionable, however.

Dumke placed particular emphasis on the interesting case of the "Wirtschaftwunder" in West Germany. Dumke's work was motivated in part by the observation of Abramovitz (1986) that although a great deal of physical capital were resources were annihilated in the war, the so-called "social capability" from growth remained high. In the words of Barro (1989), the ratio of human capital to physical capital was unusually high, thereby suggesting that subsequent growth is likely to feature high levels of investment and rapid growth in per capita income. This great disparity between the social capability of growth, and the actual physical resources available to attain that growth, lie at the centre of the was reconstruction thesis. This is a story that is very similar to that of Janossy, except that Dumke asserts that reconstruction and the technology gap arguments are complementary explanations, especially for those countries most severely damaged during the war, such as Germany, Japan, Austria and Italy.

While the model certainly appears to successfully explain the West German Wirtschaftwunder, and perhaps also the experience of countries like Italy and Japan, it does not have very much to say about the case of the UK for instance, which ex-

perienced great destruction of its physical capital stock but not the massive growth rates enjoyed by West Germany[74]. One possible explanation for the UK performance may be the lack of opportunities for reallocation out of agriculture and into industry. While Dumke's model does include a term for the labour share in agriculture, which would account for some part of British performance, it is not clear why the gap between potential and actual output was not enough to overcome the growth disadvantages of having a low share of labour in agriculture.

Smolny (2000) updates the work of both Janossy (1971) and Dumke (1990), but with a closer emphasis on the role of convergence and the evidence of labour productivity. He starts from the standard Janossy position that the destruction of productive capabilities involved a deviation from steady states, and therefore at least part of the Golden Age growth rates are attributable to the return to steady state growth rates. He further notes that technological development did not stop during the war, and that the rapid growth of the postwar era further improved the economic environment for high physical capital investment and research and development activities. Growth in the "reconstruction era" of 1947 to 1950 is strongly correlated with the extent of wartime damage (see also Craft and Toniolo (1996)), and he contrasts the experience in this regard of Germany and Austria on the hand, and to that of the US and Canada on the other to make this point. Moreover, labour productivity data show that the fastest growing countries over the following period from 1951 to 1988 were again

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[74] It is however worth pointing out that Germany endured greater destruction of its capital stock than did the UK

exactly those countries which had suffered the most extensive physical damage during the war - Japan, Italy, Austria, and Germany. The wartime gap (measured by the difference in GDP between 1938 and 1947) explains 80% of the variance of growth in the "reconstruction" phase of 1947 to 1950.

What explains this? Smolny's explanation is that an environment favorable for high rates of investment laid the foundations for continued economic growth afterwards. This effect was strengthened by the fact that technological potentials acquired during the war years were still, Smolny claims, above actual levels of production by the early fifties. Smolny's central thesis is therefore that those countries which were most damaged required the most reconstruction to return to steady state growth rates. This massive push to rebuild destroyed physical capital created a favorable momentum which sustained high rates of investment long after the reconstruction itself had ended. Therefore, reconstruction growth was helpful in starting the process of growth, but it was the convergence of TFP levels due to international technological diffusion, and the "catch-up" of technological potential and that caused high growth after 1950.

3.2.4 Structural change and reallocation

Theories based on the availability of opportunities for redeployment of labour have long featured prominently in explanations of both post-war economic growth and of economic development more generally. For instance, Kindleberger (1967) used

the influential Lewis (1954) model of excess of labour supply to describe both the positive growth experience of this era and the differences between countries in the postwar period. Kindleberger contended that an elastic supply of labour contributed to growth during this period by repressing wages and promoting peaceful relations between labour and capital. The end of the Golden Age, in this view, was induced by the diminishing pool of available labour which was reflected in the increasingly tight labour markets of the late 1960s in the OECD economies, and by the increased militancy of organized labour which sought to secure a greater share of national income.

This account was updated and extended by Temin (2002), who argued that the Golden Age was indeed the result of factor re-allocation, including labour redeployment, but enriched Kindleberger's explanation by also considering the effects of initial conditions, in order to permit a role for convergence, and by examining the effect of disequilibrium more generally. Temin argues that the Golden Age's initial growth impetus stemmed from the exploitation of re-established trade opportunities that had been occluded and even destroyed by the two world wars and the intervening worldwide economic depression; clearly, there are some similarities and linkages between this theory and the war reconstruction hypothesis. This process of expanding encouraged re-allocation of labour away from agriculture into more productive activities, thereby creating permanent structural change in national economies.

As Eichengreen (2004) points out, by the end of the second World War, the average European worker was much less productive working in agriculture as opposed to industry, with the exception of highly industrialized Britain (where much labour reallocation had taken place in the nineteenth century) and the Benelux countries, who had already specialized in high value added varieties of farming. The developmental deficit that Temin emphasizes is distinct from the convergence effect familiar from the modern literature on economic growth. Instead, this deficit is not due to low levels of capital or labour, but is rather due to a misallocation of resources.

Temple (2001) assess the quantitative importance of this labour re-allocation effect. By deriving empirical bounds to marginal product differentials between the agricultural and non-agricultural sectors for the USA and the major European economies, he is able to quantify the contribution of structural change to the TFP residual as measured from conventional growth accounting. He finds that structural change directly accounted for between 5% and 14% for his sample. The model also accords well with the predictions of Kindleberger (1967), in that the effect is smallest in those countries that had already experienced major labour force re-allocation before the war. Temple finds that reallocation was particularly important for Germany and Italy in the 1950s and to a lesser extent in France; after 1960 reallocation was important for Spain and again for Italy. For some countries, this reallocation effect had disappeared by the 1970s, which suggests that it may explain some of the post-1973 productivity slowdown, although Temple finds that the influence of reallocation on

the productivity slowdown was very modest, thereby suggesting the reasons for the decline are to be found elsewhere.

Returning to Temin's (2001) explanation, cross-country differences in economic attainment are therefore explained both by initial conditions and by the willingness of countries to engage in international trade and otherwise liberalize their economy to take advantage of global economic developments. This emphasis on openness improves on Kindleberger's (1967) model in that it allows for a richer explanation of cross-country differences; for example, Ireland enjoyed a highly elastic labour in the 1950s to the extent that there was massive emigration of labour from Ireland in this period, but did not enjoy the stellar economic performance that Kindleberger's model would have predicted. Instead, the autarkic nature of the Irish economy in this period and its dismal economic performance appears to lend support to Temin's richer theory.

Initial conditions also play a role in this theory - the comparatively poor performance of Britain in this period, for example, is explained by the model as being a consequence of the fact that much of Britain's structural re-allocation of labour away from agriculture took place in the nineteenth century, which diminished the possibility of rapid growth in the postwar growth. Moreover, the standard neoclassical convergence effect familiar from the modern empirical literature on economic growth was not likely to have as great effect in Britain compared to other countries because of its initial position at the end of the war as a developed wealthy economy.

A similar argument can be made with respect to the performance of the US economy in this period compared to the more rapid growth enjoyed by mainland Europe and by Japan.

Temin attributes the decline of the Golden Age to the end of the disequilibrium that had generated rapid growth. As the development deficit was overcome and structural re-allocations rendered largely complete, the opportunities for exceptional rates of expansion were limited. For instance, as the excess supply of labour was absorbed and labour forces began to exhibit the same per capita quantity and quality of human capital as the leading nations, opportunities for further spectacular growth advances were limited. As Craft and Toniolo (1996) make clear, convergence is not an automatic process, and "The peculiar economic institutional and political economic circumstances created by the Great Depression , autarky, war and reconstruction were particularly favorable to postwar European growth in general and catch-up in particular".

3.2.5 Domestic and international institutions

Introduction

The institutional approach to the Golden Age focuses on both domestic and international institutions. This section of the literature review first considers the role of the new international institutions, and then studies in greater the depth the literature on the newly created postwar domestic institutions. The new international

institutional arrangements included the Marshall Plan, the Bretton Woods system, the GATT, the European Payments Union, and the European Coal and Steel Community. Historians in particular have emphasized the positive contribution of these institutions to establishing security and trade in Europe, and therefore creating the conditions for a favorable macroeconomic climate. At this point, it is perhaps worth briefly considering and defining what is meant by the term "institutions".

North (1990) defined institutions as the "humanly defined constraints that shape human interaction". They matter for economic outcomes because institutions play a key role in defining the incentives faced by economic actors, including decisions on the organization of production, investment in technology and on the accumulation of physical and human capital (Acemoglu, Johnson and Robinson, 2005). Indeed, Acemoglu *et al.* argue that a fundamental tenet of economic history is that the way humans decide to organize their societies determines potential economic growth performance and the distribution of resources in the future. Extending arguments that have been made by economists and philosophers for centuries, they suggest that societies are economically successful when they design appropriate institutions, and it is those institutions that are the fundamental cause of economic prosperity. North (1990) suggested that weak institutions affect overall economic growth by reducing the efficiency of investment. Persson and Tabellini (2000) argue that growth can be reduced to an accumulation decision on the part of private individuals. Therefore,

anything that affects this decision will impact on growth in an either permanent or in a temporary fashion (depending on the specification of the production technology).

International institutions

Traditionally, economists have tended to emphasize the importance of domestic institutions over international institutions. Berger and Ritschl (1995) summarize the skepticism with international institutions by identifying two problems with the view that the new international institutions were predominantly responsible for postwar economic success. The first is that aid under the Marshall Plan was very small in relation to output, and that most of the payments came after rapid growth had already commenced. As Collins and Rodrik (1991) point out, Marshall aid averaged only 2.5% of the combined national incomes of recipient countries for the four year period in which the $13 billion of US grant aid was distributed. The second point is that rapid growth was pervasive throughout Europe, including countries which enjoyed less assistance under the Marshall Plan or which otherwise did not participate fully in the newly created institutions. For example, the German economy began to grow rapidly at this time, but received a comparatively low share of total available Marshall aid funds.

Temin (2002) takes these points further by arguing that the historians view "does not distinguish between different countries in Western Europe because the international agreements...include all the countries". While it is true that the terms

of the some of international agreements did differ between countries (notably the Marshall Plan, where the level of funds distributed differed drastically across the European countries), and that some countries were more likely to benefit from fixed exchange rates and shared production of steel and coal than others, the point remains that relying on international agreements to explain differences between countries is unlikely to be successful, given how similar the terms and effects of membership were on participating countries.

Milward (1984) argues that the Marshall Plan was unimportant when assessed against the possibility for reconstruction and catch-up growth. It is also not clear how one can account for the end of the Golden Age by relying solely on the contribution of international institutions. While it is true that the beginning and end of the Bretton Woods systems corresponds closely to the start and end dates of the Golden Age, it is unclear in such accounts why the end of this particular arrangement dominated the continued existence and strengthening of other institutions such as the nascent European Community and ongoing and intensifying negotiations on GATT.

However, a new view of the effect of these postwar international arrangements, especially the role of the Marshall Plan, which is associated primarily with the work of Barry Eichengreen (see, in particular, Eichengreen and Uzan 1992, and Eichengreen 1995, 1996 and 2004), has begun to question the comparative neglect in the economics literature on the role of international institutions. The new view argues that the primary effect of new institutions such as the Marshall Plan, Bretton Woods

and the European Payments Union was to create a political atmosphere that was favorable for growth.

Eichengreen starts from the position that the proximate cause of high growth in postwar Europe was high investment, which, as we saw above, was nearly twice as high in the fifties and sixties as any period before or after. The domestic institutional developments that facilitated these high investment rates are discussed below, but Eichengreen sees the Marshall Plan and other international arrangements as having provided a vital initial impulse to early postwar growth. Eichengreen is in agreement with the proposition that the direct effect of the Marshall Plan was small. He accepts that the influence of the aid through the direct channels of aiding capital formation was relatively unimportant. Instead, the contribution of the Marshall Plan is more subtle and its influence is closely connected to the unique economic problems facing Europe at this time. In general terms, Eichengreen and Uzan (1992) see the economic problem of Europe in the immediate postwar period as being one of "marketability". In the mid-to late forties, three major obstacles (Eichengreen, 2004) existed in hindered the ability of farmers, producers, workers and other economic actors to bring their factor supplies to the market.

The primary problem was a fundamental issue which was of first-order importance: essential resources in Europe were in short supply. Reserve holdings of dollars were soon exhausted in the post war period as countries imported capital goods from the US to redevelop vital infrastructure services. Germany had long provided

much of Europe's steel and other heavy industry requirements, but was under occupation and operating far below full capacity. A second problem was the pervasive use of price controls. The market economy had not been successfully re-established anywhere in Europe, meaning that producers and consumers could not use the information on prices to guide their supply and demand decisions. Hoarding and reliance on the black market became common and governments increasingly financed deficits by printing money.

The third problem was more political in nature. By 1947, Communists were in control of key positions of the coalition governments in France and Italy, and radical left-wingers featured prominently in the governments of many other countries, and worker militancy was increasing (Eichengreen and Iversen, 1999). There was concern in the US and in Europe that the continent was extremely vulnerable to invasion and occupation from the Soviet Union. This political uncertainty affected workers as well as producers, who entertained legitimate worries that the fruits of their labour and investments could be appropriated or inflated away. All of these problems increased the uncertainty associated with investment, with returning to work, and with reducing hoarded stocks of raw materials. Maddison (1991) also notes the clear preference for *dirigiste* policies on the part of many European governments in the aftermath of the war.

The Marshall Plan, according to Eichengreen, solved all of these problems more or less simultaneously. The balance-of-payments constraint was sharply re-

duced by the opportunity to use the newly available funds to finance the purchase of needed imports. This effect went a long way towards relieving resource bottlenecks. The problem of the abolition of the command economy and its replacement with a reconstituted and functioning market economy was facilitated by the bilateral treaties signed by the US and recipient countries. By signing these bilateral treaties, the recipient countries undertook to introduce the prerequisites of a market economy, which included the relaxation and abandonment of price controls, the stabilization of exchange rates, and balanced budgets (Eichengreen, 2004).

The US also exerted a strong anti-protectionist influence over policy at this time (Maddison, 1991). This greatly aided in reducing political uncertainty, as the bilateral treaties signaled a clear commitment to a market oriented economy. French (1948) and Italian (1947) communists resigned from their respective national governments on the acceptance of the Marshall Plan. The USSR refused to accept Marshall aid on the grounds that it would not countenance foreign interference in its economy, and it used its political influence in Central and Eastern Europe to prevent other countries such as Poland and Czechoslovakia from making requests for Marshall aid.

The effect of the Marshall Plan was therefore to help European economies reach their underlying growth path more quickly than otherwise. Eichengreen and Uzan (1992) also suggest that its absence may have lead to a widespread political collapse and a dangerous weakening of commitment to market forces. Viewed in this light, it played an essential role in getting Europe growing again. As such,

emphasizing the Marshall Plan does not offer, nor does it purport to offer, a complete explanation of the rise and fall of the Golden Age. However, it is likely that some of the cross-country differences in observed growth patterns are attributable in part to the different implementations and adaptions of the institutions in different countries. Eichengreen and Uzan (1992) accept that the Marshall Plan probably did not have long-run growth effects, but that it may have given Europe an incentive to shift to a high investment, deferred compensation equilibrium, and this point will be expanded upon in more detail below[75].

Domestic institutions, high investment, and growth

As noted in the introduction to this chapter, high investment was a feature of the Golden Age. In the words of Eichengreen and Vasquez (1999), "In a postwar context characterized by severe capital shortage and a backlog of unexploited technologies,

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[75] Before going on to examine the role of domestic institutions in postwar growth, it is also worthwhile to briefly review the contributions of other international institutions during this period. In addition to the Marshall Plan, the European Payments Union is seen as playing a similar role to the American aid package in that it facilitated the recovery of the market system in Europe. The European Payments Union replaced various bilateral trade agreements with a multi-lateral framework that allowed for clearing, trade credit (thereby enabling temporary trade deficits to be financed) and trade liberalization. the net balance of each country with other countries was reported to the Bank for International Settlements, which cancelled offsetting claims (see Eichengreen, 2004 and Eichengreen and Uzan, 1992). The Payments Union was, as Eichengreen (2004) notes, an important stepping stone towards collective governance, a development very much favoured and encouraged by the American authorities. This trend was to continue with the formation of the European Coal and Steel Community, which gave further impetus to the increasing openness of European economies, a process itself aided by ongoing negotiations on GATT. The exports of western European countries rose by over 8% a year on average in the fifties and sixties. These international institutions allowed countries to overcome the disadvantages of small domestic market size, to specialize according to comparative advantage, to permit productive investment, and to allocate resources to those sectors where such resources could be most productively used. (Eichengreen, 1996). This line of reasoning parallels that of Temin's (2002) model of structural change, in which closed economies missed out on the rapid growth occurring elsewhere because the pressure of competitive international markets did not exist to encourage the transfer of labour out of agriculture.

investment was the one indispensable ingredient for growth". In turn, high investment was facilitated by wage moderation and export growth, which, as Eichengreen (1996) notes, stands in contrast to the interwar period when world trade collapsed and labour became increasingly militant. The question then arises: what caused wage moderation, export growth and ultimately high investment?

The postwar international arrangements discussed above certainly helped with stabilizing the nascent postwar market economy and GATT, Bretton Woods, the EPU and the successor treaties to the European Coal and Steel Community all helped international trade to grow rapidly. Eichengreen has written extensively of the role played by domestic institutional structures that were complementary to the these new international institutions. New domestic arrangements were complementary in the sense that the newly evolved labour market institutions solved coordination and communication problems between the owners of capital and labour in a way that encouraged workers to accept moderate wage increases in return for high rates of productive investment, which was itself in turn facilitated by the international institutions.

Eichengreen takes his starting point from the models of Lancaster (1973), Grout (1984) and van der Ploeg (1987), who consider the dynamic interaction between owners of capital and owners of labour. In these models, overall welfare is maximized for each group when capital owners and workers both agree to sacrifice current consumption for future consumption. This means workers accept only moderate increases in wages, while capital owners agree to limit dividend payments and instead use prof-

its to fund productive investment. Both groups benefit from this higher investment in the future in the form of higher wages and profits. In this equilibrium, the benefits of higher income in the future dominates the benefits of increased consumption now.

However, each party faces incentives to renege on the agreement. After the firm has restrained dividend payments and committed to productive investment, workers may act opportunistically and demand higher wages once the investment is sunk. This behaviour will be especially problematic if the investment involves specificity. Specificity relates to the degree to which an investment or asset would lose its value if directed to another use (see Hart, 1995 for an exposition of the general problem as it applies to the design of contract, institutions and in other economic contexts).

As Caballero and Hammour (1997) explain "In the absence of complete and binding contract, investment specificity gives rise to quasi-rents that are appropriable by workers who may engage in opportunistic behaviour". The prospect of opportunism weakens or even destroys the firm's incentives to invest. Cabellero and Hammour (1997) further note that capital appropriation will encourage the exclusion of labour from joint production processes by choosing more capital intensive technologies, increasing the amount of capital in the economy thereby and reducing the marginal product of capital. This effect will also work to diminish investment incentives.

On the other hand, firms themselves may act opportunistically by exploiting the willingness of workers to accept moderate wage increases by failing to reinvest dividends after workers have agreed to a conservative pay bargain. A solution to problems of this nature is to provide the participating parties with appropriate incentives. It is a major theme of Eichengreen's work that newly evolved domestic labour market institutions effectively constituted a binding contract to invest and restrain wages and thereby provided the appropriate incentives to capital and labour owners in the aftermath of the second World War.

These new institutions bonded together labour and capital by offering concessions and incentives to each party to the bargain. For instance, Eichengreen (1996) describes the welfare state as serving as bond that would be forfeited by labour in the event of opportunistic behaviour manifested in the form of excessive wage demands. In this scenario, improvements in areas such as increased protection for sick leave, unemployment benefits and protected working practices all cooled worker militancy and encouraged the acceptance of slow wage growth.

A clear example of this line of reasoning is the adoption by the first postwar Belgian government of a social security scheme in exchange for labour's adherence to the 1944 Social Pact, which limited wage increases. The Norwegian and Danish governments undertook similar measures immediately after the war (Eichengreen, 2004). Holland and Sweden also adopted explicit policy measures to restrain wage growth. Moreover, the institutions monitored compliance of each party to the con-

tract. A famous and influential example of this is the German Co-Determination Law of 1951, which explicitly gave workers an input into the investment decisions of large firms. Similar developments appeared in Holland, Austria, Norway and to a lesser degree in France (Eichengreen, 1996).

Another important institutional development was the rise of centralized collective bargaining for the setting of wages. Collective bargaining in conjunction with the existence of large unions encouraged wage restraint because participants to the negotiations were able to perceive more clearly the implications of excessive wage demands on investment and government financed social security programmes (see Calmfors and Driffill, 1988 and Alesina and Summers, 1993). Moreover, Eichengreen points out that workers could see the benefits of reduced wages in the form of higher investment and ultimately higher wages flowing as higher profits entered the capital market and were distributed throughout the economy. Economy-wide setting of wages also reduced the possibility that firms could face surplus appropriation by opportunistic workers.

Unique circumstances also supported the operation of these institutions (Eichengreen and Iversen, 1999). These historically specific conditions included the great scope for growth at the beginning of this period, migration from Eastern Europe and a generally elastic labour supply, and a homogenous workforce working on what Eichengreen and Iversen refer to as the Fordist mode of production. This involved semi-skilled male labourers working on mass production assembly lines; in the words

of Eichengreen and Iversen (1999), manufacturers "...merely had to import technologies of mass production from the United States and to apply to them substantial inputs of capital and semi-skilled labour".

Institutional implementation and execution displayed significant cross country differences, and this is regarded as having being an important determinant of differences in national growth rates. Eichengreen (1996) characterizes France, Italy, Ireland and the UK as having initially lacked the centralized policies required to monitor and enforce wage bargains, although he does note that these countries increasingly came to rely on such arrangements. In general, the tendency was for all European countries to increase their degree of corporatism and centralization during the fifties and sixties. International institutions also monitored the activities of member countries with the aim of increasing trade and hence productive investment. The ECSC monitored the trade policies of its members. The EPU had the ability to punish countries violating its terms. Acceptance of Marshall aid entailed a host conditionalities, while membership of GATT implied increasing openness and both competition and cooperation between countries.

How does Eichengreen's institutional approach account for the end of the Golden Age? Eichengreen rejects the conventional view that labour market tightness had a significant role, citing evidence that many European labour markets in the early part of the fifties experienced inelastic labour supply, especially for skilled workers. One explanation, emphasized by Eichengreen and Iversen (1999), is the rise in demand for

skilled workers. This shift in labour demand away from the semi-skilled workforce, which had flourished under the Fordist mass production labour market, undermined the consensus between unions and firms that had played such a vital role in moderating wage growth and increasing investment after the war. The work of Aghion (2002) also contributes a useful insight into why the consensus may have weakened. Aghion's paper models wage dynamics and endogenous technical change with quality improving innovation (see Aghion and Howitt, 1992). When a new General Purpose Technology is developed and diffused, wage premia and hence inequality are likely to rise even if the supply of skilled labour is growing because demand for skilled labour is highest at the point at which the diffusion throughout the economy of the GPT begins to accelerate.

The consensus may also have been undermined by rising international capital mobility. In an increasingly small world, economic sanctions by unions could not be brought to bear on firms who wished to use their profits for purposes other than reinvestment, since such capital could be moved abroad with increasing ease by the early seventies. However, this theory has been criticized by Eichengreen (1996) and Thelen (1991) because the use of an exit option by firms should have encouraged the cooperation of labour. This suggests the need for a theoretical model which can model and allow for these complicated possibilities in a rigorous and consistent manner and such a model was provided by Cameron and Wallace (2002), which is discussed below.

Eichengreen (1996 and 2004) also discuss the possibility that the end of one prominent postwar international institution may have inaugurated the end of the high growth era. It is been hypothesized that the end of Bretton Woods destabilized price expectations on the part of workers and firms, who had grown used to the nominal anchor of constant par values. As Eichengreen (2004) notes, "So long as countries were committed to defending their exchange pegs, there was no possibility that they would succumb to sustained devaluation". This destabilization is sometimes believed to have caused an increase in union militancy and thereby undermined the postwar growth consensus.

However, it is as least as plausible that the chain of causality ran in the opposite direction, and that labour militancy, which became especially prominent in the late sixties, was the cause and not the consequence of the end of Bretton Woods. The oil shocks are sometimes seen as having finally persuaded workers to abandon the low wage consensus in favour of much greater pay increases, but as noted above, labour militancy became prominent in the late sixties, many years before the oil price increases occurred (Eichengreen, 1996).

Cameron and Wallace (2002) investigate further and more formally the possibility that a small change in economic circumstances may have tipped the balance in favour of higher wage rates and therefore away from the low wage-high investment equilibrium. This paper models the dynamic interaction between unions and firms as a coordination game and use global game arguments to discuss the equilibrium

selection problem. As Morris and Shin (2000) explain, global games analysis is especially well suited to situations where a player's payoffs depend on the player's own actions, the actions of other players, and unknown fundamental economic variables. Cameron and Wallace's model reveals that only small changes in economic circumstances are sufficient to change the equilibrium in the interaction between employers and unions from one of high investment/low wages to one of low investment/high wages. This model and its implications will be discussed in greater detail in the next section of this chapter.

A final question remains to be resolved at this point: why didn't the creatively designed postwar institutions reinvent themselves and adapt to the new economic climate of the seventies? Eichengreen (1996) suggests that the unique and exceptional circumstances constituted a once-off chance to forge new arrangements to overcome the political and economic difficulties witnessed in the thirties. This is certainly a plausible argument given the world-changing impact of the upheavals of the thirties and the catastrophes of the forties. These institutions were well adapted to the needs of a postwar world, but inertia, the absence of another major continent political wide convulsion, and perhaps the effect of capture (Olson, 1982) meant the institutions may have in some sense "overshot" their usefulness. The next section discusses how this chapter seeks to test some of the hypotheses of these authors, noting well Temin's (1997) criticism of work on the Golden Age, in which Temin bemoaned the lack of testing of Eichengreen's hypotheses.

3.2.6 Conclusion

This section of the chapter presented a literature review of explanations for the rise and fall of the Golden Age. Particular attention was paid to a body of explanations which have been the subject of almost no empirical testing; this set of explanations accounted for the rise and fall of the Golden Age by emphasizing the role played by newly constructed institutions which shaped behaviour in domestic economies. Specifically, labour market institutions have been advanced as a reason for the exceptional macroeconomic performance of the post-war era, and the next section of the chapter describes in detail how one might test the hypothesis that such institutions had a positive and material impact on economic growth in that period.

3.3 Approach of this chapter

3.3.1 Motivation

This chapter is the first work to utilize a newly created dataset of labour market institutions (Nickell and Nunziata, 2001) to study the influences of these institutions on Golden Age growth, and thereby to test the theories of Eichengreen and Cameron and Wallace (2002). There are several reasons for adopting such an approach.

The first reason for examining the effect of labour institutions is to test what may be called, based on the foregoing discussion, the Eichengreen hypothesis. The policy implications of results supporting Eichengreen's arguments are potentially

very significant, especially with regard to the design, creation and operation of labour markets policies and institutions. Interestingly, the other three explanations for macroeconomic performance which were discussed above have been the subject of far more empirical research than has the institutional labour market hypothesis. This is in part a consequence of the fact that the other theories have been present in the literature for a longer period of time. Indeed, as noted above, Temin's (1997) review of Eichengreen (1996) concludes that "Eichengreen's discussion of the institutions is necessarily both broad and brief; it is more hypothesis generation than hypothesis testing". The lack of testing is primarily due to lack of data; data appears to be more readily available to test other hypotheses regarding Golden Age growth. This chapter seeks to redress this imbalance and contributes to this literature by using the Nickell and Nunziata (2001) dataset, which is discussed in more detail in the Appendix to this chapter.

Another reason is that institutional variables have long been a feature of the modern empirical literature on economic growth, but many of these studies have suffered from a number of econometric problems, in addition to the types of more general econometric problems which appear in the growth literature and which were discussed in earlier chapters. Aron (2000) provides an excellent and comprehensive review of this literature, noting the poor quality with which the institutional variables are often measured. The institutional variables that have traditionally appeared in these studies are both numerous and distinct. As Aron notes, "...In the empirical

literature the terms politics and institutions encompass a wide range of indicators, including institutional quality (the enforcement of property rights), political instability (riots, coups, civil wars), characteristics of political regimes (elections, constitutions, executive powers), social capital (the extent of civic activity and organizations), and social characteristics (differences in income and in ethnic, religious, and historical background)". The quality of measurement of these variables, and their correspondence to meaningful underlying political and economic realities, is often questionable. This chapter seeks to improve on this state of affairs by utilizing a much more carefully measured and precisely defined institutional dataset. Whilst this chapter cannot claim some of the generality of previous studies on growth and institutions, it does seek to account for the relationship between growth and one particular set of institutions in a careful manner.

The treatment of investment by researchers studying the links between growth and institutions has been described by Aron (2000), Bassanini, Scarpetta and Hemmings(2001), and Alesina, Ozler, Roubini and Swagel (1996), amongst others, as being a particular problem in empirical work in this field. Therefore, an additional aim of this chapter is to address some of these problems. Investment may be defined as being the purchase of any asset or service that will result in higher production in the future (Stiroh, 2000). A typical growth regression might include both investment and measures of institutions (and policies) on the right hand side. However, the estimated coefficient on the institutional variables will only pick up part of their

influence on growth if they also exert a separate positive effect on growth through their positive influence on investment.

This is a fundamental part of many models on labour institutions and growth (especially those cited above), and seems both reasonable and very likely to be the case in practice. Therefore, the estimated coefficient on institutions will under-represent the impact of the particular institutional variable in such a growth regression. On the other hand, if an institutional variable has an independently positive effect on growth, but a negative effect on investment, then the coefficient on this variable in a growth equation that also includes investment as an independent variable will be biased upwards. Aron (2000) recommends the use of a separately specified investment equation to complement growth regressions in such a context and this approach is adopted here, and will be explained below.

Barro (1991), and some of the research that has followed in this tradition, has addressed this problem by leaving investment out of growth regressions and instead focusing on institutional and other variables. A problem with this approach, noted by Aron (2000) and Bassanini, Scarpetta and Hemmings (2001) is that it assumes that the included variables are not themselves driven by investment, and thus involves a fair amount of *a priori* reasoning to establish which variables are likely to be exempt from investment-driven influences. Bassanini, Scarpetta and Hemmings(2001) estimate separate growth and investment equations in their study of growth and institutions in the OECD. However, they do not consider any possible correlation between

the error terms in the two equations, and hence any improved efficiencies in estimation that may arise from using a systems estimator. Alesina, Ozler, Roubini and Swagel (1996) use a simultaneous equations approach to deal with this problem in their study of the relationship between growth and measures of political instability.

Endogeneity of institutional measures is another problem that is prevalent in this literature (Aron, 2000). While institutions can and often do remain unchanged over a number of years, it is also the case that they are altered in response to changes in macroeconomic performance and perhaps also levels of investment. Instrumentable variables are the conventional remedy to this econometric problem. Instrumental variables may take the form of lagged values of explanatory variables. In the case of institutional variables, it is not clear that this approach would be successful or indeed appropriate, since very long lags are likely to be required if institutional change is subject to major inertia, which seems likely to be the case. Belloc (2004) attempts to address this problem by proxying labour market institutions with political variables.

It is useful to briefly review a number of papers which adopt a similar approach to this chapter, in that they study explicitly institutions and growth in a multi-country framework. Eichengreen and Vasquez (1999) seeks to take Eichengreen's earlier theoretical and narrative work on the role of newly evolved international and domestic institutions to the data. This paper provides results of separate cross-sectional (year-averaged) models of investment, wage growth, export growth and GDP growth for 21 OECD countries for the period from 1950 to 1988. GDP growth is esti-

mated as a function of population growth, investment, investment variability, growth in investment and in exports, and the growth of intra-European trade. Investment is modeled as a function of GDP, the share of government consumption in GDP, the labor share, tax rates, political instability, the real interest rate, and the variability of labour costs. Exports are estimated as a function of GDP and investment variables, as well as variables capturing the effect of membership of international agreements such as the ECSC, and the EPU.

The cross-sectional models estimated by Eichengreen and Vasquez (1999) confirm the importance of the international institutions, but the limited data on domestic institutional arrangements means that the results are not capable of lending meaningful support to Eichengreen's hypotheses on the importance of labour market institutions. Moreover, it is questionable whether simple OLS specifications are capable of accurately capturing the complexity of the relationships under investigation.

Bassanini, Scarpetta and Hemmings (2001) include some limited institutional variables in a panel study of OECD growth. The purpose of the exercise is to uncover institutional influences on growth. A separate investment equation is also modeled, in part to overcome certain problematic assumptions of growth which were discussed above, but this investment equation is not estimated jointly with growth and therefore efficiencies in estimation from so doing are not obtained. GDP growth for 21 OECD countries is estimated as a function of human capital, the share of investment in GDP, and other measures that include the level and standard deviation of inflation, the share

of government consumption in GDP, measures of trade openness, the ratio of direct to indirect tax receipts, various measures of research and development, and measures of financial development. Investment is conceived as being a function of inflation, the government's share of capital formation and of consumption, financial development measures (such as stock market capitalization and the extent of credit extended by banks to the private sector), and trade openness.

Broadly speaking, their results support the inclusion of such variables in both the growth and investment equations. However, it is possible that their results do not establish the importance of institutions for growth, since many of their variables could conceivably be picking up the effects of changes in the business cycle, and not the effect of institutions *per se*. Variables in this category include the financial development measures, the share of both government consumption and investment, and the inflation measures. When viewed in this light, it is clear that these results do not provide a particularly persuasive perspective on the role of institutions in general and of domestic labour market institutions in particular.

3.3.2 Theoretical considerations

Having already reviewed in detail the arguments of Eichengreen, it is helpful at this point to examine Cameron and Wallace's theoretical formalization of Eichengreen's domestic labour institutions hypotheses. Cameron and Wallace (2002) study the interaction between firms and unions in the context of a coordination game. This

formalization of Eichengreen's work is useful because it makes specific predictions concerning the likely sign of certain labour market variables and these predictions are useful both for identifying the labour market variables that are likely to be important and which therefore should be included in any regressions, as well as for interpreting the outcomes of such regressions.

In the Cameron and Wallace model, firms are interested in the sum of discounted future profits. Unions are concerned with discounted total future wages. In the context of the particular coordination game they consider, it is profitable for the firm to invest if the union submits a moderate wage claim, but it is not profitable to do so if the union submits a high wage claim. If the unions knew with certainty that the firms would definitely engage in productive investment and avoid distributing large dividend payments, low wages are optimal from the point of view of the union. These two features of the game result in two pure strategy Nash equilibria. One equilibrium may be described as "good", and the other "bad". In the good equilibrium, the unions exercise wage restraint and investment is high. The bad equilibrium is characterized by a wage push on the part of unions, and low investment from firms. The authors demonstrate that the good equilibrium of wage restraint Pareto dominates the other equilibrium.

However, if one were to introduce global game considerations into the argument, a risk-dominant equilibrium would not necessarily correspond with the Pareto-dominant equilibrium of wage restraint and high investment. Cameron and Wallace

show that which of the two equilibria is chosen can be shown to reduce to an important selection condition. The authors demonstrate that the following inequality corresponds to the selection condition in this model and hence determines which of the two equilibria will be chosen:

$$\frac{\delta_F}{\delta_U}\left[\left(1+\delta_U\right)\omega_0-\omega_H\right]L_0 > \frac{\alpha}{1-\alpha}I \tag{3.1}$$

As long as the expression on the *right hand* side is greater than that on the *left hand* side, the "good" equilibrium of wage restraint and high investment will be chosen as the outcome of the coordination game. Here, the δ terms represent the discount rates of the firm and the union. The ω terms represent wages in the high investment/moderate pay equilibrium (ω_0) and low investment/high wage equilibrium (ω_H). The I term is the fixed cost of investment; the A term captures TFP. L_0 represents the current employment of the firm (i.e., that level of employment that the firms employ under conditions of wage moderation and high investment) and given the particular parametric specification of the production function considered by the authors can be expressed as follows:

$$L_0 = \left(\frac{\alpha A}{\omega_0}\right)^{\frac{1}{(1-\alpha)}} \tag{3.2}$$

Tipping out of the wage restraint equilibrium is therefore more likely to occur f the discount rates of the firms and the unions increase, if there is an increase in union bargaining aggression, and if there is an adverse technology shock (from the

A term in the production function and therefore also in the expression for L_0). As Cameron and Wallace (2002) emphasize, the inequality which determines equilibrium selection has a "knife-edge" character, in the sense that only small changes in any of the variables may be enough to cause the equilibrium to switch from wage restraint and high investment to the much less favourable outcome of high wage claims and stagnant investment.

This model therefore offers a suggestive explanation for the rise and fall of the Golden Age - the high investment equilibrium that has been identified as existing in numerous OECD countries after the war was, in this account, adversely affected as the Golden Age progressed by increases in union bargaining power, by macroeconomic shocks, and more generally by a fracturing of the postwar consensus that had helped to encourage cooperation and coordination between firms and workers.

Cameron and Wallace identify and discuss a number of possible factors that in practice could have acted to destabilize the coordination-facilitated high investment equilibrium. The incentive to switch equilibrium will increase if, for example,

- future growth is expected to be slower
- corporatist institutions are "captured", (see, for example, Olson, 1982 and Crafts and Toniolo, 1996)
- unions become more powerful

- changes in employment protection
- wage setting becomes disorganized or less effective than previously
- a macroeconomic shock occurs
- capital mobility and openness to trade increase.

The effect of each of these incentives is discussed below.

If future aggregate growth in the economy is expected to be slower, firms have less incentive to invest and union less incentive to exercise wage restraint. The importance of wage setting institutions in assisting unions to take an economy-wide perspective of the consequences of their actions was discussed extensively in the literature review section. Deterioration in the ability of firms and unions to implement mutually beneficial coordination, whether in the form of capture or an increase in corporate or union discount rates which places relatively less emphasis on the future benefits of cooperation.

Given Eichengreen's and Cameron and Wallace's emphasis on "coordination enforcers/facilitators", it could be the case that increased employment protection induced unions to bargain less aggressively for high wages, as part of a broad range of welfare state type policies that engendered consensus and not conflict. In terms of the model, employment protection may act to lower the union's discount rate, and therefore we could observe a positive sign for this variable. On the other hand, em-

ployment protection may cause union's to behave *more* aggressively if it is harder for firms to adjust their employment levels. One may make similar arguments with respect to other corporatist welfare state policies, such as the size and length of unemployment benefits. On the other hand, high tax wedges and replacement rates are probably more likely to affect the high investment equilibrium in a negative manner, by frustrating the abilities of workers to work as much as they would like.

The effect of an oil shock, or other similar macroeconomic shock, in tipping the equilibrium is more straightforward. The interaction of productivity shocks and asymmetric information between unions and workers is likely to make it more difficult to persuade unions of the necessity for a fall in real wages. A more interesting case is the effect of capital mobility and international trade. Increases in exposure to international competition are seen by Eichengreen as being, in most cases, beneficial for investment and growth, although Cameron and Wallace suggest that trade may weaken the good equilibrium by exposing domestic firms to more intense competition on world markets.

Eichengreen (1996) recognized that greater capital mobility has complex effects. Cameron and Wallace (2002) note that the ability of firms to move operations overseas may help discipline unions and result in moderate wage claims being submitted. However, the same effect could increase unions impatience in an attempt to act opportunistically before the firm has time to move abroad.

Having reviewed the theoretical Cameron and Wallace model of the Golden Age, it is worth emphasising that a direct empirical test of the precise predictions of the Cameron and Wallace model is complex, since successfully disentangling the contributions of different interdependent explanatory variables to establishing and then perhaps changing an equilibrium is a difficult task, and one that is hard to properly address using yearly data from 1960-1998. However, although the model possess a "knife-edge" character, it can be easily reconciled with the econometric application if it allowed that there may some inertia in wage and investment decisions so that it takes some time for an economy to respond and that different industries will respond in different ways too, which will tend to smooth adjustment so that empirically there is a continuous effect rather than a discontinuous one.

3.3.3 A model of growth

It therefore remains to introduce a growth model which admits direct effects of labour institutions on growth. To this end, only relatively minor modifications are required to the basic augmented Solow model which was studied in Chapter Two. Consider the basic human capital-augmented production function only one type of capital in this case:

$$Y(t) = K(t)^{\alpha} H(t)^{\beta} (A(t)L(t))^{1-\alpha-\beta} \tag{3.3}$$

The difference in this case (compared to Chapter Two) is that A is composed of two parts: technological progress and economic efficiency. Economic efficiency is a modeled as a function of labour institutions (which is consistent with North's (1990) definition above), while technological progress grows at the conventionally assumed rate $g(t)$. This simple modification is also employed in Cellini (1997) and Bassanini, Scarpetta and Hemmings (2001). To see these modifications, it is worth presenting explicitly the key equations:

$$\frac{dk}{dt} = s_k(t)y(t) - (n(t)+d)k(t)) \tag{3.4}$$

$$\frac{dh}{dt} = s_h(t)y(t) - (n(t)+d)h(t)) \tag{3.5}$$

$$A = I(t)\Omega(t) \tag{3.6}$$

$$\ln(I) = p_0 + \Sigma_j p_j \ln X_j(t) \tag{3.7}$$

$$\frac{d\Omega(t)}{dt} = g(t)\Omega(t) \tag{3.8}$$

$$\frac{dL}{dt} = n(t)L(t) \tag{3.9}$$

Again, most variables possess their normal definitions and interpretations. The X vector includes labour institution variables which Cameron and Wallace (2002) suggest may impact economic efficiency. $\Omega(t)$ captures technological progress. Again, steady state values can be readily obtained for h and k (that is, human and physical capital in intensive form), and these steady state values can be substituted into the production function to obtain the steady state path of output. Approximating around

the steady state and including human capital as a level (as opposed to modeling it as a ratio) in the same way that it was included in Chapter Two, results in the following equation for transitional dynamics, where the time subscripts have been dropped for convenience:

$$\begin{aligned}
\Delta \ln y(t) \;=\; & -\phi(\lambda)\ln(y(t-1)) - \phi(\lambda)\frac{\alpha}{1-\alpha}\ln s_k + && (3.10)\\
& +\phi(\lambda)\frac{\beta}{1-\alpha}\ln h(t) + \Sigma_j p_j \phi(\lambda)\ln X_j(t) && (3.11)\\
& +\frac{1-\psi}{\psi}\frac{\beta}{1-\alpha}\Delta \ln h(t)\\
& -\phi(\lambda)\frac{\alpha}{1-\alpha}\ln(n(t)+g(t)+d)\\
& +\left(1-\frac{\phi(\lambda)}{\psi}\right)g + \phi(\lambda)(p_0 + \ln\Omega(0)) + \phi(\lambda)gt
\end{aligned}$$

Note that in this case $\lambda = (1-\alpha-\beta)(g(t)+n(t)+d)$.

Again, this formulation readily lends itself again to an Equilibrium Correction Mechanism (ECM). The approach is to utilize a model which is capable of identifying the size and sign of effects of variables that facilitated or eroded the good equilibrium during the sample period, within the context of a simple two equation system which allows for these labour market institutions to influence growth both directly and indirectly (through the influence of labour institutions on investment). The baseline growth equation to be estimated therefore takes the following form:

$$\begin{aligned}\Delta \ln y_{i,t} &= \theta y_{i,t-\tau} + \beta_1 \ln s_{ki,t-\tau} + \beta_2 \ln(h)_{i,t-\tau} + \beta_3 \Delta \ln h(t)_{i,t-\tau} \\ &+\beta_4 I_{i,t-\tau} + \beta_5 Z_{i,t-\tau} + \beta_6 N_{i,t-\tau} + \eta_i + \mu_t + \varepsilon_{i,t}\end{aligned} \quad (3.12)$$

Here, $y_{i,t}$ is log per capita GDP in country i at time t, Δ indicates a difference term, τ is a unit of time, I is a row vector of regressors containing variables related to labour market institutions, Z is a vector of controls for macroeconomic shocks, N is a vector of interactions, η_i is a country specific fixed effect, μ_t is a common time effect (the fixed effect and time effect control for the $(n(t) + g(t) + d)$) terms, the trend terms and any other unobserved influences on growth, and $\varepsilon_{i,t}$ is a stochastic error term. In principle, the $n(t)$ could be included separately but this would cause multicollinearity problems, and hence this term is absorbed into the fixed and time effects. The vector of labour market variables takes the following form:

$$\beta_4 I_{i,t-\tau} = \beta_{41} EP_{t-\tau} + \beta_{42} BRR_{t-\tau} + \beta_{43} BD_{t-\tau} + \beta_{44} UD_{t-\tau} + \beta_{45} CO_{t-\tau} + \beta_{46} TW_{t-\tau} \quad (3.13)$$

Here, EP is a measure of employment protection, BRR is the unemployment benefit replacement rate, BD measures the duration of unemployment benefit, UD measures union density, CO measures coordination in wage bargaining, and TW measures the tax wedge (calculated as the sum of the direct, indirect and labour

tax rates). The construction of these variables is described in more detail in the appendix. The vector of labour market interactions contains the following elements.

$$\begin{aligned}\beta_6 N_{i,t-\tau} &= \beta_{61}(BRR * BD)_{t-\tau} + \beta_{62}(UD * CO)_{t-\tau} + \beta_{63}(TW * CO)_{t-\tau} \\ &+\beta_{63}(OIL * CO)_{t-\tau} + \beta_{64}(UD * EP)_{t-\tau} + \beta_{65}(CO * EP)_{t-\tau}\end{aligned} \tag{3.14}$$

Where the variables are defined as above; the OIL variable is the price of oil and is defined as the US dollar spot price of a barrel of West Texas Intermediate. As it does not vary across countries it cannot be included as a level effect on its own, but can be included as an interaction with other variables.

The vector of macroeconomic shocks is comprised of the following variables.

$$\beta_5 Z_{t-\tau} = \beta_{51} TFP_{t-\tau} + \beta_{52}\Delta^2 MS_{t-\tau} + \beta_{53} TT_{t-\tau} \tag{3.15}$$

Here, $\Delta^2 MS$ is a shock to the money supply (measured as the acceleration in the money supply), and TT represents a terms of trade shock. The TFP term is calculated as the deviation from its trend. These shocks encompass a reasonably broad range of macroeconomic conditions, and are therefore likely to be reflective of the types of shocks that the sample countries are likely to have faced. Again, these terms are defined and discussed in more detail in the Appendix. Note also that these shocks are, by construction, stationary variables.

It was noted above that a problematic feature of much of the literature on growth and institutions was a failure to properly recognize or account for an indirect effect of institutions on investment. It is worth re-emphasising this point; Aron (2000) provides a useful summary: "Where the variables that measure the quality of institutions enter this [growth] equation, they can be interpreted as having a direct effect on growth because they improve the efficiency of investment. Since investment is already included in the growth equation, any effects that institutional variables exert on growth through an increase in the volume of investment are indirect. A separate investment equation would be necessary to ascertain the direct effects of institutional variables on the volume of investment".

For example, Bassanini, Scarpetta and Hemmings (2001) recognized the problem in their study of OECD institutions and policy by specifying and estimating a separate investment equation. This approach was used to determine whether there was indeed a link between investments and institutions and therefore to indicate whether the growth regressions were affected by this bias. They did find significant effects from their policy and institutions variables on investment which meant that their growth regressions did suffer from this bias. While this approach at least recognizes the problem by identifying the bias and provides a rough estimate of the size of the potential bias, it does not solve the problem of the bias.

The approach adopted here, as noted above, is to use a simple two-equation systems approach. In this case, a simple neoclassical investment equation is derived

which admits an influence of labour institutions in the manner suggested by Cameron and Wallace (2002) and Eichengreen and Iversen (1999). A relatively parsimonious specification of the investment equation is studied, in part because of the difficulty of estimating the "perfect" or correct investment equation[76]. Data considerations also played a role in the investment equation to be studied. These data issues are discussed in more detail below.

3.3.4 A model of investment

The objective of this section is to construct and estimate a simple model of aggregate investment which will control for the separate influence of labour institutions on growth and investment. To this end, a simple aggregate canonical flexible accelerator model is studied; Cabellero (1997) notes in his influential review of aggregate investment that this relatively simple model of investment has achieved some measure of "empirical success" and this is an important consideration in a study such as that of this chapter, where the goal is not necessarily to understand investment *per se* but rather to control for the effect of other variables within the system .Consider the flexible accelerator model of investment as studied in, *inter alia*, Bond, Elston, Mairesse and Mulkay (2003); the desired capital stock is a (log) linear function of output and the real user cost of capital:

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[76] On the difficulty of finding the "correct" empirical investment equation, see Bond, Elston, Mairesse and Mulkay (1997) or Hall, Mairesse and Mulkay (1998)

$$k_{i,t} = \alpha + y_{i,t} + r_{i,t} \tag{3.16}$$

Here, $k_{i,t}$ is the desired capital stock,$y_{i,t}$ is output and $r_{i,t}$ is the real user cost of capital; all of these variables are expressed in (natural) logs. The i and t subscripts denote, as usual, cross sectional and time units respectively. Taking first differences, and using the approximation that

$$\Delta k_{i,t} \approx \frac{I_{i,t}}{K_{i,t-1}} - \delta \tag{3.17}$$

Where δ is depreciation gives rise to the following investment equation:

$$\frac{I_{i,t}}{K_{i,t-1}} = \delta + \Delta y_{i,t} - \Delta r_{i,t} \tag{3.18}$$

This equation expresses a relationship between the ratio of investment to lagged capital stock and output and user costs. In many empirical applications, the ratio of investment to capital stock is replaced by the ratio of investment to output. This is done for a number of reasons. One reason is that the investment ratio is often of more interest than the investment/capital stock ratio because of the application at hand. In the case of this chapter, it is useful to model the determinants of the investment ratio since this ratio appears on the right hand side of the growth equation, and it is of interest to see if, as hypothesized, institutions affect growth both directly and through their effect on investment, which is often measured by this ratio of investment to output. Another consideration is that GDP statistics, especially those

extending over the long time period considered in this chapter, may be more reliably constructed than are capital stock statistics. While capital stocks could be estimated on the basis of the available investment data, this would introduce another layer of assumptions that are unlikely to materially improve the accuracy of the estimation. In any event, the coefficients that would be obtained from considering equations based on investment/capital ratios can be easily recovered from estimates based on the investment/GDP ratio, since the latter estimated coefficients will be higher than in the former case by the multiple of the capital output ratio[77].

Adopting the assumption of Bond *et al.* (1997) that variation in user costs can be controlled for by including fixed effects and time effects, and including dynamic adjustment terms and a vector of labour market institutions which are identified by Cameron and Wallace (2002) as potentially influencing investment, results in the following equation[78] for investment:

$$\frac{I_{i,t}}{Y_{i,t-1}} = \rho\left(\frac{I_{i,t-1}}{Y_{i,t-2}}\right)+\beta_0\Delta y_{i,t}+\beta_1\Delta y_{i,t-1}+\beta_3 I_{i,t-\tau}+\beta_4 Z_{i,t-\tau}+\beta_5 N_{i,t-\tau}+d_t+\eta_i+\upsilon_{i,t} \tag{3.19}$$

Here, d_t is a time dummy, η_i is a country specific fixed effect, I is again the vector of labour market institutions, Z contains macroeconomic shocks, and N contains interactions, and $\upsilon_{i,t}$ is an error term.

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[77] This assumes that the capital output ratio is roughly constant. For example, if the capital-output ratio is 2.5, the estimated coefficients from the investment/GDP ratios will be 2.5 higher than the coefficients from the investment/capital stock equations.

[78] Dehn (2000) studies a similar econometric specification..

The econometric specification that is actually employed is the one below, in which the lag of the dependent variable has been subtracted from both sides of the equation in order to obtain a differenced dependent variable:

$$\Delta \frac{I_{i,t}}{Y_{i,t-1}} = (\rho - 1)\left(\frac{I_{i,t-1}}{Y_{i,t-2}}\right) + \beta_0 \Delta y_{i,t} + \beta_1 \Delta y_{i,t-1} + \beta_2 X_{i,t} + d_t + \eta_i + \upsilon_{i,t} \quad (3.20)$$

A further precaution was taken in the systems estimation by using appropriately lagged instruments for the output terms which may in particular be correlated with the error term and appropriate lagged instruments are also used for this purpose in the 3SLS estimation. In particular, the output terms may be endogenous with respect to investment, and these variables are instrumented using longer lags. These precautions as to potential bias are similar to those adopted in other recent growth papers which adopt a 3SLS estimation strategy, such as for example in Cameron (2005) and Guellec and van Pottelsberghe de la Potterie (2004).

Two equations are to be estimated: one of growth and one for investment. It is important to address the possibility that non-stationarity may contaminate the estimation results. Many of the labour market variables are, by their nature, constant for long periods (the example of the coordination variable being a case in point) or change very slowly over time, and as such these variables can be treated as being stationary. Likewise, the human capital variable, which appears as both a level and a

difference term in the growth equation, is a variable which, by its nature, changes very slowly over time. The macroeconomic shock variables are stationary by construction. The investment equation contains differenced output terms, and these are also treated as being integrated of order zero.

In principle, it would be possible to test the stationarity of these variables using methods such as the Augmented Dickey-Fuller (ADF) test, but such tests are generally of low power in samples of the size studied here, and therefore it seems sensible to adopt the plausible hypothesis that particular variables are stationary, rather than subject the data to statistical testing that is likely to be uninformative.

3.3.5 Conclusion

A two-equation system of equations has been obtained. The first equation relates per capita output growth to a variety of variables, which variables include vectors containing labour institution variables, some interactions of these variables, as well as a vector of macroeconomic shocks. The second equation relates a measure of the investment/output ratio to a similar but different set of variables. The next section estimates these models.

3.4 Empirical formulation and estimation results

The baseline equations, introduced above, are the basis for the econometric testing. Initially, the baseline equations are estimated separately for the purposes of com-

parison. A systems approach for the panel is then introduced, and the growth and investment equations are then studied using an equilibrium correction framework using the three stage least squares estimator on the panel data. The data used in this analysis are discussed in the first appendix to this chapter.

3.4.1 Estimating the model

It was noted above that a major deficiency of the existing literature on institutions, growth and investment is the failure of that literature to include and model supplementary investment equations. As noted, this chapter also uses a three stage least square (3SLS) systems estimator to address the main problems of the existing literature[79]. The major advantage to a systems approach, wherein the growth and investment equations would be modeled jointly, is that, since they incorporate all of the available information when forming estimates, they have a smaller asymptotic variance-covariance matrix than the single equation estimates (Kennedy, 2000). This estimator is the systems counterpart of the two stages least square estimator (2SLS). 3SLS estimation proceeds by calculating equation-by-equation estimates of the identified equations in the system. These 2SLS estimates are then used to estimate the errors of the structural equations and are used to estimate the system's variance-covariance matrix. Finally, in the third step, generalized least squares are

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[79] A small but growing number of papers has begun to address this problem of the earlier literature by using three stage least squares estimators (3SLS) to jointly model the effect of institutions on both investment and growth. These papers include, *inter alia*, Baldwin and Seghezza (1996), Wacziarg (2001) and Ulubasoglu and Doucouliagos (2004).

applied to the entire system. The resulting 3SLS is consistent and will be asymptotically be more efficient than the corresponding consistent 2SLS estimator applied to separate equations. It achieves efficiency through optimal weighting. A version of Breusch and Pagan's (1979) LM test is used below to test the null hypothesis that the cross-equation system residual matrix is diagonal.

However, inconsistent estimates will be produced if cross country heterogeneity is important in this panel (Pesaran and Smith, 1995). This issued was discussed in some detail in Chapter Two. One approach would be to adopt a completely unpooled specification such as the Mean Group estimator of (Pesaran and Smith, 1995). However, in this case we would lose any advantages that may arise with respect to efficiency and consistency from pooling the data (Fuertes and Smith, 2004). Another possibility would be to apply the Pooled Mean Group estimator, which is also discussed extensively and applied in Chapter Two. However, the MG and PMG estimators cannot be applied to this dataset as some variables (notably, the coordination and employment protection variables), do not change over time and accordingly equations including such variables cannot be estimated on a country-by-country basis.

The use of PMG estimation techniques would also involve surrendering the considerable advantages associated with studying growth, investment and institutions in an instrumented systems environment. Since one of the biggest criticisms of the empirical literature on growth and institutions is a failure to apply such systems

estimators, it would be somewhat perverse not to exploit such estimation techniques here, just as the criticism that heterogeneity was overlooked in equipment-growth regressions was a major motivation for applying PMG techniques to the study of that topic in Chapter Two. A final defense of the methods used here is to note Baltagi and Griffin's (1995) point that pooling may be acceptable in cases where the gain in efficiency from pooling is greater than the detriment wrought by the bias induced by not explicitly accounting for heterogeneity.

3.4.2 Econometric results

Introduction

The results of the 3SLS stage estimation are presented below. The estimation results are presented in a number of stages in order to develop a robust picture of the key relationships. The first set of results consists of the baseline estimates. This specification applies the 3SLS estimator all labour market institutions variables, controlling for macroeconomic shock variables, and including interactions suggested by Cameron and Wallace (2002) and Eichengreen (various years), in addition to the production function type variables from the augmented Solow model and the investment equation, as well as fixed effects and year effects. This baseline specification is then modified; it is estimated using alternative estimators and different explanatory variables. The first equation is the baseline estimated using 3SLS, and the second

equation is the same specification estimated using the Zellner's (1962) SUR (Seemingly Unrelated Regression) estimator, which was also discussed in Chapter Two.

The next two sets of results provide another alternative perspective on the baseline 3SLS results in that these equations do not use a systems approach. The third specification estimates the growth and investment equations separately using the 2SLS instrumental variable estimator, while the fourth specification also estimates the two equations separately using a standard within fixed effect estimator. These particular regressions are the separate (non-system) specifications of the baseline specification mentioned above.

The institutional variables were included as their second lag. It seemed to appropriate to model a slightly extended impact of these institutional variables on growth to allow for the fact it is likely to take time for changes in these variables to affect growth and investment. Conversely, the macroeconomic shock variables were lagged one period, reflecting the fact that these shocks, by their nature, are likely to have a somewhat more rapid impact on growth and investment. To test the reasonableness of these assumptions, the models were also estimated using institutional variables which were lagged once. The baseline model estimated using this specification appeared badly formed, inasmuch as it exhibited imprecisely estimated parameters and an unsatisfactory performance overall and therefore the second lag was used for these variables in all future specifications.

All 3SLS (and 2SLS) specifications were estimated using instrumental variables. It is possible to attain greater econometric precision by adding variables to the instrument set which do not necessarily appear as exogenous variables in either of the two equations. The instrumental variable set consisted of all exogenous variables (and their first and second lags), and the first and second lag of the endogenous variables[80]. The results are presented below.

3.4.3 Analysis and discussion of results

With respect to the influence of labour market institutions in the baseline specification, the significance of the different labour variables differs between the growth and investment equations. In the baseline 3SLS specification, union density enters negatively and significantly (at the 10% level), and is negative in all specifications and significant in the growth equation. Its coefficient is also negative in the investment equation, and just fails to be significant at the 10% level in the baseline case, although it is significant in most of the other specifications. This finding of a negative coefficient on union density is in accordance with what may be termed the "conventional" view of unions. It is conceivable that union density could have worked as "coordination facilitators"[81] and thereby entered the equations with positive esti-

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[80] This is the same approach to instrumentation adopted for the 3SLS estimation in Guellec and van Pottelsberghe de la Potterie (2004) and in Cameron (2005), and is somewhat similar to the approach adopted in Spolaore and Wacziarg (2005).

[81] Perhaps by facilitating union "voice" in the sense of Freeman (1976).

	(1) 3SLS	(2) SUR	(3) 2SLS	(4) singleFE
DiffGDP				
GDP_{t-1}	-0.1043	-0.1044	-0.1012	-0.116
	(0.0233)***	(0.0231)***	(0.0293)***	(0.0279)***
Inv_{t-1}	-0.0385	-0.0397	-0.0501	-0.0435
	(0.0104)***	(0.0098)***	(0.0126)***	(0.0109)***
H_{t-1}	0.0384	0.0367	0.0159	0.0266
	0.0315	0.0316	0.0397	0.0378
$DiffH_{t-1}$	0.0335	0.0325	0.0182	0.0115
	0.0628	0.0634	0.0794	0.0773
Labour institutions				
EP_{t-2}	0.0189	0.0195	0.0199	0.0213
	(0.0046)***	(0.0046)***	(0.0052)***	(0.0050)***
BRR_{t-2}	-0.0067	-0.0071	-0.0074	-0.0098
	0.0057	0.0057	0.0063	(0.0059)*
$BDAV_{t-2}$	-0.0042	-0.0044	-0.0042	-0.0053
	0.0055	0.0055	0.0061	0.0057
UD_{t-2}	-0.0258	-0.0214	-0.0268	-0.0157
	(0.0148)*	0.0145	0.0163	0.0108
CO_{t-2}	0.0384	0.0456	0.0328	0.0448
	0.0283	(0.0266)*	0.0318	0.0281
TW_{t-2}	0.0469	0.0365	0.0546	0.0398
	(0.0191)**	(0.0138)***	(0.0216)**	(0.0139)***
Interactions				
$(BRR*BDAV)_{t-2}$	-0.0035	-0.0033	-0.0028	-0.0109
	0.0077	0.0077	0.0085	0.0074
$(UD*CO)_{t-2}$	0.0487	0.0442	0.0492	0.0389
	(0.0201)**	(0.0200)**	(0.0222)**	(0.0156)**
$(TW*CO)_{t-2}$	-0.039	-0.0351	-0.0444	-0.0351
	(0.0170)**	(0.0160)**	(0.0189)**	(0.0156)**
$(OIL*CO)_{t-2}$	0.004	0.0032	0.004	0.0041
	0.0048	0.0048	0.0053	0.0046
Macroeconomic shocks				
TFP_{t-1}	0.1367	0.1283	0.1553	0.1213
	(0.0590)**	(0.0587)**	(0.0661)**	(0.0629)*
$D2MS_{t-1}$	0.02	0.0198	0.0197	0.0195
	(0.0072)***	(0.0072)***	(0.0079)**	(0.0077)**
TT_{t-1}	0.0789	0.0796	0.0725	0.0792
	0.0555	0.0555	0.0612	0.0588
Notes				
Systems estimator?	✓	✓	×	×
Fixed effects?	✓	✓	✓	✓
Year effects?	✓	✓	✓	✓
Time trend?	×	×	×	×
"R-squared"	50.20%	49.97%	50.27%	47.01%

Figure 3.1: Estimates of GDP equation

	(1) 3SLS	(2) SUR	(3) 2SLS	(4) singleFE
DiffInv				
$(It/Yt\text{-}1)_{t\text{-}1}$	-0.3369	-0.335	-0.3428	-0.3423
	(0.0348)***	(0.0335)***	(0.0426)***	(0.0401)***
$diffGDP_{t\text{-}1}$	-0.4579	-0.4221	0.0537	0.1128
	(0.2095)**	(0.2067)**	0.2641	0.2555
$diffGDP_{t\text{-}2}$	-0.0458	0.1051	-0.3925	0.2621
	0.3884	0.1913	0.4821	0.2359
Labour institutions				
$EP_{t\text{-}2}$	0.0416	0.0451	0.0417	0.041
	(0.0189)**	(0.0185)**	(0.0209)**	(0.0203)**
$BRR_{t\text{-}2}$	-0.0359	-0.0347	-0.0335	-0.0291
	0.0245	0.0242	0.027	0.0263
$BDAV_{t\text{-}2}$	-0.0675	-0.0707	-0.0674	-0.0718
	(0.0237)***	(0.0234)***	(0.0261)***	(0.0254)***
$UD_{t\text{-}2}$	-0.0676	-0.0424	-0.0705	-0.0272
	0.0656	0.0619	0.0729	0.0677
$CO_{t\text{-}2}$	-0.1749	-0.128	-0.1846	-0.1505
	0.1162	0.1096	0.1288	0.1199
$TW_{t\text{-}2}$	0.24	0.1527	0.2313	0.1384
	(0.0757)***	(0.0555)***	(0.0842)***	(0.0608)**
Interactions				
$(BRR*BDAV)_{t\text{-}2}$	-0.0811	-0.0798	-0.0844	-0.0849
	(0.0328)**	(0.0323)**	(0.0361)**	(0.0352)**
$(UD*CO)_{t\text{-}2}$	0.1023	0.0754	0.0982	0.0447
	0.0894	0.085	0.0994	0.0929
$(TW*CO)_{t\text{-}2}$	-0.1945	-0.1463	-0.1981	-0.1366
	(0.0734)***	(0.0675)**	(0.0814)**	(0.0737)*
$(OIL*CO)_{t\text{-}2}$	0.0057	0.0111	0.004	0.0148
	0.021	0.0203	0.0232	0.0221
Macroeconomic shocks				
$TFP_{t\text{-}1}$	0.712	0.6443	0.5673	0.2263
	(0.3498)**	(0.2912)**	0.412	0.3332
$D2MS_{t\text{-}1}$	0.0787	0.0787	0.0779	0.0806
	(0.0308)**	(0.0304)***	(0.0339)**	(0.0331)**
$TT_{t\text{-}1}$	-0.2192	-0.2154	-0.3351	-0.2526
	0.2456	0.2374	0.2723	0.2594
Notes				
Systems estimator?	✓	✓	×	×
Fixed effects?	✓	✓	✓	✓
Year effects?	✓	✓	✓	✓
Time trend?	×	×	×	×
"R-squared"	39.3%	43.2%	38.6%	43.5%

Figure 3.2: Estimates of investment equation.

mated coefficients. In the context of the results presented here, it would appear that the negative effects of unionization on growth and investment, familiar from other macroeconomic contexts, outweighs any potentially positive contributions. However, positive contributions do show up to a certain extent in the interaction terms for some of the labour variables, and these are discussed in more detail below.

An interesting finding is that employment protection is positive and strongly significant for both growth and investment in the baseline equation and indeed in all other specifications. This is noteworthy because many conventional macroeconomic accounts of the labour market suggest that employment protection is likely to increase unemployment as it hampers the ability to adjust their labour force to optimal levels. On the other hand, employment protection may have facilitated cooperation between workers and their employers by providing a measure of job security and in fact seems to have fulfilled this function over the sample period; employment protection also enters positively and significantly in the various specifications of the investment equation. This interpretation - that employment protection encouraged and facilitated cooperation between employers between and workers- is consistent with Eichengreen and Cameron and Wallace (2002). More difficult to interpret is the high and robust estimate of a positive effect on both growth and investment of the tax wedge variable, which is positive and significant across specifications and in both the growth and the investment equations; it could perhaps be the case that this variable is somehow proxying for other influences on the labour market but it is not clear

what the channel of influence might be. One possible explanation may be that the high tax wedge figure is picking up the effect of increased spending on public goods which facilitated growth and investment, but there is no robust basis for assuming that this was in fact the case in practice.

Average benefit duration is negative but not significant for the baseline growth equation, although it is significant for the SUR investment equation estimates, when the year effects are replaced by a trend, and the baseline estimates when the interaction between oil, coordination and openness is controlled for. It is significant for the baseline investment equation. Its negative sign is in line with what might be expected - unlike employment protection, which may conceivably have raised productivity by alleviating concerns of workers over their employment, long benefit durations are unlikely to have exerted a direct positive productivity influence over employed workers and may have correspondingly retarded growth and investment. It is also likely that long benefit durations required great government expenditure, and therefore higher labour taxes, than did employment protection. For example, Layard, Nickell and Jackman (1991) find that benefit duration was positively related to unemployment over the period from 1983 to 1988 in the OECD.

The unemployment benefit replacement rate is negative, but is not significant under any specification. The extent of coordination narrowly fails to be significant at the 10% level in the baseline growth equation, but does reveal a significant influence in interaction with other variables, indicating the general importance of this variable.

The coordination variable is even less significant in the baseline investment equation, and is negative under some specifications. This outcome can may perhaps by explainable if wage bargaining may simply have different effects on growth than it does on investment, although its effect when interacted with other variables is similar as between the two equations.

The estimated coefficients on interaction terms also provide some measure of support for the predictions of Cameron and Wallace (2002) and of Eichengreen. The positive coefficient on the interaction between employment protection and union density also supports the ideas that engendering consensus was important for post-war growth and investment, although surprisngly the coefficient on the union density/coordination interaction is positive.

One feature of the results is the lack of significance of measured human capital. The variable enters positively (with the exception of the separate investment fixed effect "within" equations) but insignificantly in the different specifications. This lack of an estimated effect from human capital is not unknown in cross-country growth studies, and especially cross-country studies that utilize macroeconomic panel data.

The macroeconomic shock variables also have estimated coefficients are also indicate that increases in the change in the money supply and positive TFP shocks

provide a stimulus to growth and investment, which is as one would expect, although the terms of trade effect is generally not significant.

It is also informative to examine the long run impacts of the significant labour institution variables in the main results. This can be deteremined by multiplying the long run coefficients of the significant variables by the standard deviation of of those variables across the sample. Referring to the 3SLS results, employment protection (short run coefficient of 0.019, long run coefficient of 0.17 , and standard deviation of 0.58) and the tax wedge variable (long run coefficient of 0.042 and standard deviation of 0.07) are significant, while in the investment equation these variables (long run coefficient of 0.031 on employment protection and 0.24 on the tax wedge variable) as well as the average benefit duration variable (long run coefficient of -0.055 and standard deviation of 0.35) are significant.

Given this information, a one standard deviation increase in the employment protection variable would increase growth by 1%, while a one standard deviation increase in the tax wedge variable would increase growth by 0.3%. Performing the same analysis for the investment equation variables, a one standard deviation increase would be associated with a change in investment of 1.8% in the case of employment protection, -1.7% for average benefit duration, and 1.2% for the tax wedge variable. This simple analysis illustrates that, as one would expect, labour institutions have a small but nevertheless significant influence on growth and investment in this sample,

but are nevertheless dominated as influences by elements such as capital, human capital, and labour input more generally.

As has already been noted, a variety of different estimators were applied to the data in order to certify the robustness of the baseline 3SLS specification. The estimates generated using the SUR method, which estimate coefficients taking into account heteroskedasticity and covariance correlation between the equations, also produces very similar results to the 3SLS approach. The SUR results are therefore also useful because they convey the incremental advantages to the use of the 3SLS instrumenting, although one should of course bear in mind that the SUR results are almost certainly tainted by endogeneity bias (a bias which is controlled for in the 3SLS).

The 2SLS results are interesting because they provide information regarding coefficients and their significance in the context of a non-systems estimator which is nevertheless instrumented by the same instrument set used in the 3SLS regressions. Likewise, the separate (non-systems) fixed effect regressions estimate coefficients without an instrument set. It is evident in both of these specifications, in which growth and investment are not estimated jointly, fail to estimate variables as precisely as the more efficient 3SLS and SUR estimators. Nevertheless, it is again re-assuring that the non-system specifications replicate, by and large, the signs and significance levels of the systems approaches.

Regression Diagnostics

The results support the theoretical emphasis on labour market institutions, given the significance of many of the estimated coefficients on the labour market variables, the interactions and the macroeconomic shocks, in both the investment and growth equations. The different formulations of the regression equations each explain about 40% to 50% of the variation in the respective dependent variables, as measured by the R^2 statistics.

The results of the Breusch-Pagan test, which tests for the null of no-correlation in the correlation matrix of the residuals of each of the equations in the system, and which is distributed as χ^2 with one degree of freedom, strongly rejects the null with a test statistic of 96.031 and a p-value of 0.000 (that is, zero to at least three decimal places). These results indicate that the residuals of the two equations are (strongly) correlated, thereby supporting the case for applying a systems approach to this type of problem. Moreover, this cross-equation covariance in the error terms means that systems estimator will be more efficient than other estimators - this manifests itself in the lower standard errors which are generated for variables in the systems specifications, as compared to the other estimators; in other words, the systems specifications are estimating the regression coefficients with greater precision.

One reassuring aspect of the results is that, although the Breusch-Pagan statistics strongly support the idea of cross-equation correlation of the covariance matrices,

the non-systems estimators (that is, the separate 2SLS and fixed effect "within" estimators) produce estimates which are, on the whole, very similar to those of the baseline system 3SLS estimation results. This is reassuring because mis-specification of one equation can contaminate other equations in a system due to the correlation between the covariance matrices (see Greene, 2000). Therefore, the fact that the non-systems estimators accord reasonably close to the baseline systems estimators suggests mis-specification is not an issue for the baseline models.

A further diagnostic test of the baseline regression was also applied in the form of a simple F-test of joint significance of all the exogenous variables in the first stage of the 3SLS baseline regressions. This was achieved by running two separate OLS regressions; one regression for each of the dependent (endogenous) variables in the system. In essence, this simple procedure tests the robustness of the specification by testing whether the instrument set is jointly significant and therefore statistically related to the variables for which they instrument[82]. In both cases, the null of zero coefficients is strongly rejected for each equation; in the case of the growth equation the F statistic was 5.79, with a p-value of 0.000; for the investment equation the statistic took a value of 4.15, again with a p-value of 0.000.

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82 A similar procedure is undertaken by Spolaore and Wacziarg (2005).

Alternative specifications

In addition to the four different estimators applied to the baseline specification, a further five different specifications of the baseline were examined as an exercise in robustness. Each equation was estimated using 3SLS.

Replacing year effects with a common time trend has little impact on the sign or significance of the variables, although in the growth equation the coefficient on some of the significant variables increases, whilst this specification is the only one in which the interaction between oil prices and coordination is significant. The time trend itself is significant in both the investment and growth equations, which is unsurprising in light of the fact that the (unreported) annual time effects are generally positive and significant. The signs and significances of the variables do not change dramatically under this specification, although the oil and coordination interaction is again significant, the benefit duration variable is positive (but insignificant, in common with the other specifications). Employment protection was also interacted with union density and coordination.

The sample was also split into two distinct time periods. This was done because it is of some interest because of the possibility, raised by Cameron and Wallace (2002) and some of the Eichengreen work, that the signs and significance of variables may have changed before and after the oil shocks; that is, before and after the conventional end date for the "Golden Age". It is to be expected that parameters will

	(5) TREND	(6) OIL*CO*OPEN	(7) EP*UD & EP*CO	(8) 1960-1973	(9) 1974-1998
DiffGDP					
GDP_{t-1}	-0.1181	-0.1039	-0.1141	-0.0969	-0.0539
	(0.0235)***	(0.0233)***	(0.0240)***	-0.0865	(0.0198)***
Inv_{t-1}	-0.03	-0.0389	-0.0363	-0.085	-0.0484
	(0.0103)***	(0.0104)***	(0.0108)***	(0.0302)***	(0.0132)***
H_{t-1}	0.0551	0.0394	0.0364	-0.0914	0.07
	0.0352	0.0315	0.0314	0.2665	0.0437
$DiffH_{t-1}$	0.0823	0.0327	0.0278	-1.0296	0.082
	0.0677	0.0628	0.0627	2.5049	0.0726
Labour institutions					
EP_{t-2}	0.0154	0.0189	0.0484	0.0263	0.006
	(0.0053)***	(0.0046)***	(0.0236)**	(0.0090)***	-0.0162
BRR_{t-2}	-0.0077	-0.0067	-0.0064	0.0171	-0.0201
	0.0067	0.0057	0.0058	(0.0068)**	(0.0092)**
$BDAV_{t-2}$	0.0031	-0.0044	-0.004	0.0016	0.0051
	0.0064	0.0055	0.0056	0.0175	0.0073
UD_{t-2}	-0.0278	-0.0256	-0.0166	-0.0289	-0.0263
	0.0173	(0.0148)*	0.0154	0.0473	-0.0195
CO_{t-2}	0.0376	0.0377	0.0132	0.9346	-0.0046
	0.0311	0.0284	0.0325	0.8978	0.0442
TW_{t-2}	0.0395	0.0473	0.0378	0.0516	0.0573
	(0.0186)**	(0.0190)**	(0.0199)*	0.0366	(0.0327)*
Interactions					
$(BRR*BDAV)_{t-2}$	-0.0015	-0.0039	-0.006	-0.0036	-0.0052
	0.009	0.0077	0.0078	0.0148	0.011
$(UD*CO)_{t-2}$	0.0476	0.0486	0.0219	0.0832	0.0442
	(0.0235)**	(0.0201)**	0.0233	0.0815	(0.0264)*
$(TW*CO)_{t-2}$	-0.032	-0.0393	-0.0436	-0.102	-0.0442
	0.0196	(0.0170)**	(0.0170)**	(0.0353)***	0.029
$(OIL*CO)_{t-2}$	-0.0074		0.0041	0.3439	-0.0039
	(0.0018)***		0.0048	(0.1148)***	(0.0020)**
$(UD*EP)_{t-1}$			0.0233		
			(0.0104)**		
$(CO*EP)_{t-2}$			-0.0105		
			0.0262		
Macroeconomic shocks					
TFP_{t-1}	0.1878	0.1356	0.1339	-0.4685	-0.146
	(0.0631)***	(0.0590)**	(0.0596)**	(0.1400)***	(0.0726)**
$D2MS_{t-1}$	0.0269	0.02	0.0201	0.0201	0.0206
	(0.0080)***	(0.0072)***	(0.0072)***	-0.0166	(0.0087)**
TT_{t-1}	-0.0083	0.0708	0.0607	0.3937	-0.0468
	0.0567	0.0563	0.0556	(0.1679)**	0.0624
Other variables					
TREND	0.0011				
	(0.0006)*				
$(OIL*COIB*OPEN)_{t-1}$		0.0012			
		0.0013			
Notes					
Systems estimator?	✓	✓	✓	✓	✓
Fixed effects?	✓	✓	✓	✓	✓
Year effects?	×	✓	✓	✓	✓
Time trend?	✓	×	×	×	×
"R-squared"	28.8%	50.3%	50.9%	74.7%	49.1%

Figure 3.3: Robustness testing of GDP equation.

	(5) TREND	(6) OIL*CO*OPEN	(7) EP*UD & EP*CO	(8) 1960-1973	(9) 1974-1998
Diffinv					
$(It/Yt-1)_{t-1}$	-0.3393	-0.3373	-0.3349	-0.7258	-0.3777
	(0.0356)***	(0.0349)***	(0.0350)***	(0.1207)***	(0.0410)***
$diffGDP_{t-1}$	-0.3397	-0.456	-0.4749	-1.17	-0.3542
	(0.1832)*	(0.2093)**	(0.2122)**	0.882	0.2344
$diffGDP_{t-2}$	-0.1769	-0.0401	-0.1587	0.4706	-0.3255
	0.2436	0.389	0.403	1.098	0.4794
Labour institutions					
EP_{t-2}	0.0259	0.0417	0.1447	0.1026	0.0674
	0.0197	(0.0189)**	0.1027	(0.0454)**	0.066
BRR_{t-2}	-0.0435	-0.0356	-0.0352	0.0104	-0.0493
	0.0265	0.0245	0.025	0.045	0.0363
$BDAV_{t-2}$	-0.0483	-0.0679	-0.0653	-0.016	-0.0436
	(0.0257)*	(0.0237)***	(0.0243)***	0.1027	-0.029
UD_{t-2}	-0.0947	-0.0666	-0.0475	-0.3251	-0.0697
	0.0697	0.0656	0.0677	0.2838	0.0785
CO_{t-2}	-0.197	-0.1761	-0.2654	-0.188	-0.1293
	0.1234	0.1162	(0.1399)*	0.6029	0.1778
TW_{t-2}	0.231	0.2395	0.2191	0.4334	0.0827
	(0.0719)***	(0.0755)***	(0.0768)***	(0.1420)***	0.1075
Interactions					
$(BRR*BDAV)_{t-2}$	-0.0743	-0.0817	-0.086	-0.1499	-0.0709
	(0.0356)**	(0.0328)**	(0.0333)***	-0.0916	-0.0441
$(UD*CO)_{t-2}$	0.1226	0.1015	0.0303	0.3387	0.1324
	0.0944	0.0893	0.1014	0.5421	0.1057
$(TW*CO)_{t-2}$	-0.2001	-0.1951	-0.2058	-0.2496	-0.2097
	(0.0778)**	(0.0734)***	(0.0743)***	0.1549	(0.1170)*
$(OIL*CO)_{t-2}$	-0.0299		0.0058		
	(0.0073)***		0.0211		
$(UD*EP)_{t-1}$			0.0661		
			0.0453		
$(CO*EP)_{t-2}$			-0.0601		
			0.1102		
Macroeconomic shocks					
TFP_{t-1}	0.9028	0.705	0.7566	0.2362	0.6256
	(0.2986)***	(0.3498)**	(0.3571)**	-1.3373	(0.3555)*
$D2MS_{t-1}$	0.1022	0.0787	0.0784	0.0391	0.0843
	(0.0319)***	(0.0308)**	(0.0309)**	-0.1018	(0.0347)**
TT_{t-1}	-0.2871	-0.2346	-0.2852	3.3051	-0.5011
	-0.2291	-0.2478	-0.2512	(0.9974)***	(0.2612)*
Other variables					
TREND	-0.0038				
	(0.0011)***				
$(OIL*COIB*OPEN)_{t-1}$		0.0023			
		-0.0055			
Notes					
Systems estimator?	✓	✓	✓	✓	✓
Fixed effects?	✓	✓	✓	✓	✓
Year effects?	×	✓	✓	✓	✓
Time trend?	✓	×	×	×	×
"R-squared"	25.0%	39.3%	38.3%	53.4%	40.7%

Figure 3.4: Robustness of investment equation.

be estimated with much less precision for such a short time period, since these estimates disregard about 75% of the time dimension and two of the countries in the form of Germany and Portugal. Indeed, the regression as estimated is unstable and is included here only for completeness and as such no reliance should be placed on the results from this period. Unfortunately, as this period is usually taken as representing the second half of the postwar Golden Age, it is regrettable that the regressions are not capable of shedding more light on this part of the era. Some of the coefficients are not stable for this specification.

However, the regressions for the period from 1974 to 1998 are formed in a somewhat more satisfactory way, and unlike the 1960-1973 regressions include data from Portugal and West Germany. A perhaps somewhat surprising feature of the split sample results is that there is little evidence that coefficients change sign between the different periods, although given the quality of the regressions from the pre-1973 period it seems sensible not to read too much into this. Human capital, the benefit replacement rate, and TFP change sign.

A more instructive and informative comparison may be made by comparing the results for the entire sample with the results from the 1974-1998 regressions. A major difference between these results is that the investment equations performs poorly (in the sense that only one variable is significant) for the subsample, although all variables retain the same sign across the two investment equations. A number of differences are also apparent in the growth equation. The employment protection variable

is insignificant and its coefficient is of a smaller size. The benefit replacement rate becomes larger (more negative) and becomes significant, whereas the benefit duration variable changes sign but becomes insignificant in the sub-sample. The output elasticity of the tax wedge is larger in the sub-sample, while both union density becomes more negative and the coordination variable changes sign to be negative.

Can one anything infer anything from these differences between the subsample period from 1974 onwards with the results for the whole sample? Clearly, it would have been desirable to be in a position in which the results of two well-formed regressions could be compared. Unfortunately, the results for the Golden Age sub-sample indicate that the regression is unstable, and hence is not suitable for comparison with the post-1973 regressions. There does not appear to be another natural choice of year on which to split the sample, given this chapters focus on the period of the Golden Age, which is almost universally adjudged to have ended at the time of the first oil price shocks.

Nevertheless, the results from comparing the 1974-1998 subsample with the whole sample are quite suggestive. For instance, employment protection becomes negative in the subsample, perhaps indicating that this variable played a "coordination facilitator" role in the Golden Age, but ceased to be economically meaningful once the high growth, high investment of the Golden Age collapsed (or at least appeared to collapse). Similarly, coordination appears to retard growth in the more confrontational period after the Golden Age; it could be argued that union density

becomes more negative in the sub-sample for similar reasons. Drawing firm conclusions as to the reasons for the rise and fall of these outcomes is clearly not a robust means of understanding growth in this period. These differences between the sub-sample and those for the entire period are suggestive, but not definitive, indications of that the effect of institutions changed between different epochs of the post-war era. More generally, the results for the entire sample do indicate that institutions did affect growth outcomes, and this finding lends support to the body of work which has championed their position in the literature of post-war growth.

3.4.4 Conclusion

This section has presented the results of different specifications of a two equation system of equations relating growth and investment to institutions and macroeconomic shock variables. A systems approach was deployed in order to overcome the econometric problems which arise when institutions affect growth directly and indirectly through their effect on investment, itself an important component of growth. A number of different specifications were estimated and their results were presented above.

The results support the idea that labour institutions were important for growth, both directly and through their impact on investment, even after controlling for macroeconomic shocks. As such, the findings also imply that the use of a systems estimator is a sensible approach when growth determinants may affect growth directly as well

as by means of an indirect effect on investment. This lends a measure of support to the ideas of Cameron and Wallace (2002) and Eichengreen (1996), and in that sense it appears reasonable to answer the question posed as the title of this chapter - Did labour institutions contribute to the Golden Age of economic growth? - in a positive manner.

The observation was made in the Introduction that a successful explanation for the Golden Age should account for the rise and fall of this period. The Cameron and Wallace and Eichengreen theories emphasized an important role for labour market institutions and policies. What the regressions in this chapter do not reveal is how and why these institutions both caused and eventually undermined the high rates of growth and investment during this period, an outcome suggested by Cameron and Wallace (2002). There are a number of reasons for this agnosticism. In the first instance, the available data only encompass the period from 1960 to 1998, and therefore the 1950s are necessarily ignored. This is regrettable because a good deal of the rapid growth which characterised the Golden Age took place during this period. This absence probably explains why splitting the sample in two periods did not yield results which were especially informative as to the differences in the influence of institutions between the two periods. Additionally, the absence of data for the early part of the sample for the interesting case of Germany is also unfortunate.

To summarise, controlling for macroeconomic shocks, labour institutions had a significant impact on the shape of growth and investment over the second half of

the twentieth century. What the regressions do not reveal, for reasons discussed above, is why the Golden Age began and why the period ended when it did. Despite this, had data on output, investment, human capital, macroeconomic shocks, and labour institutions been available back to 1950, it is plausible that the reasons (with respect to labour institutions) for the beginning and end of the Golden Age may have been more clear, whereas this chapter has demonstrated the more modest observation that such institutions did matter for growth in the Golden Age period[83]. Clearly, a great deal of other economic and non-economic factors "mattered" in creating and sustaining the condition which gave rise to the Golden Age; this is similar to the point made in the Introduction that there are almost as many candidate variables for explaining growth as there countries in the world.

3.5 Conclusion

This chapter has been concerned with the so-called Golden Age of economic growth. It began by critically reviewing the extensive literature on this topic, and contributed

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[83] In passing, it is worth nothing that to further understand the nature of the relationship between institutions, shocks and economic growth, a simple dynamic simulations was performed on the data. The dynamic simulations proceed by generating a new series for the growth dependent variable for each country by recursively substituting the lagged dependent variable with the previous year's prediction of the baseline model. This simulated series was then compared to one in which one or more of the right hand variables are constrained at their 1960-1973 values. By comparing the difference between these two series, one should be able to generate an estimate of the proportion of the variation in the dependent variable that can be attributed to changes in the particular regressor whose values were constrained to equal average values of the previous time period. Unfortunately, the simulated GDP series tended to overstate actual GDP, meaning that there was a poor match between actual and simulated GDP. As such, the effect of the institutional variables was overstated. Different calibrations to the simulation model did not alter this outcome, and hence the results were unsatisfactory and accordingly are not reported here.

to the debates on this important topic by testing the narrative theories of Eichengreen and the analytical theories of Cameron and Wallace (2002) using a comprehensive dataset of labour institutions in an instrumented systems model. The systems approach was used to allow for a separate but related influence of institutional and macroeconomic shock variables on both investment and growth, thereby permitting these variables to affect growth directly, and through their influence on investment, itself an important determinant of growth. It addressed the concerns of some researchers who felt research in the area had greatly lacked empirical testing of a wide range of theoretical, historical and narrative hypotheses.

The econometric modeling suggested that labour institutions did indeed have a significant impact on both growth and investment over this period, even when controlling for macroeconomic shocks. However, not all institutional variables were statistically significant in the baseline specification. In addition to the baseline specification, a number of alternative specifications were estimated, both to test the robustness of the baseline specification as well as to provide an alternative perspective on the relationships between the dependent variables and the institutional variables. The model appeared to be reasonably well specified, as evidenced in particular by the similarity of the baseline 3SLS results to the SUR results, and the results of the Davidson and MacKinnon (2004) test for 3SLS overidentification.

The model as constructed also has certain limitations. The model is probably not general enough to encompass an explanation for the rise and fall of the Golden

Age. The Introduction to this thesis discussed the difficulties associated with interpreting cross-country growth regressions of the type presented in this chapter with respect to model uncertainty. One reason for this is that the relevant data is only available from 1960 onwards, therefore missing out on some of the exceptionally rapid rates of growth observed in the 1950s. Second, the absence of data for the 1960s for Germany means that this interesting case of economic transformation cannot be studied in the same depth as for other countries. More fundamentally, the regressions presented above could not purport to demonstrate a predominant influence of institutions over other influences (such as capital, labour, geography or trade) as a determinant of growth and should not be interpreted as so doing. Instead, the regressions have attempted to provide a measure of support for the notion that institutions matter, and specifically that institutions mattered for the Golden Age and accordingly it still seems possible answer the question posed in the title of this chapter in a positive fashion. Labour institutions did matter, and this chapter has contributed to this debate by testing the narrative contributions of Eichengreen and the theoretical contributions of Cameron and Wallace (2002). The support for these theories presented above suggests that labour market institutions should feature in future accounts and explanations of the Golden Age.

3.A Appendix - Data Description

The sample period of the annual data used in this chapter is from 1960 to 1998. Twenty OECD countries are studied: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Norway, New Zealand, Portugal, Spain, Sweden, Switzerland, United Kingdom and the United States.

The figures for constant price GDP per capita and constant price investment shares (investment as a proportion real GDP are taken from version 6.1 of the Penn World Tables; both the GDP per capita and investment ratio variables are based on the Laspeyeres measures of GDP. The Penn World Tables data were discussed extensively in Chapter 2. The human capital variable is measured as average years of schooling in national populations, and is taken from de la Fuente and Domenech (2002). This OECD dataset contains updated calculations of average years of schooling and improves on other measures of average years of population, most notably the calculations which appear in Barro and Lee (1991 and 2000), by removing sharp breaks in the data, which de la Fuente and Domenech identify as being caused by changes in classification criteria.

The data relating to institutions and macroeconomic shocks were very kindly provided by Luca Nunziata. A description of the variables is provided below; this

description is based very closely on the appendix to Nunziata (2005), which contains more complete descriptions of the data sources used to construct the variables.

- Employment protection (EP)

  The range of this variable is from 0 to 2, increasing in the strictness of employment protection. It was created by interpolating Blanchard and Wolfers (2000) five year employment protection variable over the period from 1960 to 1998. The Blanchard and Wolfers data was itself created by chaining OECD (1999) data, which mostly relates to the 1990s and 1980s, with the earlier time periods covered in the Lazear (1990) data. The Lazear and OECD data was based on the construction of weighted indices which are a function of the level of severance pay, the nature of contracts (permanent versus temporary), and the notice period to be applied by firms to dismissals of workers with differing job tenure and seniority. Detailed explanation of the construction of this variable may be found in the appendix to Blanchard and Wolfers (2000). The graph below show the unweighted average of employment

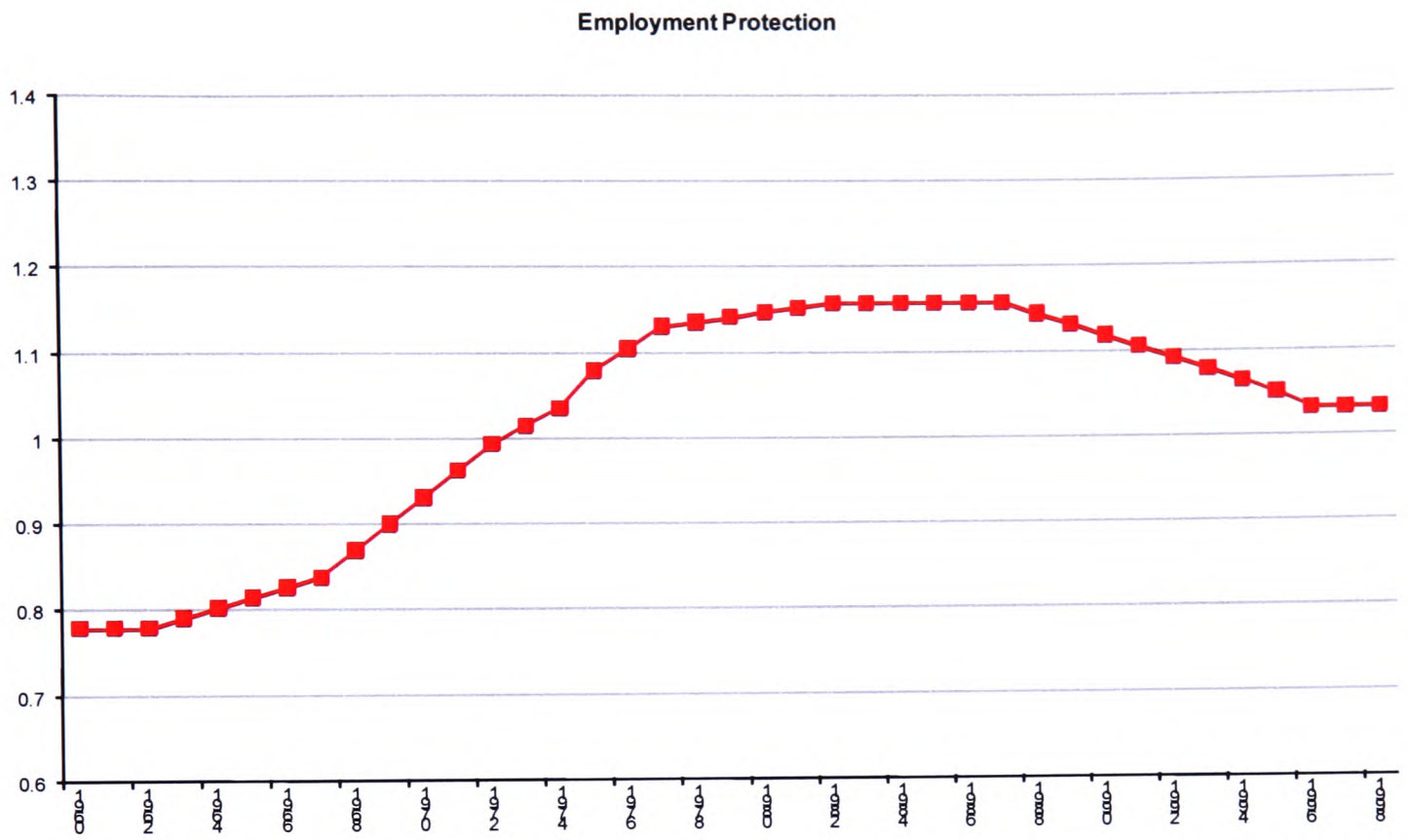

Figure 3.5: Unweighted average of employment protection.

- Benefit replacement ratio (BRR)

  This data is interpolated from biennial OECD data. The data refer to the first year of any unemployment benefits, and adjusted to account for the fact that in many countries benefit payments are linked to the size and composition of the families of the recipient. The benefits are expressed as proportion of average before tax earnings.

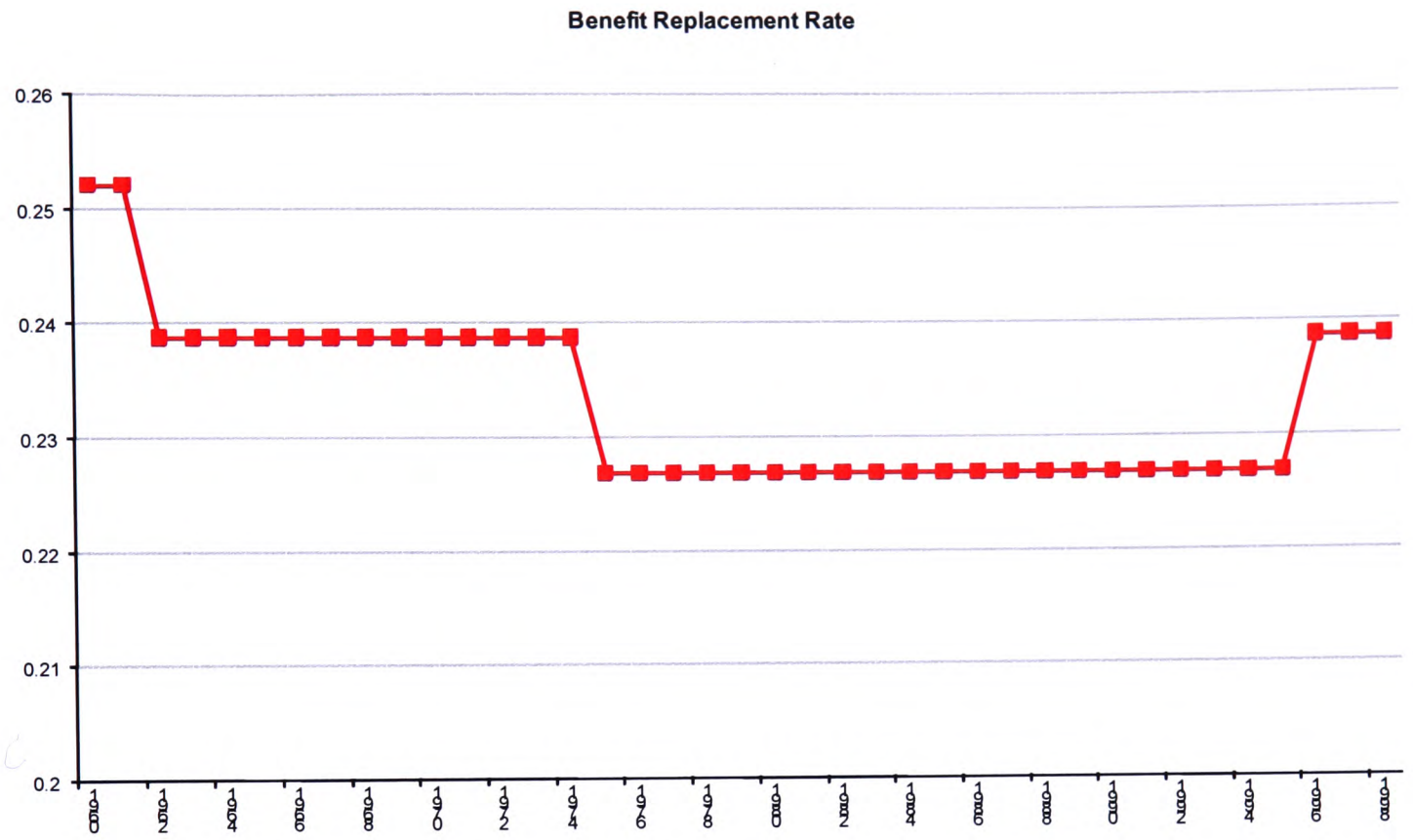

Figure 3.6: Unweighted average of benefit replacement rate.

- Benefit durations (BDAV)

  This variable was created by Nickell and Nunziata (2001). The average benefit duration (BDAV) is determined as follows:

$$BDAV = \alpha \frac{BRR_2}{BRR_1} + (1 - \alpha) \frac{BRR_4}{BRR_1} \tag{3.21}$$

  Here, BDAV represents the average duration of benefits. The BRR terms represent the benefit replacement rate. BRR_1 represents the benefit replacement rate during the first year of unemployment, BRR_2 represents the benefit replacement rate over the second and third years unemployment, BRR_4 the benefit replacement rate over the fourth and fifth years of unemployment. The α terms are weights, and more weight is given to the first year of benefits.

If the provision of unemployment benefit ceases after the first year, then $BRR_2 = BRR_4 = 0$. In this case, the value of the $BDAV$ index is obviously equal to zero. Conversely, if benefit provision is constant throughout the period, so that $BRR_2 = BRR_4 = BRR_1$, then the value of the $BDAV$ index is equal to one.

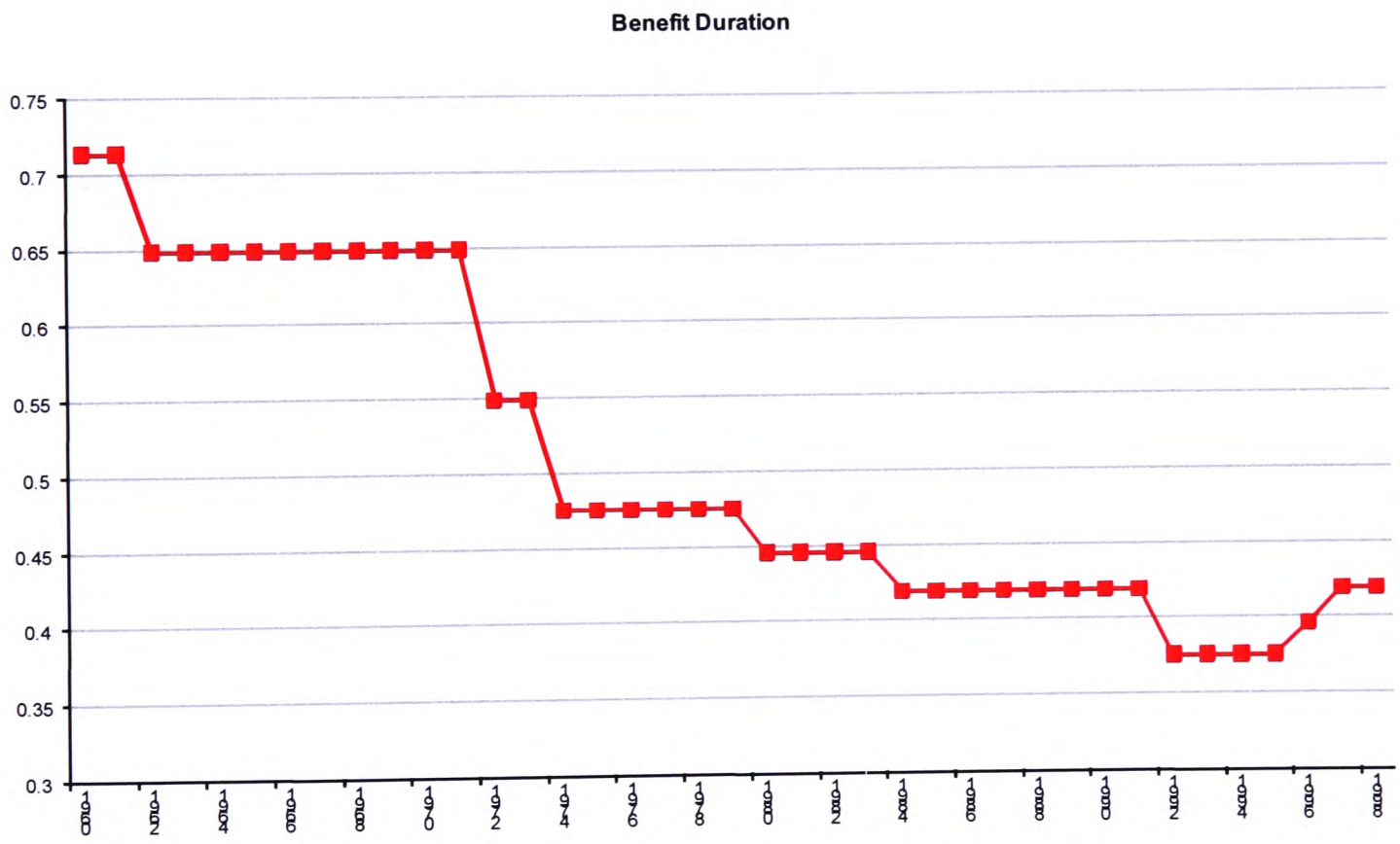

Figure 3.7: Unweighted average of average benefit duration.

- Net Union Density (UD)

This variable was constructed as the ratio of Total Reported Union Members (this is the gross figure less retired and unemployed members) to Wage and Salaried employers. For the non-European countries, this data is an updated version of the figures which appear in Visser (1996) for the total union membership figures and Huber, Ragin and Stephens (1997) for the wage and salaried employee figures. The data for the European countries is taken from Ebbinghaus and Visser (2000), except for Sweden, which is based on the same sources as the non-European countries. Nunziata (2001) provides more details on the complete construction of this variable, including information on the interpolations used for some early years in the sample for New Zealand, Portugal and Spain.

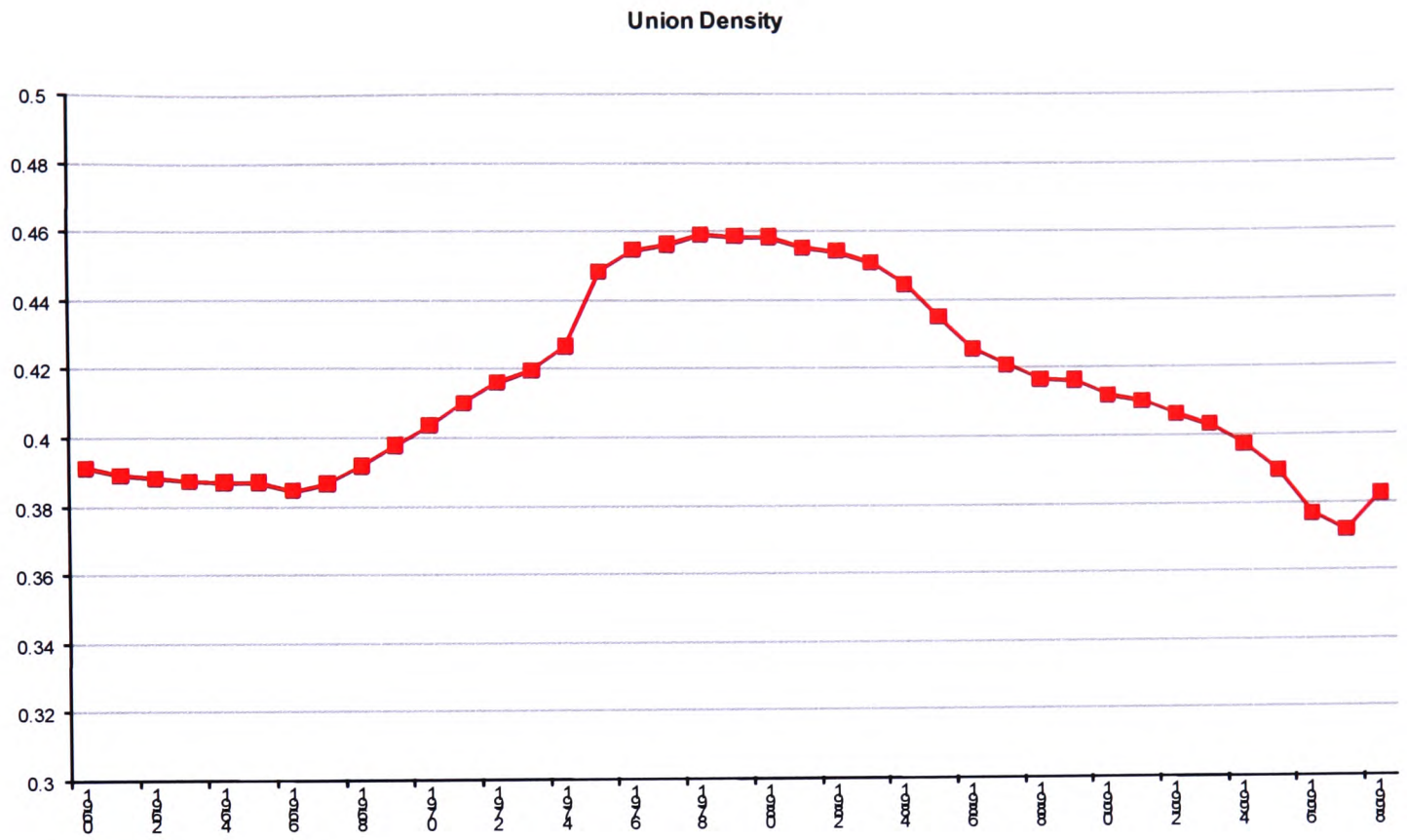

Figure 3.8: Unweighted average of union density.

- Bargaining Coordination (CO)

  This variable is an index with a range between 1 and 3. It is increasing in the degree of coordination on both the employer's side and union's side of the bargaining process. It was constructed by interpolating OECD data on bargaining coordination.

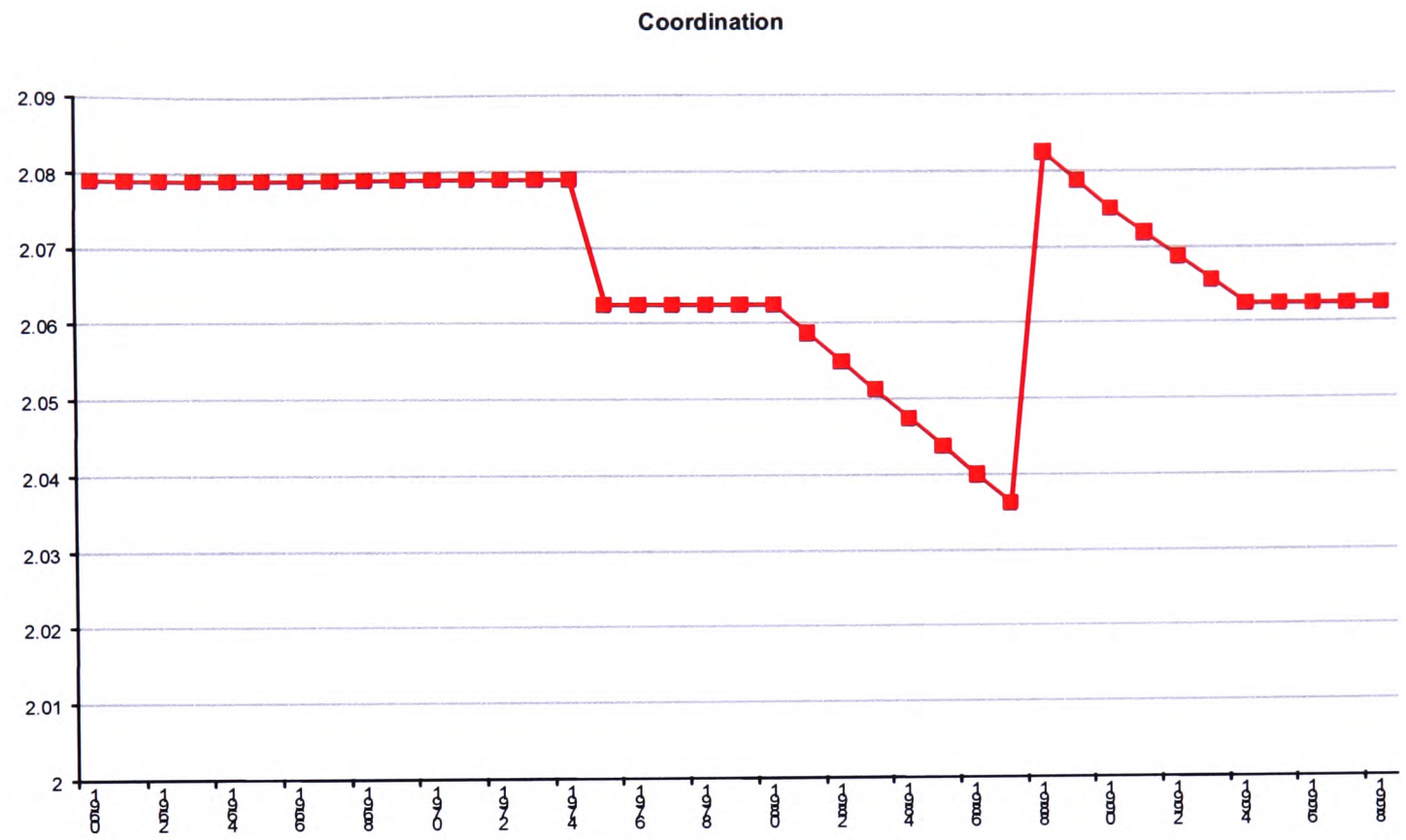

Figure 3.9: Unweighted average of bargaining coordination.

- Tax Wedge (TW)

The tax wedge is equal to the sum of the employment tax rate, the direct tax rate and the indirect tax rate.

The employment tax rate is calculated using the following ratio:

$$\frac{EC}{(IE - EC)} \tag{3.22}$$

Here, EC represents the employer's contributions for employees, while IE represents wages, salaries and social security contributions.

The direct tax rate is calculated using the ratio of direct taxes (DI) to the current receipts of households (HCR):

$$\frac{DI}{HCR} \tag{3.23}$$

The indirect tax rate is calculated as the ratio of total indirect taxation (TX) less subsidies (SB) to private final expenditure (CC):

$$\frac{TX - SB}{CC} \tag{3.24}$$

Therefore, the total tax wedge (TW) is simply the sum of these three components:

$$TW = \frac{EC}{(IE - EC)} + \frac{DI}{HCR} + \frac{TX - SB}{CC} \tag{3.25}$$

Data for the individual components of the tax wedge variable are taken from OECD National Accounts.

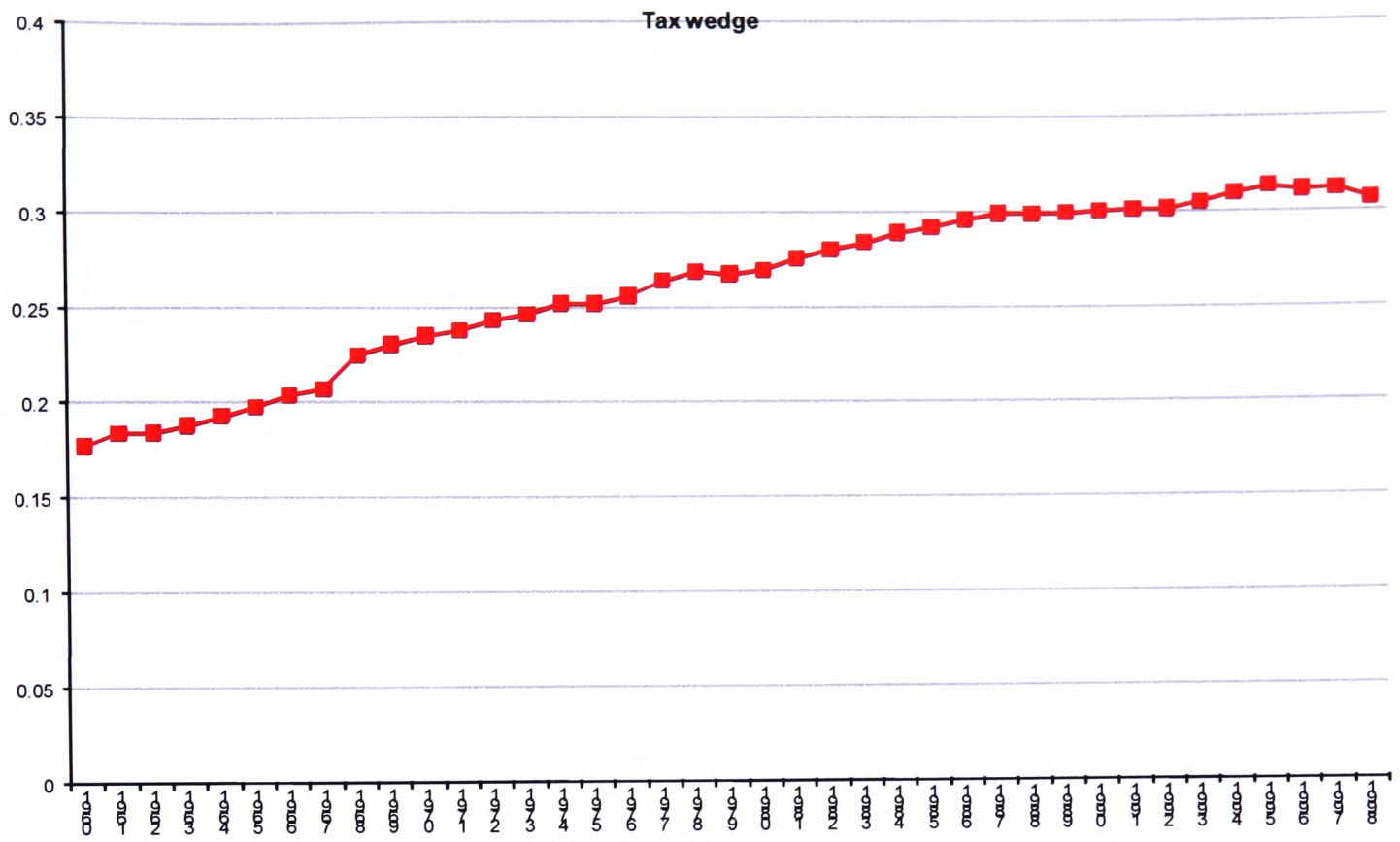

Figure 3.10: Unweighted average of tax wedge.

- Total factor productivity (TFP) shock (TFP)

  This variable is calculated as the deviation of TFP from trend, as determined by subtracting the Hodrick Prescott trend from each country's Solow residual:

$$TFPCY = \text{Solow Residual} - \text{HP Trend} \tag{3.26}$$

  The construction of the Solow residual used in this exercise is described in Nickell and Nunziata (2001).

- Acceleration in Money Supply

  The acceleration is calculated using money supply data taken from the OECD Economic Outlook Database.

- Terms of trade shocks (TT)

  This variable was created for each country using the following formula:

$$TTS = \frac{MC}{YC}\Delta\left\{\log\left(\frac{P_m}{P_G}\right)\right\} \tag{3.27}$$

  Here, MC measures imports at current prices, YC measures GDP at current prices, P_m is the import price deflator, P_G is the GDP deflator. Both deflators use 1990 as the base year.

- Openness

  A measure of the openness of the national economies is constructed in the conventional manner by calculating the ratio of the sum of imports and exports to real GDP, using the data on these variables from the Penn World Tables, version 6.1.

- Oil prices

  This chapter accounts for the role of oil prices by calculating the percentage change in the US dollar spot price of a barrel of West Texas Intermediate. Because this variable is the same for all countries, it cannot be used in the regressions in levels forms but can be used as part of an interaction term.

- Interaction terms.

  The significance of a number of interaction terms is assessed within the various regressions frameworks introduced above. The use of a particular

interaction terms that appear in the different specifications is informed by the predictions of the Eichengreen and the Cameron and Wallace (2002) models.

The table below provides summary statistics for the main labour market variables and macroeconomic shock variables.

Variable	Obs	Mean	Std. Dev.	Min	Max
EP	765	1.02	0.59	0.00	2.00
BRR	762	0.39	0.20	0.00	0.88
BDAV	760	0.42	0.35	0.00	1.04
UD	758	0.42	0.18	0.08	0.89
CO	765	2.07	0.61	1.00	3.00
TW	740	0.26	0.07	0.08	0.49
TFP	705	0.00	0.02	-0.07	0.07
MS	722	-0.01	0.17	-1.99	0.62
TT	746	0.00	0.02	-0.12	0.16
OPEN	770	45.86	25.32	7.24	171.79
OILchange	780	0.07	0.32	-0.46	1.68

Figure 3.11: Summary statistics for labour institutions variables and macroeconomic shock variables.

The following table shows the correlation between the main labour market variables:

Finally, before concluding the data section, the unbalanced nature of the panel is briefly described. Because of the unavailability data on labour market institutions for Portugal in the earlier part of the sample, the data for this country run from 1975

	EP	BRR	BDAV	UD	CO	TW
EP	1					
BRR	0.231	1				
BDAV	-0.201	0.089	1			
UD	-0.026	0.0387	0.211	1		
CO	0.342	0.032	0.007	0.259	1	
TW	0.276	0.368	0.16	0.306	0.113	1

Figure 3.12: Correlation coefficients for labour institutions variables.

to 1998, and therefore this country is excluded from most of the baseline regressions, but is included in the split sample regressions from 1974 to 1998. Where possible, data refer to West Germany. One consequence of using a West German sample is that details on investment rates are not available for the 1960s, so the West German data runs from 1970 to 1998. Hence, German (and Portuguese) data is not included in the split sample regressions from 1960 to 1973.

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