TAXATION, INVESTMENT AND GROWTH

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by

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Abstract

This thesis investigates empirically the effects of taxation policy on investment and growth.

Chapter 1 analyses whether there is any link between the structure of the tax system and the level of income per capita in the long run. Our specification closely follows that of Arnold et al. (2011), measuring tax structure using the shares of different taxes in total revenue. However, based on panel data for 17 OECD countries over the period 1970-2004, we do not find a robust ranking of different types of taxes in terms of their effects on the long-run level of income per capita, as this previous study suggested.

In Chapter 2, we estimate the long-run elasticity of the capital stock with respect to the user cost of capital by combining industry-level panel data from the EU KLEMS database with tax variables provided by the Oxford University Centre for Business Taxation for 13 OECD countries over the period 1982-2007. Our estimated long-run user cost elasticity is significantly different from zero and close to -1, suggesting that aggregate investment is highly responsive to tax incentives summarised by the tax-adjusted user cost of capital.

In Chapter 3, we estimate the long-run elasticity of capital with respect to the user cost using firm-level panel data from the Amadeus database for 9 countries over the period 1999-2008. Consistent with our findings in Chapter 2, we estimate a substantial long-run user cost elasticity which is significantly different from zero and close to -1. The main empirical results in both Chapters 2 and 3 are found to be robust to a wide range of econometric issues and different model specifications.

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Contents

Introduction

This thesis investigates how tax policy affects investment and growth. Chapter 1 analyses whether there is any link between the structure of the tax system and the level of income per capita in the long run. Chapter 2 consider the relationship between capital accumulation and the user cost of capital, using country-industry panel data and focusing on the role of corporate taxation. Chapter 3 also analyses this issue, using firm-level panel data from Amadeus.

A number of recent studies have suggested that raising a higher share of total tax revenue from taxes on consumption (particularly housing consumption) rather than from taxes on income (particularly corporate income) tends to increase the level of income per capita in the long run. These findings are consistent with the belief that different types of taxes may affect factor accumulation and growth differently. Nevertheless, the superiority of taxes on consumption over taxes on income is debatable both theoretically and empirically.

Chapter 1 contributes to this literature by estimating the effects of revenue-neutral tax structure changes on the long-run level of income per capita using panel data for 17 OECD countries over the period 1970-2004. We find that results based on the Pooled Mean Group estimator (Pesaran, Smith and Shin, 1999), which has been extensively used in this context (notably in the paper by Arnold et al., 2011), are rather sensitive to different model specifications. In contrast to Arnold et al.(2011), we do not find a robust ranking of different types of taxes in terms of their "growth effects". In particular, we do not obtain compelling evidence favouring consumption taxes over income taxes, or favouring personal income taxes over corporate income taxes. The only robust result appears to be that shifts in tax revenue towards property taxes are associated with a higher level of income per capita in the long run.

The reliability of results using the Pooled Mean Group estimator depends on the validity of the restriction that all long-run parameters in the estimated growth model are common to all countries. Moreover earlier results on tax structures measures are not found when this restriction is not imposed. This observation leads us to rigorously test the validity of the homogeneity restriction on the long-run coefficients in the estimated growth model imposed by the Pooled Mean Group estimator. Using a Wald test, we show that the commonly used Hausman test (Hausman, 1978) of the validity of this restriction may have low power in this context. In contrast, our Wald test rejects the restriction that all long-run parameters are common across all countries. Imposing only restrictions on the model specification that are not rejected by the Wald test, we find a significant positive association between the share of property taxes in total tax revenue and the long-run level of income per capita, but only for a subset of the countries in our sample.

Based on these findings, we conclude that it may be premature to draw concrete conclusions about the superiority of taxes on consumption over taxes on income, or about the superiority of taxes on personal income over taxes on corporate income, in terms of their effects on long-run income levels. In this case, caution is advisable when making policy recommendations concerning "growth-promoting" revenue-neutral tax structure reforms, especially for individual countries.

Chapter 2 revisits the the question about how responsive is the stock of capital to changes in the tax-adjusted user cost of capital, which has been extensively debated since the seminal work of Jorgenson (1963) and Hall and Jorgenson (1967).[1] The basic neoclassical investment theory predicts that, at least in the long run, the capital-output ratio is negatively related to the user cost of capital. In particular, if the production technology is Cobb-Douglas, the implied long-run elasticity of the capital-output ratio with respect to the user cost of capital is -1, which also measures the substitution elasticity between capital and labour. The user cost elasticity is not only a key parameter in assessing taxation policy but also a central element in many other aspects of macroeconomic analysis, such as the transmission mechanism between monetary policy and investment. Nevertheless, the existing literature has not reached a consensus on the magnitude of the user cost elasticity.

One explanation for this may be limited cross-sectional or time-series variation in the user cost of capital, as the majority of previous studies are based on

[1] Chapter 2 is based on a joint paper with Prof Stephen Bond, circulated as Oxford University Centre for Business Taxation WP10/15, available at http://www.sbs.ox.ac.uk/centres/tax/papers/Pages/PaperWP1015.aspx

US data over short periods of time. The novelty of Chapter 2 is that we combine recently released industry-level panel data for 13 OECD countries from the EU KLEMS database with detailed measures of statutory and effective tax rates provided by the Oxford University Centre for Business Taxation. By using this cross-country industry-level panel dataset covering more than two decades, we obtain rich cross-sectional and time-series variation in the user cost, which is essential to the identification of the user cost elasticity.

The central finding of Chapter 2 is that aggregate capital intensity is highly responsive to both relative prices and tax incentives, as summarised in the tax-adjusted user cost of capital. Based on an Error Correction Model, we estimate the long-run user cost elasticity to be significantly different from zero and close to -1.0, consistent with the prediction of (Hall and) Jorgenson's neoclassical investment model with a Cobb-Douglas production technology. Similar effects are estimated from both tax and non-tax components of the user cost. The evidence is particularly strong for investment in equipment among manufacturing industries, and it remains robust in Instrumental Variables estimations when we deal with the potential endogeneity of the user cost. Even when we allow for hetergeneous parameters in different sectors and countries, we continue to estimate a substantial long-run user cost elasticity. These findings lend support to the view that tax policy can substantially affect aggregate capital intensity in the long run.

Chapter 3 extends the empirical analysis on corporate income taxation and capital accumulation by using firm-level data from the Bureau van Dyck Amadeus database. The elasticity of substitution between capital and labour that we estimate at the industry level could reflect either substitution within individual firms or changes in the composition of aggregate production between more or less capital-intensive firms. Therefore, it remains an interesting question whether we observe a similar user cost elasticity at the firm level.

Previous empirical research using firm-level data has produced a wide range of estimates of the user cost elasticity. By pooling data for firms in different countries and in different industries, we again obtain more variation in the user cost of capital, which is essential for the estimation of the user cost elasticity. This approach has not been extensively used in previous studies.

Consistent with our results at the industry level in Chapter 2, our estimates of the long-run user cost elasticity at the firm level are significantly different from zero and close to -1. Moreover, this finding remains robust when we deal with the potential endogeneity of the user cost using a Generalised Methods of Moments (GMM) estimator, and when we control for other firm-level heterogeneities such as firm size, age, financial status and the possibility of tax losses.

To summarise, this thesis contributes to the literature on the effects of taxation on investment and growth by providing new empirical evidence. Results from Chapter 1 question whether tax structure affects growth outcomes through channels other than physical and human capital accumulation. Findings in Chapters 2 and 3 suggest that corporate income taxes can have important effects on capital intensity, and hence income per capita, in the long run. This suggests that tax policy has important implications for investment and growth. There are of course many other aspects of tax policy that may also have important implications for the economy, such as how taxes affect the allocation of capital, the supply of labour, and the accumulation of human capital. These important issues are left to be explored in future research.

Chapter 1

Does tax structure affect economic growth? Empirical evidence from OECD countries

1 Introduction

There has been a large body of literature on the optimal structure of taxation from the perspectives of efficiency and income distribution, but there is only a small number of empirical studies on the link between tax structure and economic growth. This study investigates whether there is any revenue-neutral tax structure adjustment that could be associated with a higher level of income per capita in the long run.

This is a subject where interest is particularly relevant at the present time, as the recent global economic recession makes it appealing to reform a country's tax structure to be "growth-promoting" while maintaining fiscal stability. Some countries have recently implemented changes to their tax structures, in the direction of raising less revenue from income taxes and more revenue from consumption taxes.[1] The motivation for such "growth-promoting" tax structure reforms can be summarised by the following statement:

> "No one likes paying taxes and, with tax rates already significant in most OECD countries, further rises in rates could be highly distortive and damaging to incentives. How then should additional tax revenues be raised? In a world of growing international integration, often described as 'globalisation', raising taxes on incomes (whether from earnings or capital) could be particularly harmful to employment, investment, entrepreneurship and growth....In addition the burden of taxation could be switched more toward taxes on consumption (taxed on a destination basis) and recurrent taxes on residential property."–OECD's Current Tax Agenda (June 2010, page 16).

The above statement is closely related to the premise that taxes on income are more distortionary than taxes on consumption. The choice between the two types of taxes is one of the oldest issues in taxation policy and has led to much scholarly discussion.[2] Nonetheless, the superiority of a consumption tax

[1] A recent example is the Czech Republic which implemented in 2008 a major overhaul of the personal income tax, replacing the previous progressive rate schedule with a single 15% rate levied on an enlarged base. This was accompanied by significant changes to the corporate income tax and an increase in the concessionary rate of value added tax applied to many goods and services. There are similar discussions of tax structure reform in Japan and Korea. There has also been prolonged discussion on shifting the tax base from income to consumption in the United Kingdom (the *Meade Committee Report*, 1978) and the United States (*Blueprints for Basic Tax Reform*, 1977; and Gordon et al., 2004).

[2] For example, Henderson (1948), Little (1951), and Corlett and Hague (1953) on the

over an income tax remains debatable both theoretically and empirically.

Despite growing interest in the growth effects of revenue-neutral tax structure reforms, there is only a small number of empirical studies on this topic. Early studies (Kneller et al., 1999; and Widmalm, 2001) use traditional econometric tools, such as pooled Ordinary Least Squares (OLS) and fixed-effects within-groups regressions, to estimate the effects of tax structure measures on income per capita in the long run. Implicitly, these econometric specifications restrict the slope coefficients in the growth equation to be common across countries. If this restriction is invalid, the resulting estimates may be biased and the inference may be invalid.

To address this issue, Arnold et al. (2011) apply the Pooled Mean Group (PMG) estimator, first developed by Pesaran, Smith and Shin (1999), to examine the link between tax structure and growth. Their PMG estimations specify the model in a less restrictive way by relaxing the homogeneity restriction on some of the slope coefficients in the growth equation. Arnold et al. (2011) show that given the level of tax revenue as a share of GDP, raising more tax revenue from taxes on income is associated with lower income per capita in the long run. Moreover, the authors suggest a "tax and growth ranking" in terms of effects on income per capita, with recurrent taxes on immovable property at the top of this ranking, followed by consumption and other property taxes,

effects of different taxes on the supply of effort; Atkinson and Stiglitz (1976), Chamley (1986), Judd (1985), and many others on the design of optimal tax structure from the perspectives of efficiency and distribution as surveyed in Auerbach (2006); Bankman and Griffith (1991), and Cunningham (1996) on the effects of different taxes on saving.

personal income taxes, and finally corporate income taxes. These findings lend empirical support to the policy recommendations as described in the OECD's Current Tax Agenda.

This study contributes to the literature on the link between tax structure and growth by analysing data for a panel of 17 OECD countries over the period 1970-2004. In particular, we investigate the robustness of the "tax and growth ranking" suggested in Arnold et al.(2011). We find that the results are sensitive to different model specifications. In particular, we find that the PMG estimation results are not robust under less restrictive parametric assumptions. This leads us to rigorously test the validity of the parametric restrictions imposed by the PMG estimator. We show that the Hausman test (Hausman, 1978), which is often used to guide the choice of whether to impose the homogeneity restriction on certain coefficients, may have very low power in this context. Moreover we show that some of the restrictions imposed by the PMG estimator are rejected by an alternative Wald test.

The rest of the paper is structured as follows. Section 2 provides a brief review of theories and existing empirical studies. Section 3 describes the data set. Section 4 reports the benchmark PMG estimation results. In Section 5, we check the robustness of the benchmark results by using a different sample (Section 5.1), a different measure of the share of investment in GDP (Section 5.1), and different specifications of time effects (Section 5.2). In Section 6.1, we compare the PMG estimation results with results obtained using both more restrictive pooled OLS and fixed-effects within-groups estimators, and with those obtained using the less restrictive Mean Groups estimator (Pesaran and Smith, 1995). The Hausman test results are also reported. In Section 6.2, we apply a Wald test to examine the validity of the parametric restrictions imposed in the PMG estimations. In Section 6.3, we report the estimation results that are obtained by imposing common long-run coefficients only on certain variables and within certain groups of countries that are not rejected by the Wald test. Section 7 concludes.

2 Literature Review

2.1 Related theories

In the framework of the neoclassical growth model, if different taxes affect the equilibrium capital-labour ratio differently, the choice of tax structure would affect the steady-state level of income per capita. Tax structure also matters for short-run growth when the economy approaches its equilibrium. Although growth solely depends on exogenous technical progress once the economy reaches its steady state, the transition process can be as long as many decades. Therefore, even the short-run growth effects of tax structure, if any, cannot be ignored.

Nonetheless, the debate on whether different types of taxes affect factor supplies differently has not yet reached a conclusion. For example, concerning the effects of different taxes on the supply of effort, Henderson (1948) argues that a tax on consumption has the same effect as an income tax. He points out that if people work to obtain goods, their incentives to work are affected in the same way, whether the resources available to them are reduced by an income tax or a consumption tax. Any advantage of consumption taxes in their effect on incentives is due simply to the fact that a change towards consumption taxes is usually accompanied by a reduction in the degree of progressivity in the tax system.

Corlett and Hague (1953) suggest an interesting case in which a reduction in the income tax rate is compensated by a small *ad valorem* non-uniform indirect tax in a two goods economy. This combination makes sure the same tax revenue is raised from the consumer. Their central conclusion is that in general, the consumer will work harder when the higher rate of tax is levied on the good which is more complementary with leisure, and *vice versa*. Therefore, a shift from taxes on income to taxes on consumption, raising the same revenue from an individual, can either increase or reduce the supply of effort and real income.

On the other hand, proponents of consumption taxes often argue that income taxes distort investment. For example, the neoclassical investment theory pioneered by Jorgenson (1963) and Hall and Jorgenson (1967) suggests that a corporate income tax system which implies higher cost of capital would lower investment, resulting in a lower capital-labour ratio in the long run. On the contrary, lowering the tax-adjusted user cost of capital, perhaps by providing more generous investment tax credits, allowing for faster depreciation of assets, or simply reducing the statutory corporate income tax rate, can induce additional investment.[3]

Another argument against an income tax is that it may reduce the return to saving, which is thought to be inefficient because it changes the relative prices of current and future consumption, and unfair because it discriminates between individuals with different preferences for saving. Nevertheless, the effects of income taxes on saving behaviour remains an ongoing debate and no conclusion has been reached yet.[4]

Although the link between tax structure and long-run growth is not the focus of the current study, it is worth mentioning the related literature. One source of technical progress that leads to long-run growth in the neoclassical growth models is new ideas generated by entrepreneurial activities, as emphasised in Schumpeter (1942). Cullen and Gordon (2002) show that there are several possible routes through which taxes can affect the amount of entrepreneurial risk-taking. On the other hand, in the framework of endogenous growth models, any tax policy that distorts the incentives for factor accumulation can have a permanent impact on the growth rate. Barro and Sala-I-Martin (1992) provide a comprehensive survey on the role of fiscal policy in endoge-

[3] Chapters 2 and 3 of this thesis will explore this channel empirically.

[4] Bankman and Griffith (1991), and Cunningham (1996) provide more detailed discussion on this point. Bankman and Griffith (1991), for example, argue that the difference between an income tax and a consumption tax is only significant for riskless saving as savers could adjust their asset portifolios to offset the extra tax burden.

nous growth models. Regarding the long-run growth effects of tax structure, Rebelo (1991) introduces a endogenous growth model which addresses the relative distortiveness of different taxes, whose conclusions lend some support to the premise that taxes on income are more distortionary than taxes on consumption.

As a summary, despite the long-standing theoretical debate on the choice between an income tax and a consumption tax, it is not clear whether different taxes would affect the level of income in the long run in different ways. As theories fail to provide clear-cut predictions, the link between tax structure and growth remains to be analysed empirically.

2.2 Early empirical studies

There is a large body of literature on the growth effects of fiscal policy, most of which focuses on macroeconomic variables such as total tax revenue as a share of GDP (Easterly and Rebelo, 1993; and Fölster and Henrekson, 2001) and total government spending as a share of GDP (Kormendi and Meguire, 1985; Grier and Tullock, 1987; and Barro, 1989, 1990, 1991). There is increasing interest in the link between tax structure and growth, but studies remain sparse. Early studies (Kneller, Bleaney and Gemmell, 1999; and Widmalm,

2001) estimate a regression function as in Equation (1.1):

$$\begin{aligned} Y_{it} &= \alpha + \beta_0' I_{it} + \beta_1' M_{it} + \beta_2' Z_{it} + \epsilon_{it} \\ i &= 1, 2, ...N, \text{ and } t = 1, 2, ...T \end{aligned} \tag{1.1}$$

where Y is the growth rate of real per capita GDP; I is a vector of important non-fiscal growth determinants suggested by theory, such as the investment-to-GDP ratio and the population growth rate; M is a vector of fiscal variables including indicators of tax structure; Z includes additional control variables such as the inflation growth rate; α is the intercept, β_0', β_1',and β_2' are vectors of coefficients, and ϵ_{it} is the error term for country i at time t. Importantly most studies include the initial level of real per capita income among the explanatory variables. In that case, if the dynamic model is stable, the long-run solution describes a steady state relationship between other explanatory variables and the level of real per capita income, rather than the growth rate.[5]

Both Kneller, Bleaney and Gemmell (1999) and Widmalm (2001) use five-year averages of the data to remove the effects of business cycles. Kneller, Bleaney and Gemmell (1999) argue that this allows them to separate the effects of policy variables on the transition from those on the steady state. Nevertheless, in their following study (Bleaney et al., 2001), they find that this period averaging does not appear to isolate long-run effects fully. Besides, it is generally found that the initial level of income per capita is negatively related

[5] Durlauf , Johnson and Temple (2005) provide a more detailed discussion on this point.

to the current growth rate. Widmalm (2001) points out that this is an empirical regularity reflecting conditional convergence, which is consistent with both the neoclassical growth model and certain types of endogenous growth models (for example, Rebelo, 1991). Therefore, the estimated coefficients on other explanatory variables in these studies should not be interpreted as indicating long-run growth effects.

Using panel data from 22 OECD countries over the period 1970–1995, Kneller, Bleaney and Gemmell (1999) estimate the effects of different types of taxes based on Equation (1.1).[6] In their study, Y is the five-year average annual growth rate of real per capita GDP.[7] I includes the initial level of GDP per capita,[8] the investment-to-GDP ratio, and the growth rate of the labour force. M includes "distortionary" and "non-distortionary" taxes (as a ratio of total GDP), as well as other elements in the budget.[9] Their pooled OLS and fixed-effects estimation results suggest that a higher level of "distortionary" taxes (as a ratio of total GDP) reduces income per capita. Nevertheless, the benchmark results are not robust when the authors apply Instrumental Variables estimation to deal with the potential endogeneity of the tax variables.

[6] Their data is provided by Government Finance Statistics Yearbook, published by the IMF.

[7] The period between 1970 and 1995 is divided into five sub-periods and the authors calculate the average annual growth rate of real per capita GDP for each sub-period.

[8] Measured at the start of each five-year sub-period.

[9] The authors classify different types of taxes into "distortionary" and "non-distortionary" taxes. Distortionary taxes are defined as taxes on income and profit, payroll and manpower, property, and social security contributions. Non-distortionary taxes are defined as those imposed on domestic goods and services. Both are expressed as percentages of total GDP. Similarly, government expenditures are classified as "productive" and "non-productive" expenditures, and they are included in M. Other elements of the budget are also included so that the variables in M sum up to zero.

Kneller, Bleaney and Gemmell (1999) emphasise that the estimated effects of different types of taxes may be biased if other elements in the budget, such as expenditures, are omitted. As suggested by Arnold et al. (2011), one possible solution is to focus on the growth effects of *revenue-neutral* changes in tax structure, which avoids the complication that changes in total tax revenue are reflected in changes in public spending.

Widmalm (2001) analyses the growth effects of revenue-neutral changes in tax structure based on data provided by the *OECD Tax Revenue Statistics,* which covers 23 OECD countries over the period 1965-1990. In Widmalm (2001), Y is the five-year average annual growth rate of real per capita GDP. I includes the initial level of per capita income, the investment-to-GDP ratio, and the population growth rate. Z includes variables such as the export-to-GDP ratio, the level and the variability of the inflation rate. M contains total tax revenue as a share of GDP, the share of a particular tax in total tax revenue, and a measure of progressivity.[10] Unlike Kneller, Bleaney and Gemmell (1999), different taxes are no longer grouped *a priori* into "distortionary" or "non-distortionary" taxes. Instead, taxes are grouped into five categories, namely, taxes on corporate income, taxes on labour and capital income for individuals, taxes on property, taxes on goods and services, and taxes on payrolls and social security contributions.[11]

Using the Extreme Bounds Analysis (Leamer, 1983), Widmalm (2001) finds

[10] Widmalm (2001) measures tax progressivity by estimating the elasticity of total tax revenue to GDP.

[11] All these tax variables are expressed as percentages of total tax revenue.

that there is a robust negative correlation between the share of personal income taxes and the growth rate of GDP per capita.[12] As the investment-to-GDP ratio is included in the estimation, this result suggests that tax structure may affect growth through channels other than physical capital accumulation (for example, human capital accumulation or the supply of effort). Widmalm (2001) finds that taxes on corporate income as a share of total tax revenue have a positive but fragile correlation with income growth. The evidence is also fragile in relation to taxes on payrolls and social security contributions, taxes on property, and taxes on goods and services.

2.3 Recent empirical studies

When estimating a growth equation using traditional econometric tools such as the pooled OLS and fixed-effects estimations, it is implicitly assumed that all slope coefficients in the regression function are common across groups.[13] Countries may have similar long-run growth paths in equilibrium, but the short-run dynamics may vary. This observation could have important implications, particularly for models which explicitly distinguish between the short-run dynamics and the long-run growth path. If it is indeed invalid to impose the restriction of homogeneous coefficients on the short-run dynamics across

[12] The procedure of the Extreme Bounds Analysis is as follows. First, a base regression with a set of key variables (such as tax structure variables) is estimated. Then the model is re-estimated by including different additional explanatory variables in a systematic way. If the estimated coefficient of a tax structure variable remains significant over this procedure, the correlation is said to be "robust" (and "fragile", *vice versa*). OLS estimations are applied in the Extreme Bounds Analysis.

[13] i.e. all coefficients except the intercept, which is allowed to vary across countries in the fixed-effects (withing groups) estimator.

countries, the results from the pooled OLS and fixed-effects estimations may be biased, and inference based on these specifications may be invalid.

A number of recent studies on the growth effects of tax structure (Gemmell et al., 2007; and Arnold et al., 2011[14]) apply the Pooled Mean Group (PMG) estimator, first developed by Pesaran, Smith and Shin (1999), which allows coefficients on the short-run dynamics to be heterogeneous across countries. Consider an Autoregressive-Distributed Lag (ADL) model shown below:

$$\begin{aligned} y_{it} &= \sum_{j=1}^{p} \lambda_{ij} y_{i,t-j} + \sum_{j=0}^{q} \delta'_{ij} X_{i,t-j} + \mu_i + \epsilon_{it} \\ i &= 1, 2, ...N, \text{ and } t = 1, 2, ...T \end{aligned} \tag{1.2}$$

where X_{it} $(k \times 1)$ is a vector of explanatory variables for each group i; λ_{ij} are scalars and δ'_{ij} are a vector of coefficients; μ_i represents the fixed effects and ϵ_{it} is the error term. Rearranging Equation (1.2), we obtain an Error Correction Model (ECM) as shown in Pesaran, Smith and Shin (1999):

$$\Delta y_{it} = \phi_i (y_{i,t-1} + \frac{\beta'_i}{\phi_i} X_{it}) + \sum_{j=1}^{p-1} \lambda^*_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q} \delta^{*\prime}_{ij} \Delta X_{i,t-j} + \mu_i + \epsilon_{it} \tag{1.3}$$

where $\phi_i = -(1 - \sum_{j=1}^{p} \lambda_{ij})$, $\beta_i = \sum_{j=0}^{q} \delta_{ij}$, $\lambda^*_{ij} = -\sum_{m=j+1}^{p} \lambda_{im}$ $(j = 1, 2, ...p-1)$ and $\delta^*_{ij} = -\sum_{m=j+1}^{q} \delta_{im}$ $(j = 1, 2, ...q-1)$. One advantage of the ECM specified in Equation (1.3) is that it separates the long-run relationship between variables, as captured by the term $(y_{i,t-1} + \frac{\beta'_i}{\phi_i} X_{it})$, from the short-run

[14] Earlier versions of Arnold et al. (2011) include Arnold (2008) and Johansson et al. (2008).

adjustment or convergence dynamics. The parameter ϕ_i measures the speed of convergence towards the steady state relationship. Note that in Equation (1.3), all coefficients are i specific. The long-run homogeneity assumption restricts -$\frac{\beta_i'}{\phi_i}$ to be the same across groups. The restricted version of Equation (1.3) becomes:

$$\Delta y_{it} = \phi_i(y_{i,t-1} - \theta X_{it}) + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta y_{i,t-j} + \sum_{j=0}^{q} \delta_{ij}^{*\prime} \Delta X_{i,t-j} + \mu_i + \epsilon_{it} \tag{1.4}$$

where $\theta = \theta_i$ =-$\frac{\beta_i'}{\phi_i}$. By estimating Equation (1.4) using the method of maximum likelihood, we obtain the PMG estimator.

Arnold et al. (2011) examine the effects of revenue-neutral changes in tax structure on the long-run level of income per capita, based on panel data for 21 OECD countries over the period 1970-2004 provided by the *OECD Tax Revenue Statistics.*[15] In Arnold et al. (2011), Δy_{it} is the annual growth rate of income per capita. The vector X_{it} includes the investment-to-GDP ratio, the growth rate of the working-age population, and the average years of schooling of the working-age population. To capture the effects of *revenue-neutral* changes in tax structure, total tax revenue as a share of GDP and shares of different types of taxes in total tax revenue are also included in X_{it}. Taxes are grouped into four major categories, namely, personal income taxes, corporate income taxes, consumption taxes and property taxes.[16]

[15] The 21 countries are: Australia, Austria, Belgium, Canada, Denmark, France, Finland, Greece, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, the United States, and West Germany (until 1990).

[16] Different from Widmalm (2001), taxes on labour and capital income for individuals are

The PMG estimation results in Arnold et al. (2011) are summarised in Table 1.1.[17] These results suggest that shifts in total tax revenue towards property taxes, in particular recurrent taxes on immovable property, are associated with a higher level of income per capita in the long run. The authors suggest that if there is a "tax and growth ranking" in terms of the effect of each type of tax on the long-run level of income per capita, property taxes would come top of this ranking (i.e. taxes on property tend to reduce income per capita the least), followed by consumption taxes, personal income taxes and corporate income taxes. Moreover, they find that this ranking remains robust in different model specifications with additional explanatory variables, such as the inflation rate.[18].

It is important to test the validity of the homogeneous long-run coefficients restriction as imposed in the PMG estimations. In practice, Hausman tests are often applied. The idea is to compare the PMG estimates with the Mean Group (MG) estimates of the long-run coefficients in the ECM. The MG estimates are obtained by estimating Equation (1.3) for each group separately and then averaging the group-specific parameter estimates (Pesaran and Smith, 1995). Under the null hypothesis that the long-run coefficients are homogeneous across countries, both the PMG and MG estimators are consistent while the PMG estimator is more efficient. Under the alternative hypothesis,

grouped together with taxes on payrolls and social security contributions to be termed as personal income taxes.

[17] Columns 1 and 6 in Table 1.1 are Columns 3 and 4 in Table 6 in Arnold (2008). Columns 2-5 correspond to Columns 2-5 in Table 1 in Arnold et al. (2011).

[18] These results are reported in the working paper version of Arnold et al. (2011) (Table 4, Arnold 2008).

only the MG estimator provides consistent estimates of the mean value of the heterogeneous long-run coefficients across groups; the PMG estimator does not. Rejection of the null hypothesis is then evidence against the validity of this homogeneity restriction.

It remains an empirical question whether the "tax and growth ranking" found in Arnold et al. (2011) is robust. Moreover, in Arnold et al. (2011), the important issue of testing the validity of the homogeneity restriction imposed on long-run coefficients is only partially addressed.[19] Furthermore, Pesaran, Smith and Shin (1999) point out that if the MG estimates are associated with large standard errors, the Hausman test is likely to have low power. A similar concern is raised in Gemmell et al. (2007).[20] This motivates us to rigorously test the validity of the homogeneity restriction imposed in the PMG estimations in this study.

2.4 Studies focusing on tax rates

It is worth noting that there are also empirical studies that compare the growth effects of different tax rates, such as Easterly and Rebelo (1993), Mendoza et

[19] There is some discussion of the Hausman test results in the Appendix in Arnold et al. (2011). Arnold (2008) (Table 6) reports the results of the Hausman test in the basic regression model without tax variables. The null hypothesis that the long-run coefficients on the investment-to-GDP ratio, the growth rate of working population and the average years of schooling are common across groups is not rejected by the Hausman test at the 10 per cent level in this baseline specification.

[20] Gemmell et al. (2007) analyse the growth effects of tax revenue and government spending using a panel of 17 OECD countries from 1970 to 2004. We do not review this paper in detail because it is not specifically concerned with revenue-neutral tax structure changes, and it is also closely related to Kneller et al. (1999) and Bleaney et al. (2001).

al. (1997), and Lee and Gordon (2005). Although these studies do not analyse explicitly the link between revenue-neutral tax structure changes and growth outcomes, they still shed light on the current debate.

For example, Lee and Gordon (2005) estimate a growth equation which includes the top statutory corporate income tax rates, the top average personal income tax rates, average tariff rates, and the average consumption tax rates as explanatory variables. With a 70-country sample, the authors find significantly negative coefficients on statutory corporate tax rates, controlling for other determinants of economic growth as well as other tax variables.

2.5 Summary

In summary, growth theories predict that taxes can affect the long-run level of income per capita, for example, through channels of factor accumulation. Nevertheless, it is not clear whether different taxes would affect growth in different ways. On the other hand, empirical evidence on the relationship between tax structure and economic growth is somewhat sparse and inconclusive.

Methodologically, early empirical studies implicitly restrict all parameters except intercepts in the growth equation to be common across countries, which may be invalid if countries have different short-run dynamics as the economy approaches the steady state. Recent studies such as Arnold et al. (2011) relax this restriction by applying the PMG estimator. Nonetheless, a further step towards a better understanding of the link between tax structure and growth requires one to rigorously test the validity of the common long-run parameter restriction underlying the PMG estimations.

3 Data description

We combine data from different sources to obtain a cross-country panel dataset, which covers 17 countries over the period 1970-2004.[21] Details of data sources, variable definitions and descriptive statistics of key variables are provided in Appendix A.

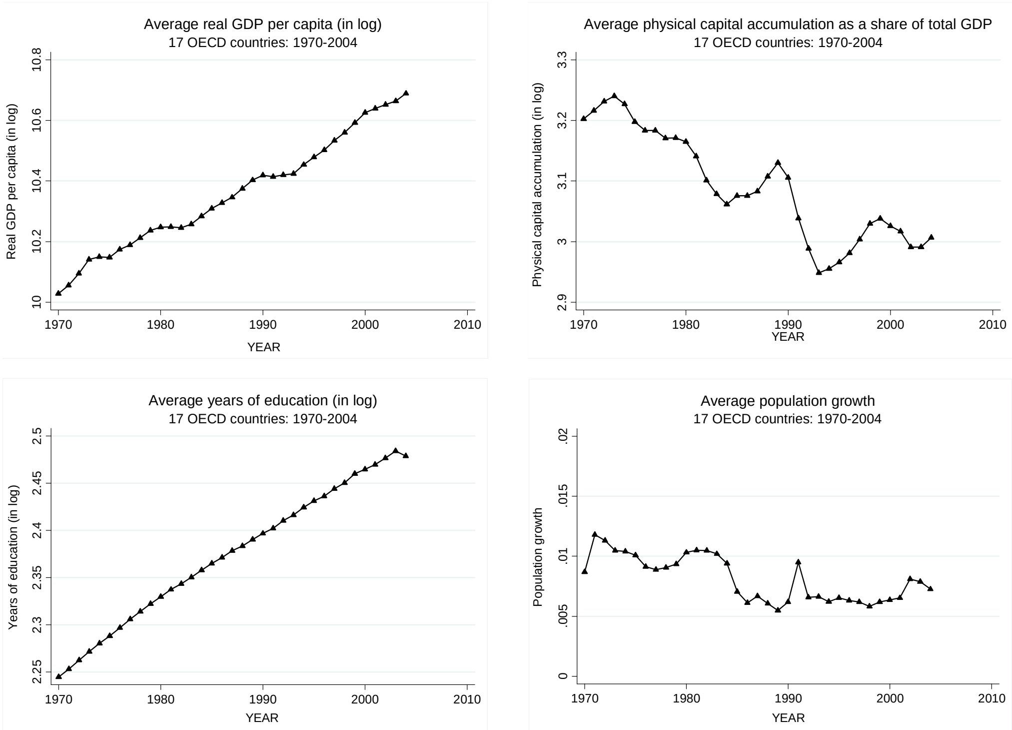
Figure 1.1 illustrates the evolution of the unweighted average real GDP per capita, physical capital investment as a share of GDP, years of education and the growth rate of the working-age population over the sample period.[22] On average, there is a clear upward trend in real GDP per capita and a downward trend in the investment share. Average years of education of the working-age population experienced a steady increase from 9 years in 1970 to 12 years in 2004. There remains mild positive growth in the working-age population on average, but the magnitude remains small throughout the sample period.[23]

[21] The 17 OECD countries are Australia, Austria, Belgium, Canada, Denmark, France, Finland, Greece, Ireland, Japan, Netherlands, New Zealand, Norway, Sweden, Switzerland, the United Kingdom, and the United States. Compared with Arnold et al. (2011), there are four countries that are not included. These four countries are West Germany (until 1990), Italy, Spain and Portugal. The main reason for choosing a smaller panel of countries is that we include only countries with longer available time series, which is essential to conducting the Mean Group estimations and the PMG estimations allowing for cross-section dependence.

[22] We use "investment" as a shorthand for physical capital investment in the rest of the paper.

[23] The average growth rate of working-age population increased from 0.62 per cent in 1990 to 0.95 per cent in 1991 (mainly due to a large increase in the working-age population in New Zealand in 1991), and it dropped to 0.66 per cent in 1992. This pattern is reflected as

Figure 1.1: Real GDP per capita, physical and human capital accumulation, and population growth over time



On average, tax revenue accounts for more than 30 per cent of total GDP in the sampled countries. The average total tax revenue as a share of GDP is highest in Sweden (around 47 per cent) and lowest in Japan (around 25 per cent). Tax structures are measured by the shares of major tax revenues in total tax revenue. Following Arnold et al. (2011), we distinguish between four main sources of tax revenue, namely, personal income taxes, corporate income taxes, consumption taxes and property taxes. Details of the classification of different types of taxes are provided in Appendix A.

Figure 1.2 plots the unweighted average shares of income taxes (personal and corporate income taxes together) as well as those of consumption and

a spike in the figure for average population growth rates.

Figure 1.2: Income taxes vs. consumption and property taxes

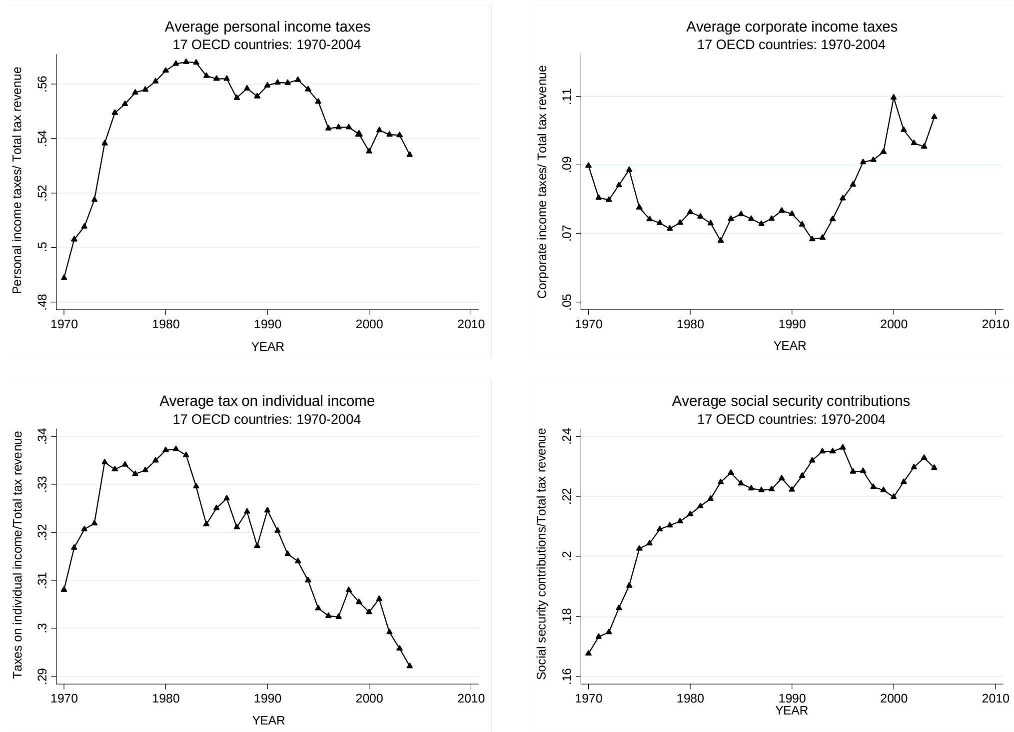
property taxes in total tax revenue for the 17 countries over the period 1970-2004. It reveals that for a typical country, taxes on income account for around 58 to 65 per cent of total tax revenue between 1970 and 2004. In 2004, the share of income taxes in total tax mix exceeded 50 per cent in all 17 countries, with the lowest share in Ireland (around 54 per cent) and the highest share in Sweden (around 70 per cent). Appendix B illustrates the evolution of the composition of total tax revenue for individual countries. The dominance of income taxes over other types of taxes is observed in the majority of the 17 countries during the sample period.[24]

In Figure 1.2, we observe an initial increase in taxes on income from around 58 per cent of total tax revenue in 1970 to around 63 per cent in 1974. This is mirrored by an initial drop in the share of consumption and property taxes in total tax revenue. Figure 1.3 shows that the initial jump in the share of income taxes in total tax revenue is largely driven by the increase in personal income taxes. Appendix B shows that this pattern is observed in many countries such

[24]Greece and Ireland during the early 1970s were exceptions with consumption taxes accounting for a slightly larger share of total tax revenue than income taxes.

as Belgium, Finland, Ireland, Japan, New Zealand and Switzerland.

Figure 1.3: Personal income and corporate income taxes



Further disaggregating personal income taxes into taxes on individual income (including wages and salaries, profits and capital gains), social contributions and taxes on payrolls, we can see that following an initial jump in the early 1970s, taxes on individual income as a share of total tax revenue declined gradually over time after the early 1980s. This decline is partly offset by the growing share of social security contributions during the same period. We do not illustrate the evolution of payroll taxes that do not confer entitlement to social benefits, as their share in total tax revenue is only around 1 per cent throughout the sample period.

As shown in Figure 1.3, the average share of corporate income taxes in total tax revenue dropped slightly from early 1970s until early 1990s. This downward trend was reversed around the year 1993 when it began to increase until the year 2000. On average, corporate income taxes account for around 7 to 11 per cent of total tax revenue. Nevertheless, this average hides a considerable spread across countries as revealed in Appendix B. For example, corporate income taxes were the second most important source of tax revenue in Japan between the 1970s and the early 1990s. In the year 2004, corporate income taxes account for only 5 per cent of total tax revenue in Austria but they account for 23 per cent of total tax revenue in Norway. Apart from the spread in statutory rates of corporate income taxes, these differences can be partly explained by features including institutional factors, the degree to which firms in a country are incorporated, taxation of oil revenues and the erosion of the corporate income tax base.[25]

Figure 1.4 shows that the average share of consumption taxes (general consumption taxes plus specific consumption taxes) in total tax revenue fell from 34 to 29 per cent between 1970 and 2004, although consumption taxes remain as the second most important source for tax revenue in most countries.[26] On average, property taxes account for around 5-7 per cent of total tax revenue.[27] Nevertheless, the share of property taxes in total tax revenue is higher in some countries than in others, as revealed in Appendix B. For example, the average share of property taxes in total tax revenue over the period 1970-2004 exceeds

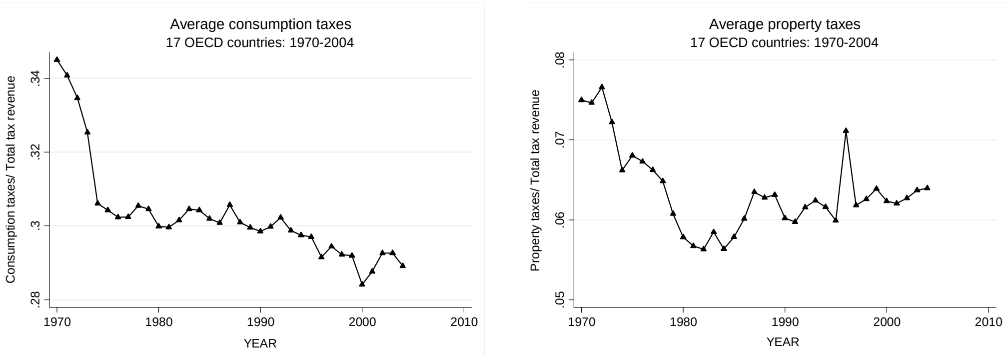
[25] For example, as a consequence of tax avoidance, generous depreciation schemes or other instruments to postpone the taxation of earned profits (*OECD Tax Revenue Statistics* 2009).

[26] Again, Japan between the 1970s and the early 1990s is an exception.

[27] There is a spike in the graph for average property taxes as a share of total tax revenue in the year 1996 and this is largely driven by the increase in property taxes in Greece in that year.

10 per cent in Canada, the United Kingdom and the United States. On the other hand, this figure is less than 3 per cent in Finland, Norway, and Sweden.

Figure 1.4: Consumption and property taxes



Appendix B shows that despite fluctuations in the absolute percentages of different types of taxes in total tax revenue, the relative importance of different types of taxes remains stable in most countries over the period 1970-2004, with personal income taxes as the most important source of tax revenue, followed by consumption taxes, corporate income taxes and property taxes. Furthermore, while the share of income taxes in total tax revenue becomes smaller towards the end of the sample period in some countries (for example, Netherlands and New Zealand), it increases in other countries (for example, Ireland).

4 Benchmark estimations

4.1 Model

The central question of the current study is, does there exist a revenue-neutral tax structure change that could shift the growth path upwards? To answer this question, we restrict ourselves to the framework of the neoclassical growth model and focus on the long-run relationship between the *level* of output per worker and tax structure variables.[28] We consider a human capital-augmented Solow model with a standard Cobb-Douglas production function.[29] In period t, output Y is given by:

$$Y_t = K_t^{\alpha} H_t^{\beta} \left(A_t L_t\right)^{1-\alpha-\beta} \tag{1.5}$$

where K and H are physical and human capital, respectively. L is labour and A captures the level of technology. α and β are the partial elasticities of output with respect to physical and human capital. The paths of these variables are described by the following equations:

$$\begin{aligned}
\dot{k} &= s^k y - (n+g+d)k \\
\dot{h} &= s^h y - (n+g+d)h \\
y &= k^{\alpha} h^{\beta} \\
\dot{A} &= gA \\
\dot{L} &= nL
\end{aligned} \tag{1.6}$$

where $y = Y/AL$, $k = K/AL$ and $h = H/AL$ are quantities per effective unit of labour. s^k and s^h stand for the shares of physical and human capital

[28]It is not the aim of the current study to distinguish between the neoclassical and the endogenous growth models. Kocherlakota and Yi (1997) provide a good reference on how to empirically distinguish between the two models when the growth effects of taxes are concerned.

[29]The formulation of the model in this study is largely based on Arnold et al. (2007).

investment in total output. n is the growth rate of labour, g is the rate of exogenous technological change and d is the depreciation rate of physical and human capital.

In equilibrium, $\dot{k} = 0$ and $\dot{h} = 0$. From Equation (1.6), it can be shown that:

$$\begin{aligned} k^* &= \frac{s^k y^*}{n+g+d} \\ h^* &= \frac{s^h y^*}{n+g+d} \end{aligned} \tag{1.7}$$

where k^*, h^* and y^* are the quantities in the steady state. By solving Equation (1.7), we obtain that:

$$\begin{aligned} k^* &= \left(\frac{s_k^{1-\beta} s_h^{\beta}}{n+g+d}\right)^{\frac{1}{1-\alpha-\beta}} \\ h^* &= \left(\frac{s_k^{\alpha} s_h^{1-\alpha}}{n+g+d}\right)^{\frac{1}{1-\alpha-\beta}} \end{aligned} \tag{1.8}$$

The steady state level of output per effective worker can be expressed as:

$$y^* = (k^*)^{\alpha}(h^*)^{\beta} = \left(\frac{s_k^{1-\beta} s_h^{\beta}}{n+g+d}\right)^{\frac{\alpha}{1-\alpha-\beta}} (h^*)^{\beta} \tag{1.9}$$

Taking the logarithms of the above equation, it is shown in Appendix 2 that the solution for $\ln y^*$ is:

$$\ln y^* = \frac{\alpha}{1-\alpha} \ln s_k + \frac{\beta}{1-\alpha} \ln h^* - \frac{\alpha}{1-\alpha} \ln(n+g+d) \tag{1.10}$$

Furthermore, the transitional dynamics can be expressed by the following equation (Romer, 1996):

$$\frac{d \ln y_t}{dt} = -\lambda \left(\ln y_t - \ln y^* \right) \tag{1.11}$$

where $\lambda = (1 - \alpha - \beta)(g + n + d)$. Under the assumption that $\alpha + \beta < 1$, the transitional path of output can be written as:

$$\ln y_t - \ln y_{t-s} = -\varphi \left(\lambda \right) \left(\ln y_{t-s} - \ln y^* \right) \tag{1.12}$$

where s is an arbitrary lag and $\varphi \left(\lambda \right) = e^{-\lambda s} - 1$. Substituting Equation (1.10) into Equation (1.12), we obtain the following expression:

$$\begin{aligned} \ln y_t - \ln y_{t-s} &= -\varphi \left(\lambda \right) [\ln y_{t-s} - \frac{\alpha}{1-\alpha} \ln s_k - \frac{\beta}{1-\alpha} \ln h^* \\ &\quad + \frac{\alpha}{1-\alpha} \ln(n + g + d)] \end{aligned} \tag{1.13}$$

If we take $s = 1$, it can be further shown that

$$\begin{aligned} \ln \widetilde{y}_t - \ln \widetilde{y}_{t-1} &= -\varphi \left(\lambda \right) [\ln \widetilde{y}_{t-1} - \frac{\alpha}{1-\alpha} \ln s_k - \frac{\beta}{1-\alpha} \ln h^* \\ &\quad + \frac{\alpha}{1-\alpha} \ln(n + g + d)] + \widetilde{V}_t \end{aligned} \tag{1.14}$$

where $\widetilde{y} = \frac{Y}{L}$, and $\widetilde{V}_t = \varphi \left(\lambda \right) \ln A_0 + g \left[\varphi \left(\lambda \right) t - \varphi \left(\lambda \right) + 1 \right]$.[30] The approxima-

[30] The calculation is shown in Appendix C.

tions of s_k, h^* and $\ln(n+g+d)$ are explained in Appendix C.

Next, we add tax structure measures to the right-hand side of Equation (1.14). It is conventional to use the Error Correction Model (ECM) for PMG estimations. One advantage of the ECM is that it distinguishes between the long-run growth path and the short-run convergence dynamics. It is this feature that enables us to examine the link between the long-run level of income per capita and tax structure, and at the same time to impose different homogeneity restrictions on the long-run and short-run parameters. As in Arnold et al. (2011), we include first differences of all the explanatory variables to control for the short-run dynamics.[31] The benchmark regression model is then specified as in Equation (1.15):

$$\begin{aligned}\Delta \ln \widetilde{y}_{i,t} \quad = \quad & -\phi_i \left(\ln \widetilde{y}_{i,t-1} - \alpha_1 \ln s^k_{i,t} - \alpha_2 \ln h_{i,t} - \alpha_3 n_{i,t} - \sum_{j=4}^{m} \alpha_j TS_{i,t} \right) \\ & + \beta_{1,i} \Delta \ln s^k_{i,t} + \beta_{2,i} \Delta \ln h_{i,t} + \beta_{3,i} \Delta n_{i,t} + \sum_{j=4}^{m} \beta_{j,i} \Delta TS_{i,t} \\ & + \gamma_i' \times \textit{Time Effects} + \delta_i + \varepsilon_{i,t} \qquad (1.15)\end{aligned}$$

where i is the subscript for each country. TS stands for a vector of indicators of tax structure, including total tax revenue (as a share of total GDP) and a combination of the tax share variables. γ_i is a vector of coefficients on the time effects. δ_i is the country-specific intercept and $\varepsilon_{i,t}$ is the error term which is assumed to follow a normal distribution. In our benchmark regressions, we

[31] This is the same model specification as in Arnold et al. (2011). We use it here for comparability. Admittedly, richer dynamic specifications could be considered with annual data.

follow Arnold et al. (2011) in using five-year period dummies to control for non-linear time effects.[32] In the benchmark PMG estimations, we restrict all the long-run coefficients (α_1, $\alpha_2 ... \alpha_m$) to be common across countries but allow the short-run coefficients ($\beta_{1,i}$,$\beta_{2,i}$...$\beta_{m,i}$), the coefficients on the time effects (γ_i) and the convergence rates (ϕ_i) to take different values for each country.

4.2 Benchmark results

Table 1.2 reports the benchmark PMG estimates of the long-run coefficients ($\widehat{\alpha}_1$, $\widehat{\alpha}_2 ... \widehat{\alpha}_m$) and the estimated average speed of convergence across countries ($\widehat{\phi} = \frac{1}{17} \sum_{i=1}^{17} \widehat{\phi}_i$), based on Equation (1.15).[33] Heteroskedasticity-robust standard errors are reported. Column 7 reports the basic results when no tax variable is included in the growth equation. Columns 8-12 report the results when different combinations of tax shares are included.

The unweighted average of country-specific convergence rates is in the range between -0.2 and -0.3 in different specifications. As expected, the estimated long-run coefficients on physical and human capital are both positive and significantly different from zero, while that on the growth rate of the working-age population is negative and significant. The estimated coefficient on total tax revenue (as a share of GDP) is negative in all models but it is not always significant.

[32] The construction of the five-year period dummy variables is explained in Appendix A.
[33] These PMG results are computed using the xtpmg command in Stata.

In Column 8, we distinguish between personal income taxes and corporate income taxes. We find that the share of personal income taxes and that of corporate income taxes in total tax revenue are both negatively associated with the long-run level of income per capita. A standard Wald test does not reject the null hypothesis that the estimated long-run coefficients on these two types of taxes are equal.[34]

Column 9 combines consumption and property taxes together and treats income taxes (personal income taxes and corporate income taxes together) as the omitted group. The significant positive coefficient on the combined consumption and property tax share suggests that at a given level of total tax revenue (as a share of GDP), raising more of this revenue from these two types of taxes is associated with a higher level of income per capita in the long run. In Column 10, we distinguish between consumption taxes and property taxes. The estimated coefficients on the two tax share variables are both positive and significant, however, this positive association with the long-run level of income per capita is estimated to be more prominent for property taxes.[35]

It is suggested by Arnold et al. (2011) that shifts in tax revenue towards recurrent taxes on immovable property are the most "growth-friendly". This is not supported by our results in Column 11, when we further disaggregate total

[34] The Wald test statistic for this restriction, which has a χ^2 (1) distribution under the null hypothesis of equal coefficients, is 1.03. The marginal significance level (p-value) at which the null hypothesis would be rejected is 0.31.

[35] The Wald test rejects the null hypothesis that the estimated coefficient on consumption taxes equals that on property taxes at the 1 percent level, with $\chi^2(1) = 9.70$ and a p-value of 0.002.

property taxes into recurrent taxes on immovable property and "other property taxes".[36] The estimated long-run coefficient on "other property taxes" is not only larger in magnitude but also significantly larger than that on recurrent taxes on immovable property.[37]

In Column 12, we compare personal income taxes, corporate income taxes and consumption taxes with property taxes as the omitted category. The estimated long-run coefficients on these three taxes are all negative and significant, indicating that shifts in tax revenue from these taxes to property taxes are associated with higher levels of income per capita in the steady state. Moreover, the Wald test results suggest that there is no significant difference between personal income taxes and corporate income taxes, but both have a long-run coefficient that is significantly lower than that on consumption taxes.[38]

4.3 Comparison with Arnold et al. (2011)

Comparing Table 1.1 and 1.2, it can be seen that the estimated long-run coefficients on the investment share are reasonably close. Differences are more prominent in the estimated long-run coefficients on human capital and on

[36] The taxes categorised as "other property taxes" include: recurrent taxes on net wealth, taxes on estates, inheritances and gifts, taxes on financial and capital transactions, non-recurrent taxes and other recurrent taxes on property (*OECD Tax Revenue Statistics* classification).

[37] The Wald test rejects the null hypothesis of equal long-run coefficients on recurrent taxes on immovable property and "other property taxes", with a p-value of 0.000.

[38] The null hypothesis that the estimated coefficients on personal income taxes, corporate income taxes and consumption taxes are all equal is rejected by the Wald test at the 1 percent level, with $\chi^2(2) = 31.52$ and a p-value of 0.00. The null hypothesis that the estimated coefficients on personal income taxes and corporate income taxes are equal is not rejected at the 10 percent, level with $\chi^2(1) = 2.41$ and a p-value of 0.121.

population growth. In Arnold et al. (2011), total tax revenue (as a share of GDP) has a negative and significant estimated coefficient, which remains robust throughout various model specifications. In contrast, the corresponding estimate in Table 1.2 is not always significant and is sensitive to different specifications.

More importantly, both studies find that raising more government revenue from taxes on income is associated with a lower steady-state level of income per capita. However, Arnold et al. (2011) find that corporate income taxes are less "growth friendly" than personal income taxes, which is not supported by our benchmark PMG results. We also do not find that recurrent taxes on immovable property are the most "growth friendly".

It is necessary to clarify several differences between Arnold et al. (2011) and the current study. Firstly, we use a different sample of countries. Secondly, we use total gross fixed capital formation (as a share of GDP) to measure the investment share, while Arnold et al. (2011) use non-housing fixed capital formation (as a share of GDP). Thirdly, we may construct the five-year period dummies in a different way.

The importance of these differences will be explored in the next section. In Section 5.1, we use a larger sample of countries. We also use non-housing fixed capital formation (as a share of GDP) as an alternative measure of the investment share. Section 5.2 considers three alternative specifications of the time effects. Section 5.2.1 presents the estimation results when a different set of five-year period dummies are included in the specification. Section 5.2.2 considers a more restrictive specification with country-specific linear trends. Section 5.2.3 controls for cross-section dependence, using the estimator proposed by Pesaran (2006). These variations also serve as robustness checks of our benchmark results.

5 Robustness checks

5.1 Alternative sample and proxy for the investment share

First, we examine the robustness of the benchmark regression results by using panel data for 21 OECD countries as in Arnold et al. (2011).[39] Table 1.3 summarises the results from the PMG estimations.[40] Comparing with corresponding columns in Table 1.2, we observe a similar pattern. In particular, contrary to Arnold et al. (2011) but consistent with Table 1.2, we find that there is no significant difference between corporate income taxes and personal income taxes (Column 16).[41]

[39] We add four countries (West Germany until 1990, Italy, Spain and Portugal) to the original set of 17 countries.

[40] We were not able to obtain a full set of results as in Table 1.2 because the likelihood function becomes non-concave in several cases. The Newton-Raphson algorithm is used for maximisation.

[41] In Column 16, we cannot estimate exactly the same model as in Column 12 because the likelihood function becomes non-concave in the PMG estimation. In Column 12, property taxes are treated as the omitted group while in Column 16, we treat personal income taxes as the omitted group. The estimated coefficient on corporate income taxes is insignificantly different from zero, indicating that imposing the same coefficient on personal income taxes and corporate income taxes would be a valid restriction.

Second, we use non-housing fixed capital formation (as a share of GDP) as an alternative proxy for the investment share.[42] Table 1.4 shows that using this different measure does not greatly affect the estimated mean convergence rate, the estimated long-run coefficient on human capital or that on the population growth rate. Now, there is some evidence that corporate income taxes are less "growth friendly" than personal income taxes in Columns 18.[43] Nonetheless, there is no evidence that recurrent taxes on immovable property are the most "growth friendly" (Column 21).

These two exercises suggest that the general pattern in our benchmark results are not very sensitive to different samples or regressors. Moreover, the discrepancies between the results in Arnold et al. (2011) and the current study cannot be fully explained by these different choices of sample and variables.

5.2 Different specifications of the time effects

In this section, we consider alternative specifications of the time effects. First, we use an alternative set of five-year period dummies to control for non-linear time effects. Second, we apply a more restrictive specification by including only a linear trend for each country instead of five-year period dummies. Finally,

[42] We do not use non-housing fixed capital formation in our benchmark specification because more observations would be lost. For example, this data is not available for Belgium in OECD National Accounts (Belgium is included in Arnold et al. 2011, suggesting that the authors may have had access to a different data source). The likelihood function also becomes non-concave for this smaller sample in many cases when we apply different specifications of the time effects.

[43] In Column 18, the Wald test of equal coefficients on personal income taxes and corporate income taxes yields a p-value of 0.005.

following Pesaran (2006), we allow for cross-section dependence.

5.2.1 A different set of five-year period dummies

Table 1.5 presents the PMG estimation results when an alternative set of five-year period dummies is included to control for the time effects. Previously we have included a dummy variable for each of the periods 1970-75, 1976-80, 1981-85, ... , 2001-04. Now instead we include a dummy variable for each of the periods 1970-74, 1975-79, 1980-84, ... , 2000-04. We can see that the results in Table 1.2 are quite sensitive to how the five-year period dummies are constructed.

Columns 24 and 25 show that shifts from taxes on income to those on consumption and property do not appear to affect the long-run level of income per capita. Nevertheless, when we distinguish between consumption taxes and property taxes, we find the results in these first two columns may be largely driven by consumption taxes, which do not appear to have significantly different effects from income taxes in this specification.[44] We continue to find that raising a higher share of tax revenue from property taxes is associated with a significantly higher level of income per capita (Column 26), and again this is largely driven by "other property taxes" (Column 27).

We observed previously that our PMG estimation results are somewhat

[44] In Column 26, the estimated long-run coefficient on consumption taxes is negative and marginally significant. In Column 28, the Wald test cannot reject the null hypothesis of equal long-run coefficients on personal inome taxes, corporate income taxes and consumption taxes (p-value equals 0.115).

closer to those in Arnold et al. (2011) when we measure the investment share using non-housing fixed capital formation (as a ratio of GDP). Nevertheless, the results based on this alternative proxy for investment are also sensitive to different ways of constructing the five-year period dummies, as shown in Table 1.6. In particular, there is now no evidence that the effects of personal income taxes and corporate income taxes are different from each other (Columns 30 and 34).[45] We also find no evidence that the effects of consumption taxes are significantly different from those of income taxes.[46] On the other hand, we continue to find that shifts of tax revenue towards property taxes, and particularly towards other property taxes, are associated with a higher level of income per capita.

5.2.2 Linear trends

In Figure 1.1, we observe an upward trend in real GDP per capita and years of education, and a downward trend in the investment-to-GDP ratio. This observation motivates us to include $\gamma_i t$ in Equation (1.15), where t is a linear time trend and γ_i is a country-specific coefficient. Table 1.7 summarises the PMG estimation results under this model specification. In comparison with Table 1.2, some differences are observed. Firstly, the magnitude of the estimated

[45] In Column 30, the Wald test of equal long-run coefficients on personal income taxes and corporate income taxes yields a p-value of 0.333. In Column 34, the Wald test of equal long-run coefficients on personal income taxes and corporate income taxes yields a p-value of 0.675.

[46] In Column 32, the estimated long-run coefficient on consumption taxes is insignificantly different from zero. In Column 34, the Wald test that the estimated long-run coefficients on personal income taxes, corporate income taxes and consumption taxes are equal yields a p-value of 0.661.

coefficient on human capital becomes much smaller. Secondly, the estimated coefficient on total tax revenue (as a share of GDP) is now strongly negative and less sensitive to model specifications.

Consistent with the benchmark results in Table 1.2, we continue to find that shifts in tax revenue towards property taxes (Column 40), and particularly towards other property taxes (Column 39) are associated with a higher long-run level of output per capita. In contrast to the benchmark results, Columns 38-40 here suggest that consumption taxes are no "better", if not "worse", than income taxes. For example, in Column 40, the estimated coefficients on personal income taxes, corporate income taxes and consumption taxes continue to be negative. Here, the estimated coefficient on consumption taxes is not significantly different from those on the two income taxes.[47]

5.2.3 Allowing for cross-section dependence

It is known that without controlling for cross-section dependence (i.e. correlation across countries in the error term for the same period), estimation based on macro-level cross-country panel data may be biased. Such bias would arise if countries tend to be affected by some common shocks, such as business cycle fluctuations. which may also be correlated with some of the included explanatory variables.

Pesaran (2006) suggests a simple procedure to allow for a form of cross-

[47] The Wald test of equal long-run coefficients on personal income taxes, corporate income taxes and consumption taxes yields a p-value of 0.350.

section dependence with a multiplicative factor structure. Analogously to allowing each country to have its own slope coefficients on the observed explanatory variables, this allows each country to have its own slope coefficient on an unobserved common factor. This form of cross-country dependence can be allowed for by including the time means $\frac{1}{N}\sum_{i=1}^{N}\Delta\ln y_{i,t}$ and $\frac{1}{N}\sum_{i=1}^{N}X_{i,t}$ as additional regressors in the ECM, where $\Delta\ln y_{i,t}$ is the dependent variable and $X_{i,t}$ denotes the vector of all explanatory variables. Countries are allowed to have heterogeneous responses towards the common factors. This formulation can also be regarded as a flexible way of introducing trends.

Table 1.8 summarises the PMG estimation results allowing for cross-section dependence in this way. We are only able to estimate the first four models in Table 1.2, as the likelihood function becomes non-concave in other cases. Now, the estimated average convergence rate is found to be higher, in the range between -0.344 and -0.593, while the corresponding estimate in Table 1.2 is in the range between -0.216 to -0.295. The estimated coefficient on human capital is insignificant in Column 41 and becomes significantly negative when more control variables are added. The estimated coefficient on total tax revenue (as a share of GDP) is negative and significant in these specifications.

Allowing for cross-section dependence in this way, there is some support for favouring personal income taxes over corporate income taxes (Column 42) but there is no evidence that a shift in tax revenue between taxes on income and taxes on consumption affects the level of income per capita in the long run (Column 43). Nevertheless, we continue to find a positive association between the share of property taxes in total tax revenue and the level of income per capita in the long run (Column 44). In this specification there is also a suggestion that the effects of taxes on consumption may be worse than those of taxes on income.

5.3 Summary

In this section, we check the robustness of the benchmark regression results by using a different sample, a different proxy for the investment share and different specifications of the time effects. The benchmark estimation results are rather sensitive to these variations. The only robust result appears to be that shifts in total tax revenue towards property taxes away from other taxes are associated with a higher level of income per capita in the long run. Relative to property taxes, the shares of personal income taxes, corporate income taxes and consumption taxes in total tax revenue are all found to be negatively related to the long-run level of income per capita. However, the ranking among these three taxes is not clear. Overall, in contrast to Arnold et al. (2011), we obtain no strong evidence for favouring personal income taxes over corporate income taxes, or for favouring consumption taxes over income taxes.

Table 1.9 demonstrates that shifts in total tax revenue towards property taxes are indeed associated with a higher long-run level of income per capita in these different model specifications. Therefore, in the next section, we will focus on the role of property taxes and proceed to test the validity of the common long-run coefficients restriction imposed in the PMG estimations.

6 Testing the validity of imposing homogeneity on long-run parameters

6.1 PMG, unweighted and weighted MG estimations

Up to this point, we have only reported results from the PMG estimations, which impose homogeneity on the long-run coefficients in Equation (1.15). It is important to examine whether estimation results are sensitive to different parametric assumptions. For example, the pooled OLS and fixed-effects within-groups estimators restrict both long-run and short-run coefficients (α_1, $\alpha_2 ... \alpha_m$, ϕ, β_1, $\beta_2 ... \beta_m$ and γ) in Equation (1.15) to be homogeneous across countries. On the other hand, the Mean Group (MG) estimator allows all coefficients ($\alpha_{1,i}$, $\alpha_{2,i} ... \alpha_{m,i}$, ϕ_i, $\beta_{1,i}$, $\beta_{2,i} ... \beta_{m,i}$ and γ_i) to be country-specific. In this case we may be interested in the central tendency of the distribution of the estimated coefficients across countries, as reflected in some estimate of the mean.

The unweighted MG estimates are obtained by simply averaging the country-specific estimates of each coefficient. One potential drawback of the unweighted

MG estimator is that they may be very sensitive to the presence of (possibly very imprecise) country-specific estimates with extreme values. The outlier-robust variant of the MG estimator (Bond, Leblebicioglu and Schiantarelli, 2010) addresses this issue by putting smaller weights on country-specific estimates with extreme values relative to the sample distribution. In practice, we first obtain country-specific estimates of each coefficient in separate estimations for each country. Then, we use a robust regression (Hamilton, 1991a) on a constant to calculate a weighted average for each coefficient in Equation (1.15).[48]

Table 1.10 summarises the PMG, weighted and unweighted MG, pooled OLS and fixed-effects within-groups estimates of the (mean) long-run coefficients and the (mean) speed of convergence based on Equation (1.15) when our measure of property taxes as a share of total tax revenue is included in the specification. We specify the time effect to be a linear trend in these and all subsequent estimations. The PMG and MG estimations allow for heterogeneous responses to the linear time effect, while the pooled OLS and fixed-effects within-groups estimations restrict the responses to be common across countries. It can be seen in Table 1.10 that the significant positive association between income per capita and the share of property taxes in total tax revenue is only found in the PMG estimations. Allowing all coefficients

[48] Following the country-by-country estimations, we regress the country-specific estimates for each variable on a constant using the STATA command "rreg", which generates the weighted average estimate by putting small weights on country-specific estimates with extreme values. Standard errors are calculated by the formula: $\widehat{\sigma} = \sqrt{\sum_i w_i \widehat{\sigma}_i^2}$, where $\widehat{\sigma}_i$ is the country-specific heteroskedasticity-robust standard error for a certain estimated coefficient, and w_i is the weight computed in the robust regression.

to be heterogeneous across countries, both the weighted and unweighted MG estimations yield positive mean long-run coefficients on property taxes, but with very large standard errors. When all (slope) coefficients are restricted to be common across countries, the pooled OLS (and within-groups fixed effects) regressions yield negative but insignificant long-run coefficients on property taxes.

The central question now is whether it is valid to restrict the long-run coefficients to be common across countries, as in Equation (1.15) and as imposed by the PMG estimator. Previous studies try to answer this question by comparing the PMG estimates with the unweighted MG estimates of the (mean) long-run coefficients, using the Hausman test. Under the null hypothesis that the long-run coefficients are homogeneous across countries, both the PMG and MG estimators are consistent while the PMG estimators are more efficient. Under the alternative hypothesis, however, only the MG estimator is consistent. Rejection of the null hypothesis is evidence against the validity of restricting the long-run coefficients to be the same across countries.

Table 1.11a reports the Hausman test results comparing the PMG with the unweighted MG estimates of the (mean) long-run coefficients. The Hausman test statistic for all five coefficients jointly has a $\chi^2(5)$ distribution under the null. The test statistic is 5.1, with a p-value of 0.404. Hence, the joint validity of the homogeneity restrictions imposed on these five long-run coefficients is not rejected. Considering the five restrictions individually, there is some doubt about the validity of the common long-run parameter restriction for the physical investment share (t-statistic = 1.906; p-value = 0.059). Table 1.11b compares the PMG and weighted MG estimates of each (mean) long-run coefficient individually.[49] Again there is some concern about the validity of the common long-run parameter restriction for the physical investment share (t-statistic =1.731; p-value =0.086). The restriction of common long-run coefficients is not rejected by these Hausman tests for any of the other variables.

It is worth noting that the weighted and unweighted MG estimates of the mean long-run coefficients on human capital and property taxes in Table 1.11 are very imprecise. Therefore, the Hausman test may have low power, which could incorrectly lead to the acceptance of the homogeneous long-run coefficients restriction. The low power of the Hausman test has been questioned previously by Im, Pesaran and Shin (1999) and Gemmell et al. (2007), but is not emphasised in Arnold et al. (2011). This motivates us to use an alternative method to examine the validity of the homogeneity restriction imposed on long-run parameters.

6.2 Alternative test of the homogeneity restriction

To further examine the validity of imposing the homogeneity restriction on the long-run coefficients, we estimate a dynamic model specified as Equation

[49] We were not able to compute the joint Hausman test using the weighted MG estimator, as this would require evaluation of the full covariance matrix for this estimator, not only the stnadard errors for each coefficient.

(1.16):

$$\begin{aligned}\Delta \ln \widetilde{y}_{i,t} &= -\sum_{i=1}^{17} \phi_i \ln \widetilde{y}_{i,t-1} + \sum_{i=1}^{17} \lambda_{i,1} \ln s_{i,t}^k + \sum_{i=1}^{17} \lambda_{i,2} \ln h_{i,t} + \sum_{i=1}^{17} \lambda_{i,3} n_{i,t} \\ &+ \sum_{i=1}^{17} \lambda_{i,4} (\frac{Total\ Tax}{GDP})_{it} + \sum_{i=1}^{17} \lambda_{i,5} (\frac{Property\ Tax}{Total\ Tax})_{it} \\ &+ \sum_{i=1}^{17} \beta_{i,1} \Delta \ln s_{i,t}^k + \sum_{i=1}^{17} \beta_{i,2} \Delta \ln h_{i,t} + \sum_{i=1}^{17} \beta_{i,3} \Delta n_{i,t} \\ &+ \sum_{i=1}^{17} \beta_{i,4} (\frac{Total\ Tax}{GDP})_{it} + \sum_{i=1}^{17} \beta_{i,5} (\frac{Property\ Tax}{Total\ Tax})_{it} \\ &+ \sum_{i=1}^{17} \gamma_i t + \sum_{i=1}^{17} \delta_i + \epsilon_{it} \end{aligned} \tag{1.16}$$

where ϕ_i is the country-specific speed of convergence and $\theta_{ij} = \frac{\lambda_{ij}}{\phi_i}$ $(i = 1, 2, ...17, j = 1, 2, ...5)$ are country-specific long-run coefficients on the investment-to-GDP share, human capital, the growth rate of the working-age population, total tax revenue (as a share of GDP) and property taxes (as a share of total tax revenue), respectively. γ_i is the country-specific coefficient on the linear time trend, and δ_i is the country-specific intercept. We can estimate Equation (1.16) by OLS and obtain standard errors that are robust to heteroskedasticity. Country-specific long-run coefficients and their associated standard errors are then obtained by non-linear transformation of the basic estimated coefficients.[50] Then, we can test whether the long-run coefficients θ_{ij} on a certain variable $(i = 1, 2...17)$ are the same across all countries, or across subsets of countries, using a standard Wald test.

Country-specific estimates of the long-run coefficients and the speed of

[50] In practice, this is achieved by the STATA command "nlcom", using the delta method.

convergence in Equation (1.16) are summarised in Table 1.12. The last column reports the p-values for the Wald test of equal long-run coefficients across all countries for each variable, individually. The Wald test does not reject the null hypothesis of equal long-run coefficients on the physical investment share across the 17 countries. Similarly, we cannot reject the null hypothesis of equal long-run coefficients on the working-age population growth rate and on total tax revenue (as a share of GDP), respectively.

However, the null hypothesis that the long-run coefficients on human capital investment are equal is rejected by the Wald test at the 1 per cent level, indicating that it is invalid to restrict this coefficient to be the same across all 17 countries. Note that the mean long-run coefficient on human capital investment was imprecisely estimated with a large standard error in both the weighted and the unweighted MG estimations and hence, the Hausman test of this restriction did not reject the null in either Table 1.11a or Table 1.11b. This exercise illustrates the low power of the Hausman test when the MG estimates are imprecise. Furthermore, the p-value of the Wald test of common long-run coefficients on the property tax share is only 0.231, which is lower than the p-values for the other three variables, and indicates some concern about the validity of imposing this parameter to be common across all 17 countries.

6.3 Relaxing the homogeneity restriction

Based on the findings in the previous section, it appears reasonable to impose the long-run coefficients on the investment share, the growth rate of the working-age population and total tax revenue (as a share of GDP) to be common across all countries (by imposing $\theta_{i,1} = \theta_1$, $\theta_{i,3} = \theta_{3,}$ $\theta_{i,4} = \theta_4$ for $i = 1, ..., 17$ in Equation 1.16), while allowing the long-run coefficients on human capital investment and property taxes to be country-specific. Table 1.13 presents the estimation results based on this restricted version of Equation (1.16).

The upper panel reports country-specific long-run coefficients on human capital investment and the property tax share. The lower panel reports the common long-run coefficients on the physical investment share, the growth rate of the working-age population and total tax revenue (as a share of GDP). The last column reports the Wald test results. Again, the Wald test rejects the null hypothesis of common long-run coefficients on human capital investment at the 1 per cent level. The Wald test of common long-run coefficients on the property tax share has a p-value of 0.219.

A closer examination of the country-specific estimates for the property tax variable in Table 1.13 reveals that there is still a considerable amount of heterogeneity across countries. In fact, for only three countries do we estimate a positive and significant long-run coefficient on the share of property taxes (Finland, Ireland and the UK) while for all other countries we find insignificant estimates. Nonetheless, in terms of this coefficient, some countries appear to be more similar to each other. This observation leads us to restrict countries within certain groups to have a common long-run coefficient on the share of property taxes. We split the 17 OECD countries into three sub-groups. The first group includes Finland, Ireland and the UK. The second group includes Austria, Belgium, France, Greece, Japan, Netherlands and the US, all of which have a positive but insignificant long-run coefficient on property taxes in Table 1.13. The third group includes the remaining 7 countries which have negative but insignificant estimates. It is worth noting that the Wald tests of common long-run coefficients on property taxes within these sub-groups all yield higher p-values than that when we pool the 17 countries together.[51]

In Table 1.14, Column 55 reports the PMG estimation results when all long-run coefficients are assumed to be common across all 17 countries. Column 56 presents the results when the long-run coefficients on both human capital investment and property taxes are allowed to be country-specific. Relaxing the homogeneity restrictions on these two variables, the unweighted average estimates of the long-run coefficients on property taxes and human capital investment both become insignificant. In Column 57, we only relax the homogeneous long-run coefficient restriction on human capital investment. In this case the estimated common long-run coefficient on the property tax share again becomes positive and significant.

[51] The p-value of the Wald test statistic is 0.455 for Group 1 countries, 0.992 for Group 2 countries and 0.930 for Group 3 countries, much higher than the p-value when we pool the 17 countries together (which is 0.219).

In Column 58, interactions between the country group dummies and the property tax variable are included in the long-run part of the PMG estimation. In this case, we restrict the long-run coefficient on property taxes to be the same across countries within a certain group, but allow this long-run coefficient to differ across groups. The results suggest that for countries in Group 1 and Group 2, a higher share of property taxes in total tax revenue is associated with a higher level of output per capita in the long run, but this association is not found for countries in Group 3.

Moreover, the Wald test rejects the null hypothesis that the estimated long-run coefficients on property taxes for all three groups of countries are equal at the 1 per cent level, but it does not reject the null hypothesis that the long-run coefficients on property taxes are equal for Group 1 and Group 2 countries.[52] Therefore, it seems reasonable to impose the homogeneity restriction on the long-run coefficient on property taxes among the countries in both Group 1 and Group 2. This restriction is imposed in Column 59. In this specification we continue to estimate a positive and significant long-run coefficient on the share of property taxes for Group 1 and Group 2 countries, while the long-run coefficient for Group 3 countries remains negative and insignificant.

[52] The p-value for the Wald test of this restriction is 0.882.

7 Conclusions

Recently, there has been considerable interest in the idea of reforming a country's tax structure to be "growth-promoting" by shifting tax revenue away from taxes on income and to taxes on consumption and property. Although recent empirical studies, notably Arnold et al. (2011), suggest a ranking of different types of taxes in terms of their effects on the level of per capita income in the long run, the findings presented in this Chapter cast doubt on the robustness of this empirical result.

In this study, we analyse data for a panel of 17 OECD countries over the period 1970-2004. Our benchmark Pooled Mean Group estimation results principally suggest that shifts in total tax revenue towards property taxes may be associated with a higher steady-state level of income per capita. This result remains robust when we use different samples, different regressors and different specifications of the time effects. Relative to property taxes, raising more tax revenue from personal income taxes, corporate income taxes or consumption taxes are all found to be associated with a lower level of income per capita in the long run. However, we find no strong evidence for favouring personal income taxes over corporate income taxes, or for favouring consumption taxes over income taxes, as previous studies have suggested.

Furthermore, when we allow the long-run coefficients in our dynamic growth model to take different values for each country, using a Mean Group estimator, we no longer find a significant positive association between the share of tax revenue from property taxes and the long-run level of income per capita. This motivates us to test the validity of restricting the long-run coefficients in the growth equation to be common across countries. Using a Wald test of these restrictions, which appears to have more power that a Hausman test in this context, we find that it is invalid to impose the homogeneous long-run coefficients restriction on all the explanatory variables in the growth equation. Further investigations, imposing parameter restriction which are not rejected by the Wald test, suggest that there may be a significant positive association between the property tax share and the long-run level of income per capita, but only for a sub-group of the countries in our sample.

Our analysis suggests that it may be premature to draw concrete conclusions about the superiority of taxes on consumption over taxes on income, or about the superiority of taxes on personal income over taxes on corporate income, in terms of their effects on long-run income levels. Therefore, caution is advisable when making policy recommendations concerning "growth-promoting" revenue-neutral tax structure reforms, especially for individual countries.

Table 1.1: PMG estimation results from Arnold et al. (2011)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
LR coefficients						
Physical capital	0.204***	0.190***	0.171***	0.168***	0.111***	0.195***
	(0.04)	(0.05)	(0.05)	(0.05)	(0.45)	(0.05)
Human capital	0.99***	1.30***	1.18***	1.40***	1.57***	1.52***
	(0.11)	(0.12)	(0.13)	(0.11)	(0.11)	(0.12)
Population growth	-0.05***	-0.08***	-0.07***	-0.07***	-0.07***	-0.08***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Tax revenue/GDP		-0.24***	-0.26***	-0.22**	-0.14***	-0.25**
		(0.05)	(0.05)	(0.04)	(0.04)	(0.04)
Personal income taxes		-1.13***				-1.35***
		(0.19)				(0.34)
Corporate income taxes		-2.01***				-2.40***
		(0.32)				(0.43)
Consumption&Property taxes			0.93***			
			(0.20)			
Consumption taxes				0.74***	0.72***	0.21
				(0.18)	(0.19)	(0.34)
Property taxes				1.45***		
				(0.43)		
Immovable property taxes					2.47***	
					(0.84)	
Other property taxes					-0.34	
					(0.51)	
Mean convergence rate	-0.30***	n.a.[1]	n.a.	n.a.	n.a.	n.a.
	(0.04)					
Five-year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	699	675	696	696	678	675

[1]No estimate is reported in Arnold et al. (2011).

[2]Robust standard errors in parentheses.

[3]*** p<0.01, ** p<0.05, * p<0.1

Table 1.2: Benchmark PMG estimations (17 OECD countries)

Variables	(7)	(8)	(9)	(10)	(11)	(12)
LR coefficients						
Physical capital	0.204***	0.190***	0.171***	0.168***	0.111***	0.195***
	(0.038)	(0.039)	(0.038)	(0.039)	(0.041)	(0.037)
Human capital	2.157***	2.441***	2.453***	2.442***	2.624***	2.438***
	(0.152)	(0.121)	(0.136)	(0.131)	(0.126)	(0.120)
Population growth	-0.023**	-0.038***	-0.036***	-0.036***	-0.050***	-0.029***
	(0.010)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Tax revenue/GDP		-0.062	-0.208***	-0.112	-0.180***	-0.032
		(0.067)	(0.077)	(0.075)	(0.068)	(0.069)
Personal income taxes		-1.047***				-2.654***
		(0.184)				(0.478)
Corporate income taxes		-1.250***				-2.946***
		(0.262))				(0.494)
Consumption&Property taxes			0.786***			
			(0.192)			
Consumption taxes				0.828***	0.570***	-1.575***
				(0.211)	(0.214)	(0.455)
Property taxes				2.324***		
				(0.492)		
Immovable property taxes					1.274**	
					(0.598)	
Other property taxes					4.975***	
					(0.663)	
Mean convergence rate	-0.295***	-0.231***	-0.253***	-0.237***	-0.223***	-0.216***
	(0.040)	(0.047)	(0.040)	(0.041)	(0.040)	(0.045)
Five-year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	575	575	575	575	575	575

[1]Long-run coefficients are obtained by imposing homogeneity across countries. The mean convergence rate is the unweighted average of country-specific estimates.
[2]In this table and the subsequent tables, short-run dynamics are included, as in Equation (1.15).
[3]Robust standard errors in parentheses.
[4]*** p<0.01, ** p<0.05, * p<0.1

Table 1.3: PMG estimation (21 OECD countries)

Variables	(13)	(14)	(15)	(16)
LR coefficients				
Physical capital	0.261***	0.163***	0.137***	0.098*
	(0.031)	(0.039)	(0.045)	(0.056)
Human capital	1.522***	2.289***	2.029***	1.938***
	(0.091)	(0.135)	(0.102)	(0.108)
Population growth	-0.023***	-0.049***	-0.048***	-0.047***
	(0.006)	(0.012)	(0.011)	(0.011)
Tax revenue/GDP		-0.159**	-0.112	-0.019
		(0.091)	(0.084)	(0.093)
Corporate income taxes				0.163
				(0.255)
Consumption&Property taxes		0.964***		
		(0.204)		
Consumption taxes			1.000***	1.553***
			(0.242)	(0.300)
Property taxes			3.423***	4.519***
			(0.599)	(0.763)
Mean convergence rate	-0.276***	-0.219***	-0.206***	-0.165***
	(0.051)	(0.033)	(0.038)	(0.033)
Five-year dummies	Yes	Yes	Yes	Yes
Observations	679	679	679	679

[1]Robust standard errors in parentheses.

[2]***p<0.01, **p<0.05, *p<0.1.

Table 1.4: PMG estimation with an alternative proxy for physical investment (17 OECD countries)

Variables	(17)	(18)	(19)	(20)	(21)	(22)
LR coefficients						
Physical capital	0.082	0.225***	0.089***	0.130***	0.000	0.221***
	(0.053)	(0.038)	(0.042)	(0.041)	(0.046)	(0.039)
Human capital	2.434***	2.633**	2.625***	2.592***	2.782***	2.607***
	(0.215)	(0.118)	(0.155)	(0.142)	(0.147)	(0.123)
Population growth	-0.022*	-0.029***	-0.044***	-0.041***	-0.050***	-0.024**
	(0.013)	(0.010)	(0.012)	(0.011)	(0.012)	(0.010)
Tax revenue/GDP		0.023	-0.108	-0.041	-0.126*	0.039
		(0.066)	(0.081)	(0.078)	(0.075)	(0.072)
PIT		-1.227***				-2.542***
		(0.188)				(0.483)
CIT		-1.774***				-3.061***
		(0.275)				(0.501)
Consumption&Property taxes			1.103***			
			(0.226)			
Consumption taxes				1.035***	0.773***	-1.275***
				(0.234)	(0.253)	(0.461)
Property taxes				2.883***		
				(0.539)		
Immovable property taxes					1.639**	
					(0.703)	
Other property taxes					5.810***	
					(0.789)	
Convergence rate	-0.257***	-0.250***	-0.267***	-0.250***	-0.227***	-0.230***
	(0.027)	(0.053)	(0.040)	(0.041)	(0.036)	(0.050)
Five-year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	533	533	533	533	533	533

[1]Robust standard errors in parentheses.

[2]*** p<0.01, ** p<0.05, * p<0.1

Table 1.5: PMG estimation with alternative five-year period dummies (17 OECD countries)

Variables	(23)	(24)	(25)	(26)	(27)	(28)
LR coefficients						
Physical capital	0.225***	0.160***	0.212***	0.197***	0.159***	0.168***
	(0.027)	(0.040)	(0.032)	(0.033)	(0.031)	(0.040)
Human capital	2.616***	2.611***	2.660***	2.562***	2.693***	2.560***
	(0.125)	(0.161)	(0.138)	(0.134)	(0.110)	(0.147)
Population growth	-0.039***	-0.059***	-0.054***	-0.052***	-0.055***	-0.057***
	(0.008)	(0.011)	(0.010)	(0.010)	(0.010)	(0.010)
Tax revenue/GDP		-0.129*	-0.116*	-0.177***	-0.262***	-0.174***
		(0.071)	(0.060)	(0.053)	(0.044)	(0.060)
Personal income taxes		-0.084				-1.056***
		(0.196)				(0.327)
Corporate income taxes		0.337				-0.883***
		(0.245)				(0.323)
Consumption&Property taxes			0.039			
			(0.184)			
Consumption taxes				-0.311*	0.087	-1.354***
				(0.177)	(0.169)	(0.328)
Property taxes				0.847***		
				(0.301)		
Immovable property taxes					-0.136	
					(0.327)	
Other property taxes					3.596***	
					(0.612)	
Mean convergence rate	-0.337***	-0.258***	-0.282***	-0.278***	-0.255***	-0.265***
	(0.047)	(0.041)	(0.042)	(0.045)	(0.051)	(0.044)
Alternative five-year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	575	575	575	575	575	575

[1]Robust standard errors in parentheses.

[2]*** p<0.01, ** p<0.05, * p<0.1

Table 1.6: PMG estimation with alternative five-year period dummies and an alternative proxy for physical investment (17 OECD countries)

Variables	(29)	(30)	(31)	(32)	(33)	(34)
LR coefficients						
Physical capital	0.170***	0.227***	-0.031	0.173***	0.113***	0.186***
	(0.035)	(0.041)	(0.056)	(0.034)	(0.032)	(0.041)
Human capital	2.925***	2.929***	3.247***	2.935***	2.750***	2.899***
	(0.169)	(0.165)	(0.272)	(0.151)	(0.119)	(0.154)
Population growth	-0.041***	-0.062***	-0.120***	-0.051***	-0.045***	-0.051***
	(0.010)	(0.013)	(0.024)	(0.012)	(0.011)	(0.012)
Tax revenue/GDP		0.052	0.292**	-0.148**	-0.249***	-0.121*
		(0.077)	(0.118)	(0.061)	(0.050)	(0.065)
Personal income taxes		-0.680***				-1.621***
		(0.231)				(0.394)
Corporate income taxes		-0.927***				-1.716***
		(0.319)				(0.401)
Consumption&Property taxes			1.080***			
			(0.311)			
Consumption taxes				0.084	0.392**	-1.470***
				(0.213)	(0.187)	(0.372)
Property taxes				1.477***		
				(0.385)		
Immovable property taxes					0.171	
					(0.373)	
Other property taxes					5.210***	
					(0.722)	
Mean convergence rate	-0.295***	-0.237***	-0.175***	-0.253***	-0.256***	-0.247***
	(0.045)	(0.047)	(0.036)	(0.043)	(0.049)	(0.049)
Alternative five-year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	533	533	533	533	533	533

[1]Robust standard errors in parentheses

[2]*** p<0.01, ** p<0.05, * p<0.1

Table 1.7: PMG estimation with linear trends (17 OECD countries)

Variables	(35)	(36)	(37)	(38)	(39)	(40)
LR coefficients						
Physical capital	0.243***	0.242***	0.245***	0.274***	0.202***	0.273***
	(0.032)	(0.030)	(0.031)	(0.022)	(0.020)	(0.022)
Human capital	-0.194	0.677**	0.863***	0.873***	0.955***	1.079***
	(0.291)	(0.307)	(0.300)	(0.249)	(0.177)	(0.268)
Population growth	-0.043***	-0.065***	-0.057***	-0.042***	-0.039***	-0.041***
	(0.012)	(0.014)	(0.013)	(0.008)	(0.008)	(0.008)
Tax revenue/GDP		-0.271***	-0.274***	-0.336***	-0.348***	-0.363***
		(0.071)	(0.067)	(0.054)	(0.024)	(0.051)
Personal income taxes		-0.804***				-1.571***
		(0.196)				(0.200)
Corporate income taxes		-0.365*				-1.714***
		(0.199)				(0.261)
Consumption&Property taxes			0.502***			
			(0.186)			
Consumption taxes				0.121	-0.525***	-1.439***
				(0.147)	(0.079)	(0.225)
Property taxes				1.676***		
				(0.220)		
Immovable property taxes					-0.123	
					(0.201)	
Other property taxes					3.308***	
					(0.218)	
Mean convergence rate	-0.217***	-0.196***	-0.203***	-0.241***	-0.257***	-0.237***
	(0.024)	(0.027)	(0.031)	(0.037)	(0.054)	(0.040)
Linear trends	Yes	Yes	Yes	Yes	Yes	Yes
Observations	575	575	575	575	575	575

[1]Robust standard errors in parentheses

[2]*** p<0.01, ** p<0.05, * p<0.1

Table 1.8: PMG estimation allowing for cross-section dependence (17 OECD countries)

Variables	(41)	(42)	(43)	(44)
LR coefficients				
Physical capital	0.176***	0.225***	0.231***	0.188***
	(0.025)	(0.009)	(0.015)	(0.015)
Human capital	-0.044	-0.360***	-0.394***	-0.278**
	(0.202)	(0.096)	(0.134)	(0.119)
Population growth	-0.035**	-0.013***	-0.022**	-0.029***
	(0.008)	(0.009)	(0.009)	(0.009)
Tax revenue/GDP		-0.241***	-0.246***	-0.327***
		(0.020)	(0.027)	(0.028)
Personal income taxes		0.095*		
		(0.051)		
Corporate income taxes		-0.214***		
		(0.091)		
Consumption & Property taxes			0.125	
			(0.083)	
Consumption taxes				-0.366***
				(0.097)
Property taxes				0.887***
				(0.195)
Mean convergence rate	-0.344***	-0.593***	-0.485***	-0.478***
	(0.054)	(0.107)	(0.081)	(0.077)
Observations	575	575	575	575

[1]Robust standard errors in parentheses.

[2]*** p<0.01, ** p<0.05, * p<0.1.

Table 1.9: Property taxes and growth in different PMG estimations

Variables	(45)	(46)	(47)	(48)	(49)
LR coefficients					
Physical capital	0.259***	0.225***	0.180***	0.266***	0.178***
	(0.035)	(0.041)	(0.039)	(0.024)	(0.017)
Human capital	2.341***	2.005***	2.449***	0.800***	0.238
	(0.137)	(0.123)	(0.154)	(0.255)	(0.162)
Population growth	-0.017**	-0.033***	-0.022**	-0.043***	-0.020***
	(0.008)	(0.009)	(0.009)	(0.009)	(0.005)
Tax revenue/GDP	-0.369***	-0.370***	-0.325***	-0.387***	-0.232***
	(0.075)	(0.083)	(0.075)	(0.050)	(0.028)
Property taxes	1.032***	1.391***	1.675***	1.606***	0.841***
	(0.354)	(0.394)	(0.436)	(0.222)	(0.194)
Convergence rate	-0.268***	-0.228***	-0.282***	-0.238***	-0.431***
	(0.044)	(0.037)	(0.046)	(0.032)	(0.054)
Five-year dummies	Yes	Yes	Yes		
Linear trends				Yes	
Cross-section dependence					Yes
Observations	575	679	533	575	575

[1]The original sample of 17 countries is used in Columns 45, 47, 48 and 49. A sample of 21 countries is used in Column 46. We use thethe alternative specification of five-year period dummies in Column 46, and the alternative measure for physical investment share in Column 47.

[2]Robust standard errors in parentheses.

[3]*** p<0.01, ** p<0.05, * p<0.1.

Table 1.10: Property taxes and growth: PMG, MG, pooled OLS and FE estimations (17 OECD countries)

Variables	(50) PMG	(51) Unweighted MG	(52) Weighted MG	(53) OLS	(54) FE
LR coefficients					
Physical capital	0.266***	0.428***	0.356***	0.223	0.019
	(0.024)	(0.088)	(0.058)	(0.426)	(0.392)
Human capital	0.800***	1.826	0.800	-0.234	0.527
	(0.255)	(1.164)	(0.862)	(1.001	(0.682)
Population growth	-0.043***	-0.070**	-0.037	-0.324*	-0.298**
	(0.009)	(0.031)	(0.023)	(0.168)	(0.168)
Tax revenue/GDP	-0.387***	-0.228	-0.181	-0.440	-0.962
	(0.050)	(0.191)	(0.179)	(0.495)	(0.708)
Property taxes	1.606***	1.526	0.852	-2.839	-2.673
	(0.222)	(2.576)	(0.868)	(2.568)	(3.731)
Convergence rate	-0.238***	-0.322***	-0.299***	-0.014	-0.024**
	(0.032)	(0.045)	(0.043)	(0.006)	(0.010)
Linear trends	Yes	Yes	Yes	Yes	Yes
Observations	575	575	575	575	575

[1]Column 50 presents the common long-run coefficients and the mean convergence rate obtained by the PMG estimator; Columns 51 and 52 present the mean long-run coefficients and the mean convergence rate obtained by the unweighted and weighted MG estimators; Columns 53 and 54 present the common long-run coefficients and the common convergence rate obtained by the OLS and the fixed-effects within-groups regressions.

[2]Robust standard errors in parentheses.

[3]*** p<0.01, ** p<0.05, * p<0.1

Table 1.11: Hausman tests of the homogeneous long-run coefficients restriction

LR coefficients	MG	PMG	Difference	S.E[1]
a. Unweighted MG and PMG				
Physical capital	0.428	0.266	0.162	0.085
	(0.088)	(0.024)		
Human capital	1.826	0.800	1.026	1.136
	(1.164)	(0.255)		
Population growth	-0.070	-0.043	-0.027	0.030
	(0.031)	(0.009)		
Tax revenue/ GDP	-0.228	-0.387	0.158	0.184
	(0.191)	(0.050)		
Property taxes	1.526	1.606	-0.080	2.567
	(2.576)	(0.222)		
Hausman test	$\chi^2(5) = 5.1$ $Prob > \chi^2 = 0.404$			
b. Weighted MG and PMG				
Physical capital	0.356	0.266	0.090	0.052
	(0.058)	(0.024)		
Human capital	0.800	0.800	0.000	0.824
	(0.862)	(0.255)		
Population growth	-0.037	-0.043	0.007	0.021
	(0.023)	(0.009)		
Tax revenue/ GDP	-0.181	-0.387	0.206	0.172
	(0.179)	(0.050)		
Property taxes	0.852	1.606	-0.754	0.839
	(0.868)	(0.222)		

[1]S.E=$\sqrt{Var(MG) - Var(PMG)}$

[2]Robust standard errors for the MG and PMG estimates in parentheses

Table 1.12: Long-run coefficients and speed of convergence for individual countries

Variables	Australia	Austria	Belgium	Canada	Denmark	Finland	France	Greece	Ireland
Convergence rate	-0.358***	-0.152	-0.399	-0.419**	-0.442*	-0.333**	-0.094	-0.212	-0.696***
	(0.107)	(0.116)	(0.262)	(0.197)	(0.233)	(0.166)	(0.221)	(0.178)	(0.115)
Physical Capital	0.187	0.785	0.195	0.428**	0.204**	0.028	0.611	0.528***	0.286***
	(0.172)	(0.560)	(0.179)	(0.221)	(0.109)	(0.192)	(0.449)	(0.132)	(0.059)
Human Capital	-4.124***	1.867	0.376	-1.785	0.439	2.873	7.508	0.329	2.455*
	(0.951)	(4.136)	(0.666)	(2.183)	(1.513)	(1.751)	(14.639)	(2.550)	(1.290)
Population Growth	-0.011	-0.097	-0.001	-0.033	0.033	0.047	0.065	-0.037	-0.022*
	(0.023)	(0.094)	(0.040)	(0.040)	(0.041)	(0.075)	(0.215)	(0.082)	(0.012)
Tax Revenue/ GDP	0.196	-0.166	-0.106	-0.221	-0.059	-0.321	-0.472	-0.186	-0.065
	(0.285)	(1.112)	(0.246)	(0.302)	(0.169)	(0.231)	(2.115)	(0.651)	(0.142)
Property Taxes	0.836	6.012	1.435	-0.294	0.262	13.495*	20.932	0.970	1.559***
	(1.477)	(7.124)	(5.740)	(2.201)	(2.551)	(7.462)	(57.136)	(1.155)	(0.567)
	Japan	Netherlands	New Zealand	Norway	Sweden	Switzerland	UK	US	Wald test (p-value)
Convergence rate	-0.328	-0.201***	-0.301**	-0.167	-0.309	-0.756**	-0.229**	-0.086	
	(0.208)	(0.074)	(0.126)	(0.143)	(0.190)	(0.306)	(0.104)	(0.184)	
Physical Capital	0.462***	0.609**	0.303**	0.369	0.273**	0.479***	-0.044	1.572	0.603
	(0.134)	(0.269)	(0.146)	(0.260)	(0.109)	(0.159)	(0.280)	(2.912)	
Human Capital	3.812**	-2.363	-1.015	2.593	-1.17	-1.673***	4.151*	16.77	0.000
	(1.661)	(2.563)	(4.379)	(3.130)	(1.538)	(0.646)	(2.362)	(38.034)	
Population Growth	0.039	-0.136	-0.014	-0.37	-0.113	-0.021	-0.166**	-0.357	0.803
	(0.110)	(0.121)	(0.020)	(0.342)	(0.073)	(0.018)	(0.084)	(0.693)	
Tax Revenue/ GDP	-0.383	-0.024	-0.869*	-2.509	-0.131	0.155	-0.424**	1.704	0.676
	(0.463)	(0.554)	(0.453)	(2.846)	(0.217)	(0.151)	(0.176)	(2.853)	
Property Taxes	-0.219	1.095	-8.795	-28.865	-0.758	-1.29	3.581***	15.982	0.231
	(1.140)	(4.997)	(6.270)	(24.312)	(0.979)	(1.259)	(1.373)	(31.015)	

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 1.13: Relaxing the homogeneity restriction on some long-run coefficients

Country-specific coefficients

Variables	Australia	Austria	Belgium	Canada	Denmark	Finland	France	Greece	Ireland
Human capital	-4.217***	-0.639	0.728	-1.261	0.713	1.244***	3.496*	2.391	2.574***
	(0.877)	(2.525)	(0.505)	(1.838)	(1.382)	(0.467)	(2.070)	(5.408)	(0.526)
Property tax	-0.208	1.556	0.678	-0.907	-1.79	3.124**	8.554	1.287	1.352***
	(0.914)	(3.488)	(1.992)	(1.312)	(2.597)	(1.390)	(9.951)	(1.336)	(0.294)
Convergence rate	-0.324***	-0.251***	-0.331***	-0.375***	-0.264**	-0.586***	-0.138**	-0.140	-0.713***
	(0.066)	(0.067)	(0.095)	(0.093)	(0.114)	(0.133)	(0.064)	(0.096)	(0.105)
	Japan	Netherlands	New Zealand	Norway	Sweden	Switzerland	UK	US	Wald test (p-value)
Human capital	3.155***	-1.790***	-7.663**	1.081	-1.118	-0.546	2.616*	52.158	0.000
	(0.751)	(0.577)	(3.487)	(1.294)	(1.026)	(0.359)	(1.502)	(226.336)	
Property tax	0.915	0.404	-1.792	-4.873	-0.439	-0.395	1.533**	18.083	0.219
	(0.954)	(2.157)	(4.886)	(3.763)	(0.703)	(0.796)	(0.620)	(77.363)	
Convergence rate	-0.298***	-0.344***	-0.236***	-0.247**	-0.377***	-0.619***	-0.250***	-0.026	
	(0.093)	(0.053)	(0.078)	(0.118)	(0.116)	(0.148)	(0.080)	(0.081)	

Common coefficients

Physical capital	0.265***
	(0.021)
Population growth	-0.026***
	(0.006)
Tax revenue/GDP	-0.168***
	(0.046)

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 1.14: Imposing data-consistent restrictions on long-run coefficients

Variables	(55)	(56)	(57)	(58)	(59)
LR coefficients					
Physical capital	0.266***	0.265***	0.260***	0.277***	0.277***
	(0.024)	(0.021)	(0.020)	(0.018)	(0.018)
Human capital	0.800***				
	(0.255)				
Population growth	-0.043***	-0.026***	-0.033***	-0.028***	-0.028***
	(0.009)	(0.006)	(0.006)	(0.005)	(0.005)
Tax revenue/GDP	-0.387***	-0.168***	-0.159***	-0.144***	-0.145***
	(0.050)	(0.046)	(0.050)	(0.042)	(0.042)
Property taxes	1.606***		1.127***		
	(0.222)		(0.214)		
Property Taxes*Group 1				1.466***	
				(0.220)	
Property Taxes*Group 2				1.361**	
				(0.667)	
Property Taxes*Group 3				-0.472	-0.471
				(0.374)	(0.374)
Property Taxes*Group 1&2					1.457***
					(0.208)
Average country-specific coefficients					
Human capital		0.110	0.135	0.056	0.056
		(0.223)	(0.207)	(0.210)	(0.210)
Property taxes		0.184			
		(0.170)			
Convergence rate	-0.238***	-0.325***	-0.284***	-0.322***	-0.321***
	(0.032)	(0.043)	(0.036)	(0.043)	(0.043)
Linear trend	Yes	Yes	Yes	Yes	Yes
Observations	575	575	575	575	575

[1]Standard errors in parentheses.

[2]*** p<0.01, ** p<0.05, * p<0.1.

Appendix A: Definition and sources of variables

The variables used in the regressions are defined as follows:

- Real GDP per capita (y): GDP at constant prices and constant PPPs (in millions US dollars) divided by the level of population aged 15-64 (in thousands). (Real GDP is provided by OECD National Accounts and the level of population aged 15-64 is provided by OECD Labour Force Statistics).

- Physical capital investment $\left(s^k\right)$: total gross fixed capital formation as a share of GDP (OECD National Account).

- Human capita investment (h): proxied by the average number of years of schooling of the population aged 25 to 64, taken from Arnold et al. (2007).

- Population growth (n): the annual growth rate of population aged 15-64 in percent (OECD Labour Force Statistics).

- Five-year period dummies: in the benchmark estimations, the period of 1970-2004 is split into 7 groups (1970-1975, 1976-1980, 1981-1985, 1986-1990, 1991-1995, 1996-2000, 2001-2004). In Section 5.2.1, the period of 1970-2004 is split into 7 groups in an alternative way (1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, 2000-2004).

  The following variables are taken from *OECD Tax Revenue Statistics.*

- Total tax revenue/GDP: this is the total tax revenue as a percentage of GDP.

- Income taxes: this includes taxes on income, profits and capital gains (categories 1000), social security contributions (category 2000) and taxes on payroll and workforce (category 3000).

- Personal income taxes: this includes taxes on individual income, profits and capital gains (category 1100), social security contributions (category 2000) and taxes on payroll and workforce (category 3000).

- Corporate income taxes: this includes taxes on corporate income, profits and capital gains (category 1200).

- Consumption and property taxes: this is the total of consumption taxes (category 5000, 6000) and property taxes (category 4000).

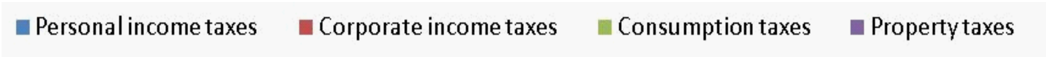
- Consumption taxes: this includes taxes on goods and services (category 5000) and other consumption taxes (category 6000). Taxes on goods and services include taxes on production, sales, transfer, etc (category 5100), taxes on the permission to use goods or to perform activities (category 5200), and unallocable between category 5100 and 5200.

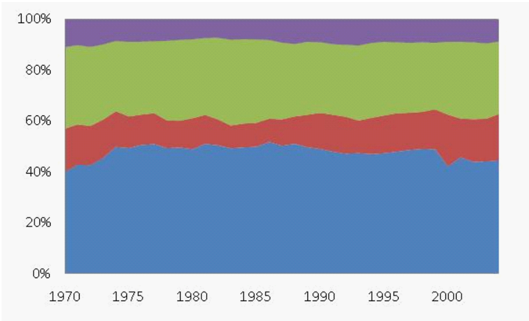
- Property taxes: this includes recurrent taxes on immovable property (category 4100), recurrent taxes on net wealth (category 4200), taxes on estates, inheritances and gifts (category 4300), taxes on financial and capital transactions (category 4400), non-recurrent taxes (category 4500) and other recurrent taxes on property (category 4600).

Descriptive statistics of key variables

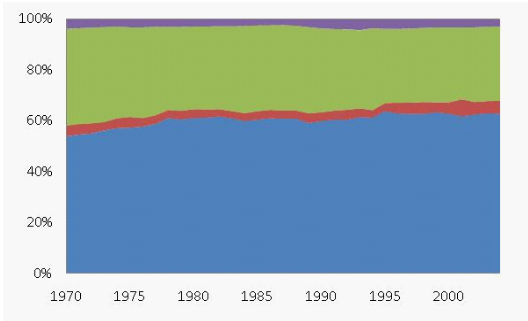
Variables	Mean	S.D	Min	Max
$\ln y$	10.358	0.249	9.563	10.978
$\ln s^k$	3.089	0.174	2.714	3.591
$\ln h$	2.374	0.123	2.001	2.595
n	0.811	0.648	-0.888	4.729
Tax revenue/GDP	0.355	0.078	0.181	0.522
Personal income taxes/Tax revenue	0.548	0.078	0.265	0.726
Corporate income taxes/Tax revenue	0.081	0.046	0.006	0.281
Consumption taxes/Tax revenue	0.303	0.076	0.128	0.524
Property taxes /Tax revenue	0.064	0.036	0.008	0.214

Appendix B: Proportions of major tax revenues in total tax mix

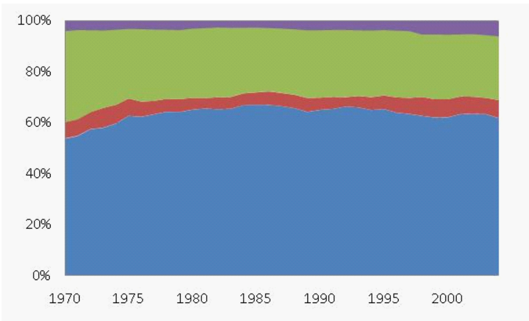




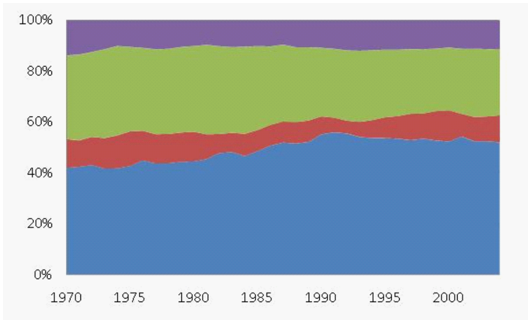
Australia



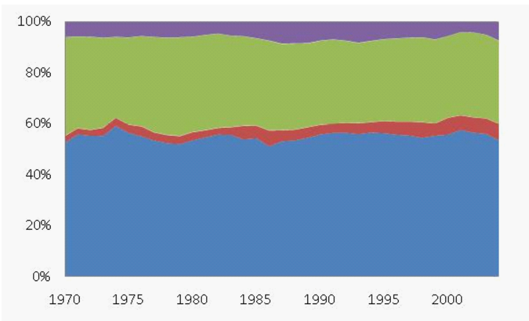
Austria



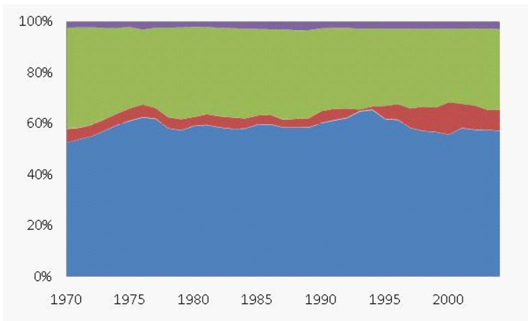
Belgium



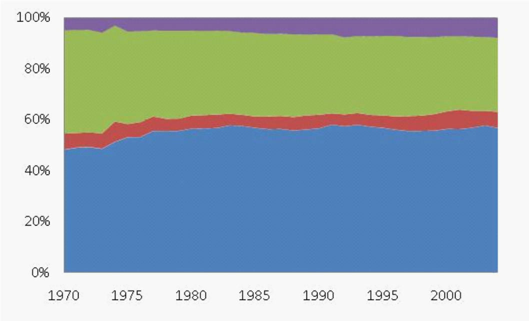
Canada



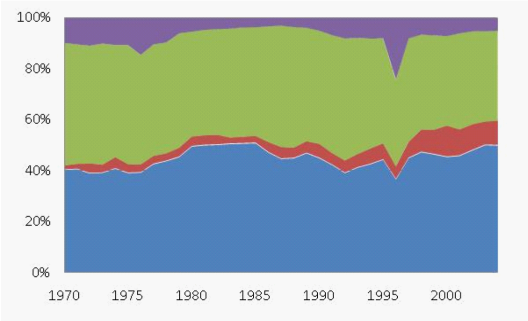
Denmark



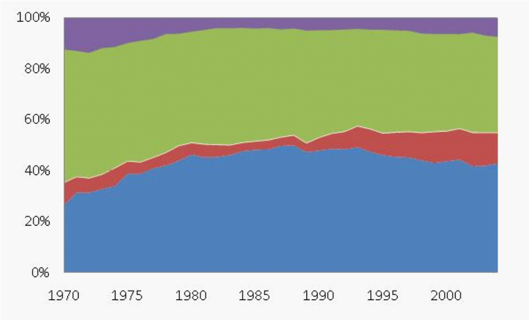
Finland



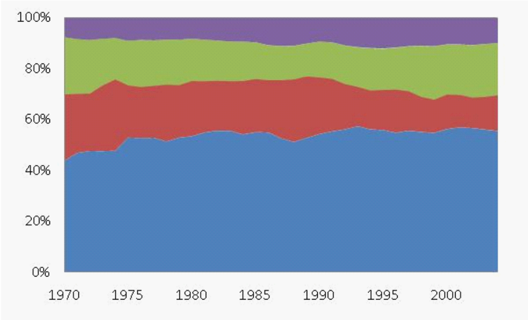
France



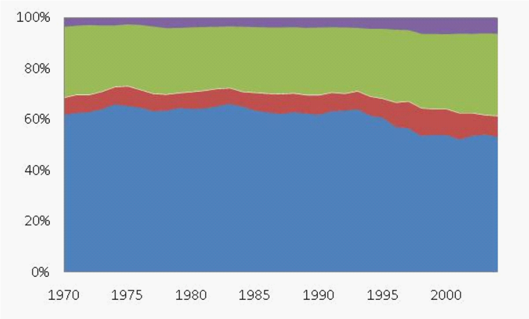
Greece



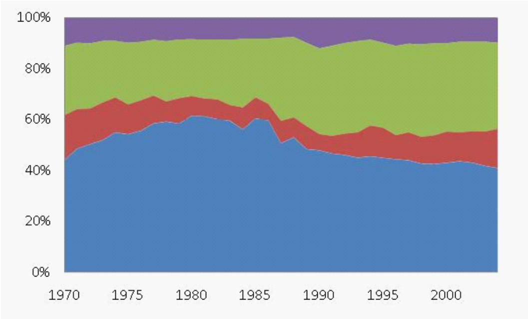
Ireland



Japan



Netherlands



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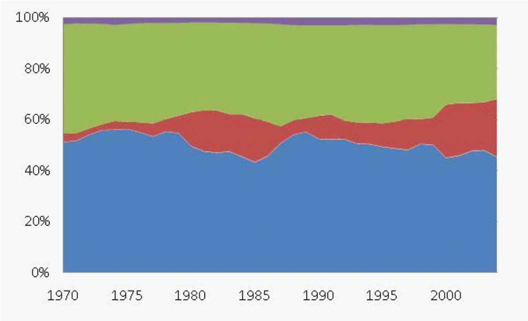
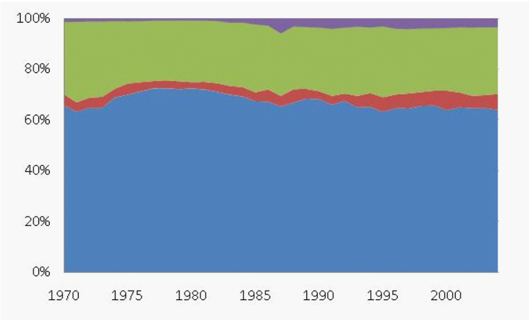
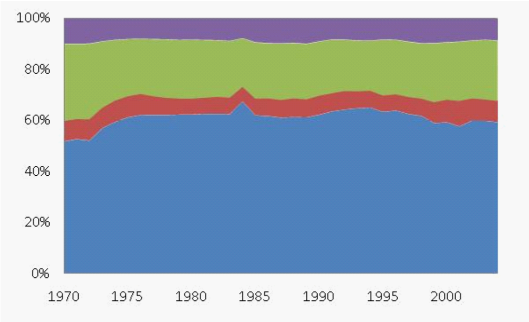


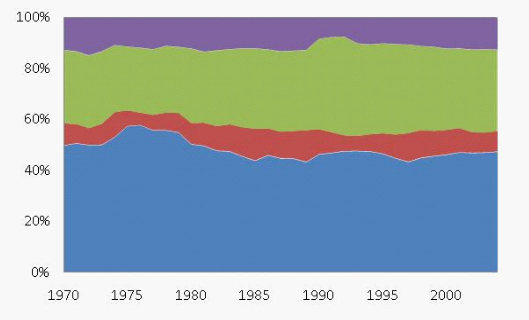
Norway



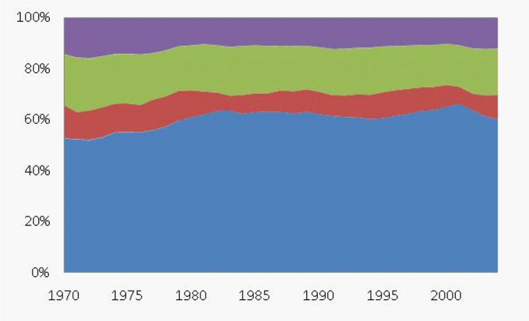
Sweden



Switzerland



United Kingdom



United States

Appendix C: Calculation of Equation (1.10) and Equation (1.14)

1. This shows how we obtain Equation (1.10).

From Equation (1.9), we have:

$$y^* = (k^*)^\alpha (h^*)^\beta = \left(\frac{s_k^{1-\beta} s_h^\beta}{n+g+d} \right)^{\frac{\alpha}{1-\alpha-\beta}} (h^*)^\beta$$

Taking logarithms, we obtain the following:

$$\begin{aligned}
\ln y^* &= \alpha \ln k^* + \beta \ln h^* \\
&= \frac{\alpha}{1-\alpha-\beta} \ln \frac{s_k^{1-\beta} s_h^\beta}{n+g+d} + \beta \ln h^* \\
&= \frac{\alpha(1-\beta)}{1-\alpha-\beta} \ln s_k + \frac{\alpha\beta}{1-\alpha-\beta} \ln s_h - \frac{\alpha}{1-\alpha-\beta} \ln (n+g+d) + \beta \ln h^* \\
&= \frac{\alpha(1-\beta)}{1-\alpha-\beta} \ln s_k + \frac{\alpha\beta}{1-\alpha-\beta} \ln \frac{(n+g+d)\, h^*}{y^*} - \frac{\alpha}{1-\alpha-\beta} \ln (n+g+d) \\
&\quad + \beta \ln h^* \\
&= \frac{\alpha(1-\beta)}{1-\alpha-\beta} \ln s_k + \left(\frac{\alpha\beta}{1-\alpha-\beta} + \beta \right) \ln h^* + \left(\frac{\alpha\beta}{1-\alpha-\beta} - \frac{\alpha}{1-\alpha-\beta} \right) \times \\
&\quad \ln (n+g+d) - \frac{\alpha\beta}{1-\alpha-\beta} \ln y^*
\end{aligned}$$

where the fourth line follows from the fact that in the steady state, according to Equation (1.7), $s_h = \frac{(n+g+d)h^*}{y^*}$. Rearranging the above equation, we obtain that:

$$\ln y^* = \frac{\alpha}{1-\alpha} \ln s_k + \frac{\beta}{1-\alpha} \ln h^* - \frac{\alpha}{1-\alpha} \ln(n+g+d)$$

2. This shows how we obtain Equation (1.14).

From Equation (1.13), we have the following expression:

$$\ln y_t - \ln y_{t-s} = -\varphi(\lambda) \left[\ln y_{t-s} - \frac{\alpha}{1-\alpha} \ln s_k - \frac{\beta}{1-\alpha} \ln h^* + \frac{\alpha}{1-\alpha} \ln(n+g+d) \right]$$

where $y = \frac{Y}{AL}$. Taking $s = 1$, then it is equivalent to express Equation (1.13) in the following way:

$$\ln\frac{Y_t}{A_tL_t} - \ln\frac{Y_{t-1}}{A_{t-1}L_{t-1}} = -\varphi\left(\lambda\right)\left[\ln\frac{Y_{t-1}}{A_{t-1}L_{t-1}} - \overbrace{\frac{\alpha}{1-\alpha}\ln s_k - \frac{\beta}{1-\alpha}\ln h^* + \frac{\alpha}{1-\alpha}\ln(n+g+d)}^{F}\right]$$

$$\rightarrow \ln\frac{Y_t}{L_t} - \ln\frac{Y_{t-1}}{L_{t-1}} = -\varphi\left(\lambda\right)\left[\ln\frac{Y_{t-1}}{L_{t-1}} - F\right] + \ln A_t - \ln A_{t-1} + \varphi\left(\lambda\right)\ln A_{t-1}$$

$$\rightarrow \ln\widetilde{y}_t - \ln\widetilde{y}_{t-1} = -\varphi\left(\lambda\right)\left[\ln\widetilde{y}_{t-1} - F\right] + \varphi\left(\lambda\right)\ln A_0 + g\left[\varphi\left(\lambda\right)t - \varphi\left(\lambda\right) + 1\right]$$

3. We follow Arnold et al. (2007) to approximate $\ln s_k$ using $\ln s_{k,t} + \Gamma\Delta\ln s_{k,t}$, as the share of human capital investment in GDP in the steady state (s_k) is not observable. Γ is a function of parameters of the model that need not be specified and the term $\Gamma\Delta\ln s_{k,t}$ is included in the short-run dynamics in Equation 1.15. Similarly, we approximate $\ln h^*$ using $\ln h_t + \Psi\Delta\ln h_t$, where Ψ is a function of parameters and the term $\Psi\Delta\ln h_t$ is included in the short-run dynamics in Equation 1.15. Following Arnold et al. (2007), we approximate $\ln(n+g+d)$ using n_t, as both g and d are not directly observable.

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Chapter 2

Corporate taxation and capital accumulation: evidence from aggregate data

1 Introduction

To stimulate investment by providing appropriate tax incentives has been a long-held objective of many economists and policymakers, although the empirical evidence for the efficacy of tax policy in altering investment behaviour has been far from conclusive. Of central importance in this debate is the elasticity of the stock of capital with respect to the user cost of capital, in particular with respect to the tax-related component of the user cost of capital.[1]

Previous attempts to estimate this elasticity often employ time-series data from a single country, most commonly the United States. Nevertheless, it is not an easy task to identify this elasticity accurately using time-series data

[1] This chapter is based on a joint paper with Prof Stephen Bond, circulated as Oxford University Centre for Business Taxation WP10/15, available at http://www.sbs.ox.ac.uk/centres/tax/papers/Pages/PaperWP1015.aspx

because there is often little variation in the corporate income tax system within a single country over a short period of time. This endemic problem also prevails in studies using less aggregated data.

Cross-country data can provide more variation in terms of the tax component of the user cost of capital and hence, facilitate the identification. Nevertheless, there is little empirical research on this issue using cross-country aggregate data. There may be two major reasons for this. First, it is notoriously difficult to measure real capital stocks across countries in a consistent way. Secondly, the necessary tax data has to be collected for many countries. The current study contributes to the literature by providing empirical evidence based on a unique data set, which combines two new data sources. The first data source is the EU KLEMS database, which provides recently released sectoral data for 30 OECD countries, of which 13 countries are used in this study. The relevant tax measures for these countries are provided by the Oxford University Centre for Business Taxation. We combine these two data sources to obtain panel data at the country-industry level for our analysis.

There are other issues which lead to difficulty in identifying the elasticity of capital with respect to the user cost. While theories predict a negative link between the optimal or desired level of the capital stock and the user cost of capital, the former is not directly observable. In reality, the adjustment process of the capital stock towards its optimal level may be extremely complicated. Traditionally, econometric models relied on the simplistic assumption of a quadratic adjustment cost function, mainly because of its mathematical tractability. Recent research has questioned the assumption of convex adjustment costs, which may be too simplistic considering factors such as investment irreversibility. This study will not attempt to identify the complicated underlying adjustment process. Instead, as an intermediate solution, it adopts a dynamic Error Correction Model (ECM) specification to estimate the short-run adjustment dynamics from the data. The ECM specification also has the advantage of separating the long-run determinants of capital accumulation from the short-run factors associated with adjustment lags and expectation formation.

To our knowledge, the only other study employing cross-country industry-level data to explore the link between investment and taxation is Vartia (2008). Compared with Vartia (2008), the current study employs an econometric model specification that is more consistent with neoclassical investment theory to capture both the long-run relationship between variables and the short-run dynamics. We also distinguish between different types of assets. In addition, we present results based on different industry samples. Furthermore, instead of imposing the restriction that the tax and non-tax components of the user cost affect investment in the same way, we formally test this hypothesis and pay special attention to the elasticity of capital with respect to the tax component. Another contribution of the current study is that we formally test whether other tax measures, such as the statutory corporate income tax rate and the effective average tax rate, help to explain capital accumulation at the aggregate level, once the marginal cost of investment is controlled for.

We check the robustness of our benchmark estimation results in a number of ways. In particular, we deal with the potential endogeneity of the user cost by controlling for country-specific time effects and by using Instrumental Variables (IV) estimations. We also distinguish between different sources of investment finance, and compare the informativeness of the cost of capital under the assumption of equity finance with that under the assumption of debt finance.

The structure of this paper is as follows. Section 2 reviews the related theories and the existing empirical studies. Section 3 introduces the empirical model. Section 4 describes the EU KLEMS data and the tax variables. Section 5 reports the estimation strategies and the benchmark results. We provide results of robustness checks in Section 6. Section 7 provides conclusions and suggestions for further research.

2 Related Literature

Jorgenson (1963) and Hall and Jorgenson (1967) show that under the assumptions of perfect competition, no adjustment costs, risk-neutral decision-making and an exogenous financial mix, the optimal level of capital is positively related to the level of output and negatively related to the user cost of capital. In particular, if the production technology is Cobb-Douglas, the implied long-run elasticity of the capital stock with respect to the user cost of capital (user cost elasticity) is -1.0.[2]

Subsequently, there have been many studies using aggregate data to estimate the user cost elasticity (for example, Eisner 1969, Eisner and Nadiri 1968, Tevlin and Whelan 2003, Schaller 2006, and Smith 2007). Chirinko (1993), Hassett and Hubbard (2002), and Bond and Van Reenen (2007) provide excellent surveys on this topic. These aggregate time series studies have usually been based on the US data. It is often found that output is far more important in explaining aggregate investment than the user cost of capital. The failure to identify an important user cost elasticity may be related to the underlying assumptions in the basic neoclassical investment theory. On the other hand, mismeasurement of capital stock and endogeneity of tax variables could also confound the estimates. To further complicate the identification, the assumption of instantaneous and costless adjustment maintained by the basic neoclassical investment theory leads to a static relationship between capital, output and the user cost. To introduce dynamics, early studies often assume ad hoc delivery lags or use restrictive dynamic specifications like the partial adjustment model in empirical investigations. Nonetheless, how to model the underlying adjustment process of capital remains an unresolved issue.

Another possible explanation for the failure of early attempts to identify the user cost elasticity is the limited variation in the user cost of capital within

[2] Instead of estimating this elasticity, these two studies restrict it to be unity and pay more attention to the estimation of the short-run dynamics.

one country, as major tax reforms which can substantially change the cost of capital are infrequent, especially over a short period of time. One way to introduce more variation in the user cost of capital at the aggregate level is to employ cross-country panel data. Nevertheless, as far as we know, the only other study which uses cross-country panel data at the industry level is Vartia (2008). The data set employed by Vartia (2008) covers 16 OECD countries and 21 industries over the period 1983-2001.[3] In the model specification estimated in Vartia (2008), the dependent variable is the investment-to-capital ratio and the explanatory variables include the lagged investment-to-capital ratio, the level of tax-adjusted user cost, growth in output and an indicator of anti-competition regulation. The author finds a negative and significant long-run elasticity of the investment-to-capital ratio with respect to the tax-adjusted user cost of capital. Nevertheless, the model used in Vartia (2008) may be mis-specified. The dependent variable, namely the investment-to-capital ratio, is approximately the *growth rate* of the capital stock.[4] Hence, to be consistent with the theory, the growth rate rather than the level of the user cost should be included in this specification.

It is worth noting that the majority of aggregate-level studies attempt to estimate the user cost elasticity using standard regression methods. Schaller

[3]The 21 sectors cover both manufacturing and non-manufacturing industries, including financial intermediation. The industry data on value-added, investment and real capital stock are based on an industry level data set from Scarpetta and Tressel (2002) covering years between 1970 and 1998. The data series on value-added and investment are updated using the growth rates of these variables in the OECD STAN database. The tax data are provided by the Institute for Fiscal Studies.

[4]This is because $\frac{I_t}{K_{t-1}} \approx \triangle \ln K_t + \delta$, where δ is the depreciation rate of the capital stock.

(2006) argues that it may be more sensible to estimate the long-run relationship using cointegration analysis. The observed capital stock is jointly determined by the demand and supply curves of capital. In the short run, the demand curve of capital is more likely to shift upwards and downwards while the supply curve tends to be more stable. Schaller (2006) argues that as long as the short-run supply curve of capital is upward sloping, empirical attempts to estimate the user cost elasticity based on short-run variations are likely to pick up the positive relationship between capital stock and the price of capital along the supply curve. Indeed, to identify the user cost elasticity, it is often assumed that the supply of capital is perfectly elastic. This may be a reasonable assumption for a small open economy, or for a small sector, or for a single firm. But for a large economy s a whole, like the United States, this may hold only when the long-run equilibrium is concerned. Using Canadian aggregate data for the period 1962:1 to 1999:4, Schaller (2006) estimates a substantial negative long-run user cost elasticity (around -1.6) by applying cointegration techniques. We note that this strategy requires all the time series considered to be both non-stationary and cointegrated, a question that we will consider for our data in Section 5.2.1 below.

Micro-level studies which attempt to estimate the user cost elasticity also provide mixed evidence. Cummins, Hassett, and Hubbard (1994) use US tax reforms as natural experiments and their estimated user cost elasticity is between -0.5 and -1.0. By examining a large sample of plants in the US manufacturing sector over the period 1972-1988, Caballero, Engel and Haltiwanger

(1995) find that the average long-run elasticity of the capital-output ratio with respect to the tax-adjusted user cost of capital is around -1.0, consistent with the prediction from Hall and Jorgenson (1967). Nevertheless, as Bond and Van Reenen (2007) point out, the literature has not yet reached "a consensus about the nature and magnitude of tax policy on investment demand". For example, using a sample of 4,095 US firms over the period 1981 to 1991, Chirinko, Fazzari and Meyer (1999) estimate that the elasticity of investment with respect to the user cost of capital is only around -0.25.[5]

Later refinements of the basic neoclassical investment model, such as the q model (Brainard and Tobin 1968, and Tobin 1969, 1978) and the Euler equation approach (Abel 1980), attempt to model expectations and the adjustment process of capital more explicitly. Unlike the basic neoclassical model in which either expectations play no role or firms are assumed to have static expectations, the q model and the Euler equation approach allow firms to be forward looking with rational expectations. Moreover, rather than introducing dynamics in an ad hoc manner, a quadratic adjustment cost function is directly incorporated into the firm's optimisation problem.

Nevertheless, empirical applications of the q model and the Euler equation approach are often disappointing (Summers, 1981, Blanchard and Wyplosz, 1981, and Hayashi, 1982). It is often found that measures of q explain little of the variation in investment, the residuals are highly serially correlated, the implied adjustment costs are implausibly high and additional variables other

[5]More detailed discussions on existing micro-level studies will be provided in Chapter 3.

than q have significant explanatory power. There are a number of possible reasons for the empirical failures of the q model and the Euler equation approach. For example, marginal q is not directly observable. Hayashi (1982) suggests that marginal q could be replaced by average q, but this is valid only under restrictive assumptions. Even when these assumptions are valid, the measurement of average q based on share price data could be highly noisy (Bond and Cummins, 2000). Besides, these approaches assume the adjustment cost function is quadratic, which may not be realistic as pointed out by recent literature (Abel and Eberly 1994, 1996; Doms and Dunne 1994; and Cooper and Haltiwanger 2006). For these reasons, we do not follow these approaches and instead focus on the user cost of capital. The difficulty in modelling the adjustment process also provides another reason for us to focus on the *long-run* relationship between capital stock and the user cost.

3 Model

We consider a firm whose net present value in period t is given in the absence of taxes by:

$$V_t = E_t\left[\sum_{j=0}^{\infty}\beta_{t+j}(D_{t+j} - N_{t+j})\right] \tag{3.1}$$

where D_t is dividends paid in period t and N_t is the revenue raised from new equity issued in period t. $E_t\left[.\right]$ denotes the conditional expectation based on information available at the start of period t, and β_{t+j} is the discount factor given by:

$$\beta_{t+j} = \prod_{i=1}^{j} (1 + r_{t+i})^{-1}, \ j = 1, 2, ..., \infty; \ \beta_t = 1 \tag{3.2}$$

where r_{t+1} is the required nominal rate of return between period t and period $t+1$.

3.1 Investment financed by retained earnings

3.1.1 In the absence of corporate income taxes

Sources and uses of funds for a firm that issues no debt are given by:

$$D_t - N_t = \Pi_t \tag{3.3}$$

where Π_t denotes net revenue generated in period t. In the absence of corporate income taxes, the net revenue Π_t can be written as:

$$\Pi_t = P_t (Q_t) F (K_{t-1}, L_t) - P_t^K I_t - w_t L_t \tag{3.4}$$

where $Q_t = F (K_{t-1}, L_t)$ denotes the production function in period t. The firm uses capital K_{t-1} at the beginning of period t and labour L_t to produce output. P_t, P_t^K and w_t are prices of output, capital and labour, respectively, and I_t denotes real gross investment in period t. To ensure that the firm's value maximisation problem has a solution in the absence of adjustment costs, we assume that there is some degree of monopolistic competition and the firm faces a downward sloping demand curve for its output of the isoelastic form

$$P_t\left(Q_t\right) = BQ_t^{-\frac{1}{\eta}} \tag{3.5}$$

where B is a demand shift parameter and $\eta > 1$ is the price elasticity of demand.

The firm is assumed to maximise its net present value subject to the capital accumulation constraint

$$K_t = (1-\delta)K_{t-1} + I_t \tag{3.6}$$

where δ is the rate of depreciation.

The firm's objective function can be written as the following Bellman's equation

$$V_t\left(K_{t-1}\right) = \Pi_t\left(K_{t-1}, I_t\right) + E_t\left[\beta_{t+1}V_{t+1}\left(K_t\right)\right] \tag{3.7}$$

Differentiating Equation (3.7) with respect to I_t yields

$$(\frac{\partial \Pi}{\partial I})_t + E_t\left[\beta_{t+1}\frac{\partial V_{t+1}}{\partial K_t}\right] = 0 \tag{3.8}$$

and differentiating Equation (3.7) with respect to K_{t-1} yields

$$\frac{\partial V_t}{\partial K_{t-1}} = \frac{\partial \Pi_t}{\partial K_{t-1}} + (1-\delta)\,E_t\left[\beta_{t+1}\frac{\partial V_{t+1}}{\partial K_t}\right] \tag{3.9}$$

Multiplying Equation (3.8) by $(1-\delta)$ and subtracting from Equation (3.9) gives

$$\frac{\partial V_t}{\partial K_{t-1}} = \frac{\partial \Pi_t}{\partial K_{t-1}} - (1-\delta)\frac{\partial \Pi_t}{\partial I_t} \tag{3.10}$$

As $\frac{\partial \Pi_t}{\partial K_{t-1}} = P_t\left(1-\frac{1}{\eta}\right)\frac{\partial F}{\partial K_{t-1}}$ and $\frac{\partial \Pi_t}{\partial I_t} = -P_t^K$, we obtain:

$$\frac{\partial V_t}{\partial K_{t-1}} = P_t(1-\frac{1}{\eta})\frac{\partial F}{\partial K_{t-1}} + P_t^K(1-\delta) \tag{3.11}$$

Equating Equation (3.9) and Equation (3.11), we have

$$P_t^K = E_t\left[\beta_{t+1}\frac{\partial V_{t+1}}{\partial K_t}\right] \tag{3.12}$$

and using Equation (3.10) we obtain

$$P_t^K = E_t\left[\beta_{t+1}\left(P_{t+1}(1-\frac{1}{\eta})\frac{\partial F}{\partial K_t} + P_{t+1}^K(1-\delta)\right)\right] \tag{3.13}$$

Assuming r_{t+1} is known at the beginning of period t and the firm holds static expectation of the relative price $\frac{P_t^K}{P_t}$, we reach the familiar expression for the user cost of capital in the absence of taxes as that in Jorgenson (1963)[6]

$$C_t = \frac{\partial F}{\partial K} = \frac{P_t^K}{P_t\left(1-\frac{1}{\eta}\right)}(r_{t+1}+\delta) \tag{3.14}$$

[6] It is worth noting that in Jorgenson (1963), Hall and Jorgenson (1967), and Devereux and Griffith (2003), firms are assumed to be price-taking, so that $\left(1-\frac{1}{\eta}\right)=1$.

3.1.2 Adding corporate income taxes

Next, we take corporate income taxes into consideration. The net revenue function becomes

$$\Pi_t = (1-\tau_t)\, P_t F\left(K_{t-1}, L_t\right) - P_t^K I_t(1-\phi_t) - (1-\tau_t)\, w_t L_t + \widetilde{A}_t \qquad (3.15)$$

where τ_t is the statutory corporate income tax rate, ϕ_t is the value of the first year allowance against corporation tax on a unit of investment in period t, and $\widetilde{A}_t$ is the value of writing-down allowances on past investments that can be claimed against corporation tax in period t. Following Hayashi (1982), we define A_{t+j} as the present value in period $t+j$ of all current and future tax allowances associated with a unit of investment in period $t+j$ and A_{t+j}^* as the part of $\widetilde{A}_{t+j}$ which results from investments made before period t. Defining

$$\Pi_t^* = (1-\tau_t)\, P_t F\left(K_{t-1}, L_t\right) - P_t^K I_t(1-A_t) - (1-\tau_t)\, w_t L_t \qquad (3.16)$$

we can formulate the net present value of the firm in period t as

$$\begin{aligned} V_t &= E_t\left[\sum_{j=0}^{\infty}\beta_{t+j}(\Pi_{t+j}^* + A_{t+j}^*)\right] = E_t\left[\sum_{j=0}^{\infty}\beta_{t+j}^*\Pi_{t+j}^*\right] + E_t\left[\sum_{j=0}^{\infty}\beta_{t+j}A_{t+j}^*\right] \\ &= V_t^* + E_t\left[\sum_{j=0}^{\infty}\beta_{t+j}A_{t+j}^*\right] \qquad (3.17) \end{aligned}$$

The second term in the above equation is the present value of current and future tax savings associated with investments made before period t. Therefore, it is independent of the sequence of current and future investments, and the optimal investment which maximises V_t^* also maximises V_t. The firm's optimisation problem in Equation (3.7) can than be reformulated as

$$V_t^* \left(K_{t-1}\right) = \Pi_t^* \left(K_{t-1}, I_t\right) + E_t \left[\beta_{t+1} V_{t+1}^* \left(K_t\right)\right] \tag{3.18}$$

As $\frac{\partial \Pi_t^*}{\partial K_{t-1}} = \left(1-\tau_t\right) P_t \left(1-\frac{1}{\eta}\right) \frac{\partial F}{\partial K_{t-1}}$ and $\frac{\partial \Pi_t^*}{\partial I_t} = -P_t^K(1-A_t)$, we can combine the modified Equations (3.8), (3.9) and (3.10) to obtain the tax-adjusted user cost of capital (Hall and Jorgenson, 1967, and Devereux and Griffith, 2003) as

$$C_t = \frac{\partial F}{\partial K} = \frac{P_t^K}{P_t\left(1-\frac{1}{\eta}\right)} \frac{\left(1-A_t\right)}{\left(1-\tau_t\right)} \left(r_{t+1}+\delta\right) \tag{3.19}$$

3.2 Investment financed by debt

If investment in period t is financed by issuing one-period bonds (B_t), sources and uses of funds for a firm are then given by:

$$D_t - N_t = \Pi_t + B_t - \left[1 + i_t \left(1-\tau_t\right)\right] B_{t-1} \tag{3.20}$$

where i_t is the (pre-tax) interest rate paid on the firm's outstanding debt in period t. To finance investment I_t, the firm only needs to issue $B_t = P_t^K I_t \left(1-\phi_t\right)$ in period t, and then to pay back debt plus interest $\left[1 + i_{t+1}\left(1-\tau_{t+1}\right)\right] P_t^K I_t \left(1-\phi_t\right)$ in period $t+1$, as the interest payment is tax-deductible. ϕ_t is again the value of the first year allowance against corporation tax on a unit of investment in period t. Assuming the firm has static expectation of the future tax rate and other tax parameters, it is shown in Appendix D that in the case of debt-financed investment, the tax-adjusted user cost of capital becomes

$$C_t^{Debt} = \frac{\partial F}{\partial K} = \frac{P_t^K}{P_t\left(1-\frac{1}{\eta}\right)}\left\{\frac{(1-A_t)}{(1-\tau_t)}(r_{t+1}+\delta) - \frac{[r_{t+1} - i_{t+1}(1-\tau_t)](1-\phi_t)}{1-\tau_t}\right\} \tag{3.21}$$

If the (pre-tax) interest rate paid on the firm's debt is equal to the shareholder's discount rate ($i_{t+1} = r_{t+1}$), we obtain

$$C_t^{Debt} = \frac{\partial F}{\partial K} = \frac{P_t^K}{P_t\left(1-\frac{1}{\eta}\right)}\left\{\frac{(1-A_t)}{(1-\tau_t)}(r_{t+1}+\delta) - \frac{r_{t+1}\tau_t(1-\phi_t)}{1-\tau_t}\right\} \tag{3.22}$$

This expression is the same as in Devereux and Griffith (2003). Comparing Equation (3.22) with Equation (3.19), we can see that the user cost of capital for debt-financed investment is lower than that for equity-financed investment. This reflects the advantage of issuing debt as the source of investment when the interest rate is assumed to be equal to the shareholder's discount rate and invariant to the level of the firm's borrowing, and interest payments are deductible against the corporate income tax.[7]

[7] Note that if $r_{t+1} = i_{t+1}(1-\tau_t)$, the user cost of capital under the assumption of equity finance and that under the assumption of debt finance are the same.

3.3 Functional form for the production function

Now assume the production function has the CES functional form

$$F(K_{t-1}, L_t) = \left[\theta K_{t-1}^{-\rho} + (1-\theta)L_t^{-\rho}\right]^{-\frac{v}{\rho}} \tag{3.23}$$

In the above CES production function, θ is the share of capital input. v measures the returns to scale. If $v = 1$, the technology exhibits constant returns to scale and if $v < 1$, there is decreasing returns to scale. ρ determines the elasticity of substitution between capital and labour, σ, which equals $\frac{1}{\rho+1}$. Importantly, when $\rho = 0$ and $\sigma = 1$, the CES production function becomes Cobb-Douglas. Differentiating Equation (3.23) and substituting into Equation (3.19), it can be shown that the optimal capital stock at the beginning of period $t+1$ is

$$K_t^* = \alpha Q_t^{\left(\sigma + \frac{1-\sigma}{v}\right)} C_t^{-\sigma} \tag{3.24}$$

where $\alpha = (\theta v)^\sigma$. In the special case when the production function is Cobb-Douglas ($\sigma = 1$), as in Hall and Jorgenson (1967), the optimal level of the capital stock for a profit-maximising firm simplifies to:

$$K_t^* = \alpha \left(\frac{Q}{C}\right)_t \tag{3.25}$$

Let us initially assume that investment is financed by retained earnings only. Combining Equations (3.19) and (3.24), and taking logarithms of both sides, we then obtain a log-linear relation between the desired level of the capital stock (in the absence of adjustment costs or frictions) and the tax-adjusted user cost of capital:

$$\begin{aligned}
\ln K_t^* &= \ln\alpha + (\sigma + \frac{1-\sigma}{v})\ln Q_t - \sigma \ln C_t \\
&= \ln\alpha\left(1-\frac{1}{\eta}\right)^{\sigma} + (\sigma + \frac{1-\sigma}{v})\ln Q_t - \sigma\ln(\frac{P^K}{P})_t \\
&\quad -\sigma\ln{(r+\delta)}_t - \sigma\ln[\frac{(1-A)}{(1-\tau)}]_t
\end{aligned} \tag{3.26}$$

3.4 Short-run dynamics

In Hall and Jorgenson (1967), to specify the relationship between the desired capital stock and actual investment, it is assumed that following to a change in desired capital, a certain proportion (μ_t) of the resulting investment takes place over each subsequent period of time. Gross investment in year t, I_t, then takes the form of a distributed lag function:

$$I_t = \sum_{s=0}^{\infty} \mu_s K_{t-s}^* + \delta K_t$$

Following Jorgenson (1963) and Hall and Jorgenson (1967), the basic neo-classical investment theory has been subject to much refinement over the past few decades. In particular, it has been pointed out that the adjustment of the capital stock to its optimal level should be explicitly modelled. The q theory of investment and the Euler equation approach, for example, assume a quadratic adjustment cost function. Nevertheless, recent studies suggest that non-convexities and irreversibility also play an important role in the investment process (Abel and Eberly, 1994, 1996; Doms and Dunne, 1994; Caballero, Engel and Haltiwanger, 1995; Cooper, Haltiwanger and Power, 1999; and Cooper and Haltiwanger, 2006).

As Bond and Van Reenen (2007) point out, the actual adjustment process may be extremely complex and the structural models of investment dynamics that have been proposed to date have not been successful in characterising this adjustment process. Therefore, rather than relying on dynamic econometric specifications that are explicitly derived as optimal adjustment behaviour for some particular structure of adjustment costs, a reduced form empirical approach to modeling the capital stock adjustment dynamics may be a useful intermediate solution.

It is worth noting that when we derive the optimal level of capital stock, we assume there is no adjustment cost. Bloom (2000) points out that adjustment costs affect the short-run dynamics of investment, however, the gap between the desired capital stocks in the absence and presence of adjustment costs is bounded. If $\ln K^*$ and $\ln K$ are non-stationary $I(1)$ processes, this implies that $\ln K_t = \ln K_t^* + e_t$, where e_t is a stationary $I(0)$ process. In other words, $\ln K_t$ and $\ln K_t^*$ are cointegrated in this case. The dynamic adjustment of $\ln K_t$ can then be represented by an Error Correction Model (ECM) as:

$$\alpha(L) \triangle \ln K_t = \beta(L) \triangle \ln K_t^* + \phi \left(\ln K_{t-k}^* - \ln K_{t-k}\right) \tag{3.27}$$

where $\alpha(L)$ and $\beta(L)$ are polynomials in the lag operator. The order of differencing and the lag structure are left to be empirically determined. ϕ measures the fraction of the gap between the actual and desired levels of the capital stock that is closed in each period. The Error Correction Model also nests both partial adjustment and accelerator models as special cases. This approach was applied in the investment literature by Bean (1981), Bond, Harhoff and Van Reenen (2003) and Bond et al. (2003). In fact, the Error Correction Model is simply a rearrangement and reparametrization of an autoregressive distributed lag model. However, the ECM specification has the advantage of separating the long-run equilibrium from the short-run adjustment dynamics.

4 Data

The EU KLEMS database is part of a research project, financed by the European Commission, to analyse productivity in the European Union at the industry level. The EU KLEMS growth accounts include measures of output, productivity, employment, capital formation and technological change at the industry level for European Union member states and other major economies from 1970 onwards. The database has been constructed on the basis of data delivered by the consortium partners with cooperation of national statistical offices, and processed according to agreed procedures which were developed to ensure harmonisation of the basic data, and to generate growth accounts in a consistent and uniform way. Restricted by the availability of tax variables, the current study includes data for 13 countries covering the period 1982-2007. These 13 countries are: Australia, Austria, Czech Republic, Denmark, Finland, Germany, Italy, Japan, Netherlands, Spain, Sweden, the United Kingdom and the United States. The time coverage for each country is listed in Appendix E.

There is more than one way to select and aggregate different industries for this empirical investigation. Consequently, we focus on two distinctive samples. The main sample consists of 11 manufacturing industries for each of these 13 OECD countries. A second sample consists of these 11 manufacturing industries plus 8 non-manufacturing industries for each country. This excludes a number of industries in the original EU KLEMS database, such as education, public services, electricity and water supply. Arguably, profit maximisation may not provide a good model for the investment behaviour in these excluded industries. Moreover, for the industry of financial intermediation, the concept of capital stock may differ from that for non-financial sectors. Therefore, this industry is also excluded. The detailed lists of industries included in the two samples are provided in Appendix E.

4.1 Measuring the capital stock K

It is not an easy task to construct useful measures of the capital stock. Even if individual countries produce useful capital stock measures and report these in their own national statistics, it is not easy to reach a consistent way of measurement across countries for meaningful comparison. For instance, the price of capital goods may differ from country to country; and relevant depreciation rates may also vary in different parts of the world. One source of the problem is that the composition of the aggregate or sector-level capital stock, by detailed type of assets, may vary considerably across countries. Therefore, a naive approach of assuming common investment goods price deflators and depreciation rates for broad capital stock aggregates may not be appropriate. The difficulty of measuring capital stocks across countries in a reliable way may partly explain the scarcity of empirical studies on investment and taxation using cross-country panel data.

The EU KLEMS database aims to measure capital stocks for a set of countries in a harmonious way, by employing the Perpetual Inventory Method (PIM) for data disaggregated by eight asset types. In the EU KLEMS database, real capital stock (K) is defined as a weighted sum of past real investments (measured in 1995 prices) with weights given by the relative efficiencies of capital goods at different ages according to the formula below (industry subscripts are suppressed for convenience):

$$K_{k,t} = \sum_{\tau=0}^{\infty} \theta_{k,\tau} I_{k,t-\tau}$$

with $K_{k,t}$ the capital stock for a particular asset type k at time t, $\theta_{k,\tau}$ the efficiency of a capital good of age τ relative to the efficiency of a new capital good, and $I_{k,t-\tau}$ the investment in period $t-\tau$.[8] An important implicit assumption here is that the services provided by assets of different vintages are perfect substitutes for each other. Assuming a given constant rate of depreciation δ_k for each asset type k, so that $\theta_{k,\tau} = (1-\delta_k)^{\tau}$, it follows that the capital stock for a particular asset k at time t, $K_{k,t}$, is given recursively by:

$$K_{k,t} = \sum_{\tau=0}^{\infty}(1-\delta_k)^{\tau} I_{k,t-\tau} = (1-\delta_k)K_{k,t-1} + I_{k,t}$$

For each industry in each country, there is separate data for eight different types of assets.[9] The depreciation rates differ by asset type and industry, but for a certain type of asset in a certain industry, its depreciation rate is assumed to be constant across countries and over time. The depreciation rates are obtained from the US Bureau of Economic Analysis (BEA). The advantage of using the BEA rates rather than using ad hoc assumptions based on, for example, tax laws, is that the depreciation patterns are based on empirical evidence about used asset prices in resale markets wherever possible. For most asset types, geometric patterns are used because the available data suggest that they more closely approximate actual profiles of price declines than straight-line patterns.

For comparison, in Figure F.1 in Appendix F, we plot the time series of

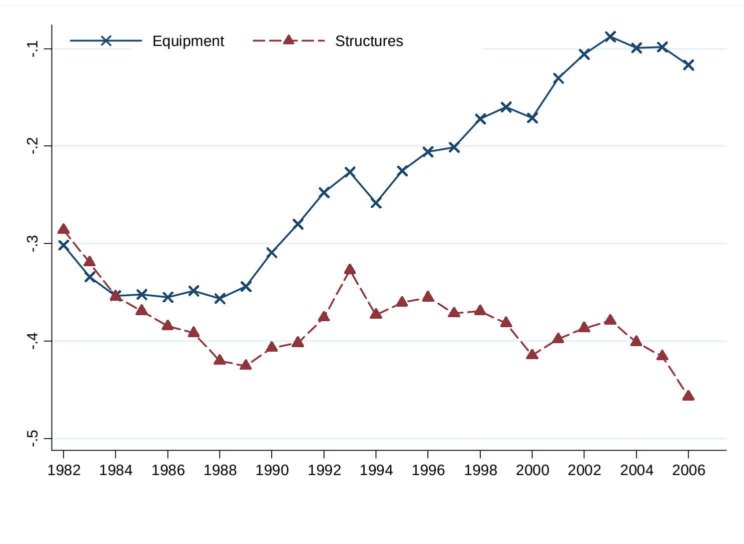
[8] For more details on the implementation of the Perpetual Inventory Method to estimate the real capital stock series in the EU KLEMS database, see Timmer et al. (2007).

[9] The eight assets include: transport equipment, computing equipment, communications equipment, other machinery and equipment, residential structures, non-residential structures, software, and others.

total real capital stock for total manufacturing industry over the period 1982-2007 from the EU KLEMS and the OECD STAN databases. The OECD STAN database only provides information on the real capital stock for 9 countries in our sample. Focusing on these 9 countries, Figure F.1 reveals that the time series of the real capital stock for each country provided by these two data sources are close in magnitude and they also show similar patterns over time.

We exclude residential structures from the total capital stock measure used in this paper, as residential housing is not primarily used as a direct input into the production function for value-added. The remaining seven types of capital assets are aggregated into three broad categories, namely, equipment and machinery, buildings and structures, and other assets.[10]

Figure 2.1: Average K/Q ratio (in logs): manufacturing industries



[10] Equipment and machinery includes transport equipment, computing equipment, communications equipment, and other machinery and equipment. Buildings and structures refers to non-residential structures. Other assets include software and others.

The level of output is proxied by using real value added data from EU KLEMS, measured in 1995 prices. Figure 2.1 plots the time-series of the unweighted average capital-output ratio for the sampled manufacturing industries in all 13 countries. Over time, there is an upward trend in the capital-output ratio for equipment. In contrast, the capital-output ratio for structures declined towards the end of the sample period. This difference reflects that investment in equipment outpaced that in structures in most of the sampled years, and the gap between the two became more distinct after the mid-1990s. A closer look at the individual country series (Figure G.1 in Appendix G) reveals that this shift in the composition of total capital from structures to equipment is found in the manufacturing sector in most countries.

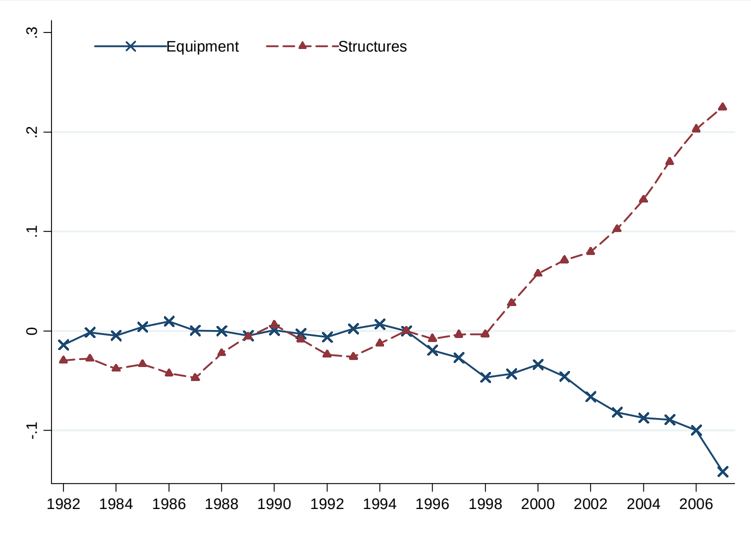
4.2 Relative price of investment goods $\frac{P^K}{P}$

The data set also provides, for each industry in each country, the price index for gross fixed capital formation (by asset type) and the price index for value added. The ratio of these two indices provides a proxy for the price of investment goods relative to the price of output. The base years for these price indices are both set to be 1995.[11] Figure 2.2 summarises the unweighted average relative prices for equipment and structures over the sample period.

A striking feature shown in Figure 2.2 is that, while the relative price of

[11] As the base year is 1995 for all price indices, differences in the level of relative prices between countries and industries are not fully reflected in these measures. This provides one motivation for including country-industry specific fixed effects in our specifications, as the fixed effects can control for price level differences across countries and industries in the base year.

Figure 2.2: Average relative prices of assets (in logs): manufacturing industries



equipment assets declined gradually over time, the relative price of structures remained stable until late 1990s and then began to increase dramatically.[12] Figure G.2 in Appendix G provides the time-series plots for each country. It shows that the rapid increase in the relative price of structures is observed in almost every country since the late 1990s, and is particularly evident in Australia, Czech Republic, Spain, Sweden and the United States.

4.3 The tax component of the user cost of capital

The tax component of the user cost of capital, $\frac{(1-A)}{(1-\tau)}$, reflects varying tax rules and tax rates in different countries and over time. Data on the statutory corporate income tax rates (τ) and the net present value (NPV) of depreciation allowances (A) are provided by the Oxford University Centre for Business Tax-

[12] The declining relative price of equipment is documented in other studies, such as Greenwood, Hercowitz and Krusell (1997) and Hsieh and Klenow (2005).

ation.[13] The NPV of depreciation allowances varies across different types of assets. Owing to the availability of data, we restrict ourselves to three main categories: general plant and machinery, structures and others. The same assumptions as in Devereux, Griffith and Klemm (2002) are adopted: the real discount rate r is assumed to be 10 per cent, the economic depreciation rate is assumed to be 3.61 per cent for buildings and 12.25 per cent for plant and machinery. It is worth noting these two figures are very close to the average depreciation rates used in the EU KLEMS database (the average depreciation rates are 3.29 per cent and 12.3 per cent, respectively). For other assets, the tax component of the user cost of capital is constructed as a simple average of those for equipment and structures.

For total assets, the tax component of the user cost of capital is a weighted average of those for the three different asset types. The weights are the proportions of each type of asset in the total capital stock. These weights differ across industries and countries, and also vary over time. The cross-sectional variation relies on the different asset structures within each industry (different combinations of equipment, structures and other assets) as well as the cross-country variation in the tax rules (NPV of depreciation allowances and the corporate income tax rate) in a particular year. The time-series variation comes from the changes in asset structures within each industry over time and also changes in the tax rules over time. For equipment assets or structures respectively,

[13] For more details on these tax variables, please see Devereux, Griffith and Klemm (2002) and Loretz (2008). We thank Simon Loretz for providing updated series for use in this study.

both the cross-sectional and time-series variation in the tax component of the user cost of capital rely only on the variation in tax rules. To sum up, in comparison to most previous studies, the data employed in the current study provides rich variation in the tax component of the user cost of capital, which greatly facilitates the identification of the effect of tax incentives on capital accumulation.

Figure 2.3: Average tax component of the user cost of capital (in logs): manufacturing industries

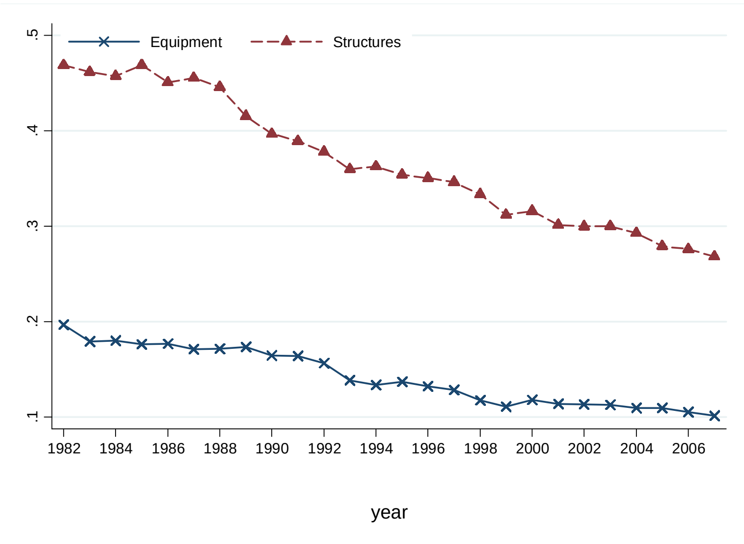


Figure 2.3 shows the unweighted average level of the tax component of the user cost of capital over time for both equipment and structures. It is evident that both types of assets enjoyed declining user costs of capital related to developments in tax rates and in tax rules. It is also worth noting that the average level of the tax-related component of the user cost of equipment assets remained lower than that of structures, which reflects the more generous depreciation allowances for equipment relative to our assumed underlying depreciation rates. Figure G.3 in Appendix G provides time-series plots for

each country, and the broad pattern observed in the average data also holds for most individual countries.

5 Estimation strategy and results

5.1 Model specification

Our initial assumption is that manufacturing investment is financed by retained earnings, consistent.[14] Owing to the existence of adjustment costs and frictions, firms may not be able to adjust the capital stock to the desired level instantly. Therefore, rather than simply estimating the long-run demand for capital specification (Equation (3.26)), we estimate Equation (5.1) which includes the lagged growth rate of the capital stock as well as current and lagged growth rates of output and the user cost of capital to control for the short-run dynamics.[15] We do not include explicitly the real discount rate r and the depreciation rate δ terms in the user cost. Instead, in our benchmark estimations, we add year dummies $YEAR_j$ (the base year is 1982) to control for common time-series variation in these two factors. We also allow for time-invariant fixed effects (u_i), which control for permanent differences in these

[14] Studies of financing patterns suggest that most investment is financed internally in developed countries. See, for example, Corbett and Jenkinson (1997).

[15] This is equivalent to restricting $\alpha(L)$ and $\beta(L)$ in Equation (3.27) to be $1 - L$. We also estimated models with different specifications of the short-run dynamics, such as allowing for more or fewer lagged growth rates, and the long-run results that we focus on below are not sensitive. We focus on the second order model in Equation (5.1) as all the short-run coefficients are significant under this specification.

factors across country-industry pairs.

$$\begin{aligned}\triangle \ln K_{i,t} &= -\phi\{\ln K_{i,t-2} - \alpha_1 \ln Q_{i,t-2} - \alpha_2 \ln[\frac{P^K(1-A)}{P(1-\tau)}]_{i,t-2}\} \\ &+\beta_0 \triangle \ln K_{i,t-1} + \beta_1 \triangle \ln Q_{i,t} + \beta_2 \triangle \ln Q_{i,t-1} \\ &-\beta_3 \triangle \ln[\frac{P^K(1-A)}{P(1-\tau)}]_{i,t} - \beta_4 \triangle \ln[\frac{P^K(1-A)}{P(1-\tau)}]_{i,t-1} \\ &+\sum_{j=1}^{25} \gamma_j YEAR_j + \alpha_0 + u_i + \epsilon_{i,t} \qquad (5.1)\end{aligned}$$

In Equation (5.1), the parameter ϕ measures the convergence rate of the capital stock towards its optimal level. A smaller value of ϕ indicates a slower adjustment process. α_0 is the constant, u_i is the time-invariant fixed effect for each country-industry pair, and $\epsilon_{i,t}$ is the time-varying residual component of the error term. The long-run relationship between variables will be captured by the coefficients α_1 and α_2. This model can be estimated by using standard fixed-effects within-groups regressions. It is worth noting that by using this strategy, it is implicitly assumed that all the parameters except the intercepts in this model are homogeneous across different country-industry pairs. This restriction will be relaxed in Section 6.2 below.

Recall Equation (3.26) which describes the long-run relationship between capital stock, output and the user cost of capital. Assuming that this holds for each industry in each country, and treating r and δ as constants, this has the form:

$$\ln K_{it}^* = constant + (\sigma + \frac{1-\sigma}{v}) \ln Q_{it} - \sigma \ln[\frac{P^K(1-A)}{P(1-\tau)}]_{it}$$

Comparing the expression inside the brackets in Equation (5.1) with Equation (3.26), we can see that the estimated coefficient α_1 on the log of output corresponds to $(\sigma + \frac{1-\sigma}{v})$, the long-run elasticity of the optimal level of capital with respect to output. This observation has several implications. First, if there is constant returns to scale ($v = 1$), the long-run elasticity of capital with respect to output will be one. On the other hand, if the estimated long-run elasticity of capital with respect to output is indeed one, it could mean either that the production technology is Cobb-Douglas ($\sigma = 1$), or CES with constant returns to scale ($\sigma \neq 1$, $v = 1$). This can be further distinguished by the estimated long-run elasticity of capital with respect to the user cost of capital (σ), which corresponds to the estimated coefficient α_2 on the log of the user cost. This also measures the long-run elasticity of substitution between capital and labour (σ), and hence in the case of constant returns to scale, the sensitivity of the capital-output ratio to relative prices, including effects of corporate taxation on these relative prices.

5.2 Results

5.2.1 Time series properties

For a panel data set with long time series and a small number of cross-section units (large T, small N), the use of standard estimation and inference methods for regression models requires the time series to be stationary. It is quite likely that the levels of capital stock and output may be non-stationary, however, the ratio of the two levels is more likely to be stationary. Formally, we test the time-series properties of relevant variables using the Fisher type panel unit-root test proposed by Maddala and Wu (1999).[16]

Table 2.1 presents the p-values of the Fisher-type panel unit-root tests when we allow for up to three lags and include a linear trend in the specification.[17] The null hypothesis is that the series has a unit root for each country-industry pair. Consistent with our expectation, these results suggest that both the levels of capital stock and output (in logs) may be an $I(1)$ process but the ratio between the two is found to be stationary. We do not find strong evidence that the user cost and, more specifically, its components are non-stationary. Nevertheless, these test results should be interpreted with caution.[18]

[16] There are other panel unit-root tests such as the Levin–Lin–Chu test and Im, Pesaran and Shin test. We choose the Fisher type panel unit-root test because it is suitable for unbalanced panels and it allows for heterogenous slope coefficients across groups. The Levin-Lin-Chu panel unit-root test does not allow for heterogeneous slope coefficients across panels and the Im, Pesaran and Shin test is only suitable for balanced panels. A detailed explanation of the procedure of the Fisher type test is provided in the note to Table 2.1.

[17] The results are not sensitive to the choice of lag length. The presence of deterministic trends for some of these series is suggested by Figure 2.1 and Figure 2.3.

[18] For example, the null hypothesis of non-stationarity is not be rejected at the 10 per cent level for the user cost for total capital. However, the null hypothesis of non-stationarity is

5.2.2 Baseline specifications

These results motivate us to impose the restriction that the long-run elasticity of capital with respect to output (α_1) is unity. This allows us to replace the two non-stationary terms ($\ln K_{i,t-2}$, $\ln Q_{i,t-2}$) in Equation (5.1) by the stationary term $\ln(K/Q)_{i,t-2}$. This restriction is equivalent to imposing constant returns to scale ($v = 1$).[19] Table 2.2 summarises the estimation results of Equation (5.1) based on our main sample of 11 manufacturing industries in 13 countries.[20] Columns 1-3 present the results for total capital, equipment and structures, respectively.[21] Panel A reports the basic estimated coefficients. Panel B summarises the implied long-run elasticities of capital with respect to the user cost of capital.[22] We first include a set of common year dummies to control for the time effects.

As Table 2.2 shows, consistent with the neoclassical investment model, we estimate a negative long-run user cost elasticity (α_2) which is not significantly different from -1.0 in Columns 1-3. The null hypothesis that α_2 equals -1.0 is not rejected at the 10 per cent level by a standard Wald test (Panel C). We also find statistically significant but rather slow adjustment of actual capital stocks

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rejected for the user cost for equipment, and for the user cost for structures; notwithstanding that the user cost for total capital is a weighted average of these two components.

[19] This is not needed if the production function is Cobb-Douglas. In this case, α_1 is unity no matter what value v takes.

[20] We provide the estimation results based on the unrestricted model in the Annex. Although the validity of this restriction is not always accepted, imposing this restriction does not affect the long-run user cost elasticity much, especially for investment in equipment. We do not emphasise these results as the logs of capital and output are likely to be non-stationary series.

[21] These results are computed using the command xtreg in Stata.

[22] In Table 1 and the following tables, the subscript i is suppressed.

towards the long-run target levels, as suggested by the estimated coefficients on the term $\ln (K/Q)_{i,t-2}$. Nevertheless, the adjustment process is somewhat faster for equipment than for structures.

To be fully consistent with our results from the Fisher type panel unit-root tests, where a linear trend was included in the specification for each country-industry pair, we re-estimate Equation (5.1) including country-industry specific linear trends in addition to a set of common year dummies. The results are reported in Table 2.3. In this specification, we formally reject the null hypothesis that the long-run user cost elasticity is -1.0 for total capital, but the point estimate remains substantial (around -0.667) and significantly different from zero. The estimated long-run user cost elasticity for equipment is around -0.831 and we do not reject the null hypothesis that $\alpha_2 = -1$ at the 5 per cent level. The estimated long-run user cost elasticity for structures is now around -0.376, significantly different from zero and also significantly different from -1.0.

It is of some interest to see whether we obtain similar results when we include industries beyond the manufacturing sector. Table 2.4 reports the estimation results based on a larger sample of 19 industries for each country, for which the assumption of profit maximisation may still be reasonable. Table 2.5 summarises the results using an even larger sample of all 27 EU KLEMS industries for each country. For some of these additional industries, such as public administration and social work, the assumption of profit maximising behaviour may not be so reasonable. The results reveal that the estimated long-run user cost elasticity remains close to -1.0 for equipment. In contrast, for total capital and structures, the estimated long-run user cost elasticity becomes smaller in magnitude as we expand the coverage of the sample, but remains significantly different from zero in each case.

5.2.3 Decomposing the user cost of capital

Of particular interest is the elasticity of capital with respect to the tax component of the user cost. The neoclassical investment model outlined in Section 3 restricts the elasticities of capital with respect to different components of the user cost to be the same. In Table 2.6, we report the empirical results when this restriction is relaxed. This is achieved by entering the two components of the user cost of capital, namely $\ln(\frac{P^K}{P})$ and $\ln[\frac{(1-A)}{(1-\tau)}]$ (labeled as $\ln TAX$), into the investment equation separately.

Table 2.6 shows that, for total capital and equipment investment, we estimate highly significant long-run effects from both components of the user cost of capital, the magnitude of which is close to -1.0 (Panel B, Columns 13 and 14). Moreover, we do not reject the null hypothesis that these two long-run elasticities are equal, at any reasonable significance level for total capital and at the 5 per cent level for equipment (Panel C, Columns 13 and 14). In contrast, for investment in structures, we do not find a significant effect of the tax component, and the null hypothesis of equal long-run elasticities is rejected at the 1 per cent level (Column 15). One explanation for this pattern may be that there is more scope for substituting between equipment and other inputs than between buildings and other inputs, although this is not supported by the results obtained for the relative price component of the user cost.[23]

These results lend support to the view that using corporate tax incentives to lower the marginal cost of investment can stimulate capital accumulation in the long run, at least for equipment investment in the manufacturing sector. The estimated long-run user cost elasticities in Columns 13 and 14 are considerably larger than those reported in Chirinko, Fazzari and Meyer (1999), and are closer to the estimates suggested by earlier studies based on US firm-level data, such as Cummins, Hassett, and Hubbard (1994) and Caballero, Engel and Haltiwanger (1995).

5.2.4 Additional tax variables

According to the basic neoclassical investment theory, the user cost of capital is a marginal concept and is an important factor for the firm's *marginal* decisions on the scale of investment, conditional on the firm's decision to invest. The effect of taxation on the user cost of capital corresponds to the effective marginal tax rate (EMTR), which measures the proportional difference between

[23] In Table I.1 (Appendix I), we report the corresponding estimation results when we control for a set of common year dummies and country-industry specific linear trends. The estimated long-run elasticities of capital with respect to tax and non-tax components of the user cost for both total capital and equipment investment remain negative, substantial, and significantly different from zero. Similar to the results in Table 2.6, we do not find a significant long-run elasticity of capital with respect to the tax component of the user cost for structures.

the required rate of return in the presence of taxation and the required rate of return in the absence of taxation. Nonetheless, as pointed out by Devereux and Griffith (1998, 2003), there is another class of *discrete* investment decisions which are instead affected by the effective average tax rate (EATR). The EATR is defined as the proportionate difference between the net present value of a profitable investment project in the absence of tax and the net present value of the same investment in the presence of tax. A prominent example is when multinational firms choose the location for a new investment. In such cases, firms will choose to locate in places where their investment can yield the highest post-tax return, which is affected by the average tax burden.

Devereux and Griffith (2003) give one example showing why the EMTR may be misleading in understanding an international firm's location choices. Consider a multinational firm which expects to earn an economic rent on its investment by exploiting some firm-specific advantage, such as a patent. Conditional on the choice of location, the size of investment depends on the EMTR. However, the location choice depends on the level of post-tax economic rent. Assume the extreme case of a cash flow corporation tax, which is levied only on economic rent. Since marginal investments are not taxed, the EMTR is zero.[24] In this case, the EATR is the more meaningful measure of the tax burden that affects the firm's location choice.

Empirically, Devereux and Griffith (1998) show that the effective aver-

[24] The tax component of the user cost of capital $\frac{(1-A)}{(1-\tau)}$ equals 1 for the cash-flow corporation tax, as investment is immediately expensed $(A = \tau)$. The cash-flow tax is conventionally described as neutral, as it has no effect on the user cost of capital.

age tax rate is a significant factor for US multinational firms choosing where within Europe to set up a production facility. Nonetheless, it remains a question whether the EATR will affect investment at the aggregate level because there may be a "crowding out" effect of foreign direct investment on domestic investment. To investigate this further, we include the EATR in Equation (5.1) and we will check whether it has any extra explanatory power in addition to the user cost of capital.

Another variable of interest is the statutory corporate income tax rate (τ). The neoclassical investment theory assumes implicitly that managers of firms are sophisticated enough to be able to calculate the user cost of capital for investment decisions. This assumption might not hold in reality. Compared with the user cost of capital, the statutory corporate income tax rate is a more straightforward and possibly more salient concept. By adding the statutory corporate income tax rate as an additional explanatory variable in Equation (5.1), we can also investigate whether this helps to explain aggregate investment outcomes.

Table 2.7 presents the estimation results.[25] Columns 16-17 report the results for equipment investment. The estimated coefficients on the lagged levels of the EATR and the statutory corporate income tax rate are both insignificant, indicating that they are uninformative here about the long-run level of

[25] Data on statutory corporate tax rates τ and EATRs (separately for equipment and structures) were also obtained from the Oxford University Centre for Business Taxation. See Devereux, Griffith and Klemm (2002) and Loretz (2008) for further details of these measures.

investment in equipment. In contrast, the estimated coefficient on the tax component of the user cost of capital remains highly significant in these specifications. Columns 18 and 19 report the results for investment in structures. Again, the EATR has no significant additional explanatory power for aggregate investment in structures in the long run (Column 18). Perhaps surprisingly, in Column 19, the estimated long-run coefficient on the statutory corporate tax rate is positive and significant.[26]

6 Robustness checks

6.1 Debt finance

So far, we have assumed that investment is financed by equity. However, the user cost of capital would be different if (marginal) investment is financed by debt. One approach would be to construct a weighted average of these user costs of capital, using the proportions of investment financed by different sources as the weights, assuming that at the margin investment is financed in the same way as it is on average. Unfortunately, we do not directly observe the proportions of investment financed by equity and by debt for each country-industry pair. Instead, in Table 2.8, we compare the informativeness of the

[26] In Table I.2 (Appendix I), we report the corresponding estimation results when we include a set of common year dummies and country-industry specific linear trends. Similar to the results in Table 2.7, neither the EATR nor the statutory corporate income tax rate appears to affect equipment investment. The estimated coefficients on the EATR and the statutory corporate income tax rate are both positive and significant in the models for structures.

user cost of capital measured under the assumption of equity finance (UC) with that under the assumption of debt finance (UC^{Debt}). We consider two scenarios, with and without decomposing the user cost of capital into tax and non-tax components, respectively. Table 2.8 reports only the long-run user cost elasticities, but additional short-run dynamics are included in the estimated models, in the same way as in our baseline specifications.

For total capital and investment in equipment, the user cost of capital assuming debt finance is found to be uninformative once we control for the user cost of capital under the assumption of equity finance, regardless of whether we combine the user cost or decompose it. The estimated coefficients on $\ln UC^{Debt}$ and on $\ln TAX^{Debt}$ are insignificantly different from zero. We obtain different results for investment in structures. In the last column, the estimated coefficient on $\ln UC^{Debt}$ is negative and significant, suggesting that debt finance may play a more important role in explaining investment in structures. Similarly, the estimated coefficient on $\ln TAX^{Debt}$ is significantly different from zero at the 11 per cent level. These results suggest that it may be useful to develop a richer model in which firms face different costs for debt and equity finance, and to allow different types of investment to be financed in different ways. For example, buildings may provide more useful collateral for borrowing than specialised equipment with thin second-hand markets. This extension is left for futher research.

6.2 Endogeneity of the user cost of capital

6.2.1 Controlling for country-specific business cycles

To obtain consistent estimates of the long-run user cost elasticity using the within-groups regression specifications presented here, we need the user cost of capital to be exogenous. Of special concern is that changes in tax policy may be endogenous responses to economic fluctuations, particularly to country-specific business cycles. For example, governments may tend to provide more generous investment depreciation allowances during economic downturns. It has been documented (Kose, Otrok and Whiteman, 2003) that country-specific factors, though less important in explaining business cycles in developed countries than common world factors, were important during some important historical episodes. Therefore, if tax policy responds to country-specific shocks, simply including a set of common year dummies to control for the common time effects may not be sufficient, and the resulting estimates could be biased.

One solution is to include a full set of country-specific year dummies to control for country-specific business cycles. Identification of the estimated parameters then relies on different variation over time between different industries in the same country, given that we continue to control for country/industry-specific fixed effects. The estimation results for this specification are reported in Table 2.9. The point estimates of the long-run user cost elasticity in Columns 20-22 are similar to the benchmark estimates in Columns 1-3 of Table 2.2, and significantly different from zero at the 1 per cent level. Moreover, the Wald test does not reject the null hypothesis that the long-run user cost elasticity is -1.0 in any of the three columns.

6.2.2 Instrumental Variables (IV) estimation

If there is any unobserved factor in the error term (other than the time effects) that affects both investment and the user cost of capital simultaneously, the within-groups fixed-effects estimations would also be biased and inconsistent. A standard procedure to deal with this endogeneity problem is to use Instrumental Variables (IV) estimation. Arguably, changes in investment demand may affect the relative price of investment goods and hence, the non-tax component of the user cost would be endogenous.[27] In contrast, it may take a long time to change tax policy, in which case the tax component of the user cost would be exogenous. Moreover, as we use the price index of investment goods to deflate the nominal capital stock and the same price index appears in the numerator of the non-tax component of the user cost, there could be a downward division bias if there are measurement errors in this price index (Borjas, 1980). To address these concerns, one strategy is to instrument the user cost by its tax component.

We first instrument the term $\triangle \ln UC_{i,t}$ in Equation (5.1) using the cur-

[27] Schaller (2006) points out that at the country level, this source of endogeneity is more likely to be relevant for large economies like the US. For a small open economy, the relative price of investment goods is likely to be determined by world factors and, therefore, more likely to be exogenous. This is also more likely to be the case for individual sectors in any country, so that this source of endogeneity may not be important for studies using country/sector data, as we do here.

rent first-difference and the lagged levels of the tax component ($\triangle \ln TAX_{i,t}$, $\ln TAX_{i,t-1}$ and $\ln TAX_{i,t-2}$) as our instrumental variables. The results are reported in Columns 23-25 in Table 2.10.[28] Comparing Tables 2.2 and 2.9, this strategy does affect the estimated coefficient on $\triangle \ln UC_{i,t}$, but more importantly, the long-run user cost elasticity remains significantly different from zero and close to -1.0. The null hypothesis of under-identification is rejected with a p-value of 0.000 by the Kleibergen-Paap rank LM statistic reported in Table 2.9 and hence, the problem of weak instruments does not appear to be a serious concern here. For the case of total capital (Column 23), the validity of the over-identifying restrictions is not rejected by the Hansen test statistic reported in Table 2.9. In contrast, the Hansen test rejects at the 5 per cent level for investment in equipment (Column 24), and rejects at the 1 per cent level for investment in structures (Column 25), implying some concern about the validity of the instruments used in these specifications.

Columns 26-28 in Table 2.10 report the IV estimation results when we only use $\ln TAX_{i,t-1}$ and $\ln TAX_{i,t-2}$ as instruments for the $\triangle \ln UC_{i,t}$ term. Dropping the contemporaneous tax component from the instrument set does not affect the estimated long-run user cost elasticity, which remains significantly different from zero and close to -1.0. Now, the Hansen test does not reject the validity of the over-identifying restrictions and the under-identification test indicates no serious problem of weak instruments. These results do not suggest that endogeneity of the user cost of capital is a serious problem in our

[28] These results are computed using the xtivreg2 command in Stata.

benchmark results.

An alternative strategy is to instrument $\triangle \ln UC_{i,t}$ by lagged levels of the user cost itself. As our specification also includes $\triangle \ln UC_{i,t-1}$ and $\ln UC_{i,t-2}$, we need to use $\ln UC$ dated $t-3$ and earlier as instruments. Results using $\ln UC$ dated from $t-3$ to $t-6$ as instruments for $\triangle \ln UC_{i,t}$ are reported in Table 2.11. In Columns 29-31, a set of common year dummies are included. In Columns 32-34, country-specific year dummies are included. These instruments also appear to be both valid (with the possible exception of Column 30) and informative (with the exception of Column 31). Again we find that using this alternative instrument set does not affect the estimated long-run user cost elasticity, which remains significantly different from zero and not significantly different from -1.0.

6.3 Pooled Mean Group and outlier-robust Mean Group estimations

In this section, we consider a more general model specification as follows:

$$\begin{aligned}\triangle \ln K_{it} &= -\phi_i\{\ln(K/Q)_{i,t-2} - \alpha_{2i} \ln UC_{i,t-2}\} + \beta_{0i} \triangle \ln K_{i,t-1} + \beta_{1i} \triangle \ln Q_{i,t} \\ &\quad + \beta_{2i} \triangle \ln Q_{i,t-1} - \beta_{3i} \triangle \ln UC_{i,t} - \beta_{4i} \triangle \ln UC_{i,t-1} \\ &\quad + \gamma_i \times Time\ Effects + \alpha_{0i} + u_i + \epsilon_{i,t} \qquad (6.1)\end{aligned}$$

Previously, we have restricted all parameters apart from the intercepts in

Equation (5.1) to be common across the country-industry pairs. It is important to check whether our benchmark estimation results are sensitive to different assumptions about the homogeneity of these parameters. One less restrictive specification is to allow the intercept, the speed of convergence ϕ_i, the short run parameters (β_{0i}, β_{1i}, β_{2i}, β_{3i} and β_{4i}) and the coefficient on the time effects (γ_i) to vary across the country-industry pairs, while restricting the long-run parameter α_{2i} to be common (i.e., $\alpha_{2i} = \alpha_2$ for all i). Underlying this model specification is the premise that different industries in different countries behave similarly in the long run, but they do not necessarily have the same short-run adjustment dynamics. The model specified in this way can be estimated by the Pooled Mean Group (PMG) estimator (Pesaran, Smith and Shin, 1999).

An even less restrictive specification is to allow all parameters to take different values for each country-industry pair, as in Equation (6.1). Interest then centres on the mean or median value of, for example, the long-run elasticity α_{2i}, representing the behaviour of an average or typical sector. We can estimate Equation (6.1) by using the time series for each country-industry pair in the first step. We then calculate outlier-robust means across the country-industry pairs for each of the estimated coefficients in the second step (Bond, Leblebicioglu and Schiantarelli, 2010).[29] This gives an outlier-robust variant of the Mean Group estimator proposed by Pesaran and Smith (1995).

[29] A more detailed explanation of the procedure used to obtain the outlier-robust Mean Group estimator is provided Section 6.1 of Chapter 1.

Limited by the length of the time series available for each country-industry pair in the sample, we here estimate a more parsimonious model specification as shown in Equation (6.2). Preliminary investigations showed that the within-groups estimates of the long-run user cost elasticity are not very different if the $\triangle \ln Q_{i,t-1}$ and $\triangle \ln UC_{i,t-1}$ terms are omitted from specification reported previously, while they differ substantially if $\ln K_{i,t-1}$ is omitted. Therefore, we keep this regressor in the specification while dropping both $\triangle \ln Q_{i,t-1}$ and $\triangle \ln UC_{i,t-1}$.

$$\begin{aligned} \triangle \ln K_{it} &= -\phi_i\{\ln(K/Q)_{i,t-2} - \alpha_{2i} \ln UC_{i,t-2}\} + \beta_{0i} \triangle \ln K_{i,t-1} + \beta_{1i} \triangle \ln Q_{i,t} \\ &\quad -\beta_{3i} \triangle \ln UC_{i,t} + \gamma_i \times Time\ Effects + \alpha_{0i} + u_i + \epsilon_{it} \end{aligned} \tag{6.2}$$

Table 2.12 summarises the results for the long-run elasticity of the capital stock with respect to the user cost of capital (α_{2i}) and the adjustment speed ($-\phi_i$) from both the PMG and outlier-robust MG estimators based on Equation (6.2).[30] For the PMG estimator, we report the common long-run user cost elasticity, and the mean estimate of the adjustment rate ($-\phi_i$) across country-industry pairs. For the MG estimator, we report the outlier-robust estimates of the mean for both of these parameters across country-industry pairs.

First, we specify the time effects to be country-industry specific linear trends. Based on the full sample of 13 countries, both the PMG and the

[30] The PMG results are computed using the xtpmg command in Stata. Code to obtain the outlier-robust MG results was adapted from that given in Bond et al. (2010).

outlier-robust MG estimators provide negative and significant estimates for the (mean) long-run elasticity of the capital stock with respect to the user cost for total capital, equipment and structures, respectively. The point estimates for the long-run user cost elasticity are significantly smaller than -1.0, but remain substantial particularly for investment in equipment. The estimated speed of adjustment is found to be higher for the average sector when we allow for heterogeneity in this parameter in both the PMG and MG estimations, compared with the benchmark results.

Second, in addition to the linear time trend for each country-industry pair, we control for cross-section dependence by including the time averages of the dependent variable and each of the explanatory variables as additional regressors in the PMG and outlier-robust MG estimations (Pesaran, 2006). It is now known that without controlling for cross-section dependence, estimation based on macro level cross-country panel data may be biased. Such bias arises because different countries may be affected in different ways by some common factors, such as a global business cycle. These common factors are then not fully controlled for by the inclusion of common year dummies or country-industry specific linear trends. Pesaran's common correlated effects (CCE) estimator allows each country, or in our case each country-industry pair, to have its own slope coefficient on the unobserved common factors.[31] The results are summarised in the last two columns in Table 2.12.[32] The results are

[31] A more detailed explanation of the procedure used to obtain the CCE estimators is provided Section 5.2.3 of Chapter 1.

[32] These estimations are based on a sample of 10 countries. Denmark, Finland and Czech Republic had to be excluded from the sample due to the shorter length of the time series

broadly similar to the previous two columns in Table 2.12 when only a linear trend is included. One difference is that the estimated mean long-run user cost elasticity for the case of structures becomes insignificantly different from zero in the outlier-robust MG estimation.

Table 2.13 reports the results when the user cost of capital is decomposed into its tax and non-tax components. For total capital and equipment, the PMG estimations with linear trends provide significant estimates for the long-run elasticity of the capital stock with respect to the tax component. In particular, this long-run elasticity for equipment remains substantial, with a point estimate around -0.7. For structures, the estimate of the long-run elasticity of the capital stock with respect to the tax component of the user cost becomes insignificant. In the outlier-robust MG estimations, the estimated means for the long-run elasticity of capital with respect to the tax component of the user cost are all insignificant with large standard errors.[33]

7 Conclusions

In this study, we estimate the long-run elasticity of capital with respect to the user cost. This study contributes to the literature by providing empirical evidence based on a cross-country industry-level panel data set with relevant tax variables. By employing an Error Correction Model (ECM) as an inter-

available for each of these three countries.

[33] The time series available for each country are too short to compute the common correlated effects (CCE) versions of these estimators for this more general specification.

mediate way to introduce capital adjustment dynamics, our estimation results suggest that there is a significantly negative link between the tax-adjusted user cost and the level of the capital stock in the long run. In many specifications, the estimated long-run user cost elasticty is close to -1.0, which suggests that long-run capital accumulation is highly responsive to changes in the corporate tax system. It also implies a large substitution elasticity between capital and labour. These findings are consistent with the predictions of neoclassical investment theory. As the level of capital per worker is a crucial determinant of income per capita in the long run, these findings also have important policy implications.

Furthermore, our estimates of this user cost elasticity are found to be larger and/or more significant for equipment assets within manufacturing industries. They become smaller and/or less significant for structures, and also when a broader range of industries are considered. Moreover, once the user cost of capital is controlled for, the effective average tax rate is found to have little additional explanatory power. We obtain some surprising results in relation to the statutory corporate tax rate, which appears to have a positive effect on investment in structures after controlling for the user cost.

The main features of our benchmark estimation results are also found in a range of robustness checks. We compare results using the user cost of capital measured under the assumption of equity finance with those for the user cost measured under the assumption of debt finance. For both total capital and equipment investment, we find that only the former has explanatory power, while this is not the case for investment in structures. Most importantly, when we treat the user cost of capital as potentially endogenous, our Instrumental Variables results are very similar to those obtained when the user cost is treated as exogenous. When we relax the homogeneity restriction imposed on the slope parameters in the benchmark ECM specification by applying the Pooled Mean Group and the outlier-robust Mean Group estimators, we continue to obtain a negative and substantial long-run user cost elasticity, at least for equipment investment.

Finally, Goolsbee (2004) shows that tax policy can have a direct effect on the quality composition of capital goods that firms purchase. He suggests that firms significantly shift investment toward higher quality varieties when they receive investment subsidies. In Goolsbee (2004), in the aggregate, all of the new investment generated by tax subsidies appears to come from firms shifting to higher quality capital goods rather than buying a larger number of their existing capital types. Insofar as higher quality capital goods have higher prices, and such changes in the composition of investment are not fully reflected in the price deflators used to construct our real capital stock series, this quality response may account for part of the impact of tax incentives on measured capital accumulation that we have estimated. Distinguishing between these quantity and quality effects remains an important topic for further research.

Table 2.1: Panel unit root tests

VARIABLES		Level	Difference
$\ln K$	Total	0.101	0.000
	Equipment	0.990	0.000
	Structures	0.000	0.000
$\ln Q$		0.307	0.000
$\ln (K/Q)$	Total	0.002	0.000
	Equipment	0.017	0.000
	Structures	0.006	0.000
$\ln UC$	Total	0.296	0.000
	Equipment	0.000	0.000
	Structures	0.000	0.000
$\ln \frac{P^K}{P}$	Total	0.016	0.000
	Equipment	0.000	0.000
	Structures	0.861	0.000
$\ln TAX$	Total	0.000	0.000
	Equipment	0.009	0.000
	Structures	0.000	0.000

Notes: This table presents p-values from the Fisher tests for unit roots in heterogeneous panels (Maddala and.Wu, 1999). Suppose the stochastic process, y_{it}, is generated by an autoregressive process:$\triangle y_{it} = \alpha_i + \beta_i y_{i,t-1} + \delta_i t + \sum_{j=1}^{p} \gamma_{ij} \triangle y_{i,t-j} + \epsilon_{it}$, where t is a linear trend. The null hypothesisis is $H_0 : \beta_i = 0$ for all i, and the alternative is $H_1 : \beta_i < 0, i = 1, 2, ...N_1$, $\beta_i = 0$, $i = N_1 + 1, N_1 + 2, ...N$, $0 < \lim_{N\to\infty}(N_1/N) \leq 1$. The Fisher test first computes the p-value π_i for each group using the Phillips-Perron unit-root test (Phillips and Perron, 1988). Then it computes the statistic $-2\sum \log_e \pi_i$, which follows a χ^2 distribution with $2N$ degrees of freedom. We report the p-values of the χ^2 statistics in this table. Results are reported for the lag length $p = 3$,but are not highly sensitive to this choice. These tests are computed using the command xtfisher in Stata.

Table 2.2: Basic ECM estimations: manufacturing industries

VARIABLES	(1) Total capital	(2) Equipment	(3) Structures
Panel A			
$\ln{(K/Q)}_{t-2}$	-0.026***	-0.056***	-0.014***
	(0.004)	(0.008)	(0.002)
$\ln UC_{t-2}$	-0.028***	-0.065***	-0.013***
	(0.004)	(0.010)	(0.002)
$\triangle \ln K_{t-1}$	0.483***	0.386***	0.539***
	(0.035)	(0.067)	(0.031)
$\triangle \ln Q_t$	0.067***	0.113***	0.022***
	(0.010)	(0.016)	(0.006)
$\triangle \ln Q_{t-1}$	0.056***	0.090***	0.028***
	(0.007)	(0.012)	(0.006)
$\triangle \ln UC_t$	-0.071***	-0.130***	-0.010***
	(0.009)	(0.019)	(0.004)
$\triangle \ln UC_{t-1}$	-0.049***	-0.092***	-0.017***
	(0.007)	(0.012)	(0.004)
Panel B: LR coefficients			
α_2	-1.106***	-1.165***	-0.981***
	(0.138)	(0.109)	(0.195)
Panel C: Test (p-value)			
$\alpha_2 = -1$	0.445	0.134	0.922
Year dummies	Yes	Yes	Yes
No. of country-industries	143	143	143
Observations	2882	2882	2879
R^2	0.462	0.385	0.427

[1]In this table and subsequent tables, standard errors are robust and clustered over time within country-industry pairs.

[2]*** p<0.01, ** p<0.05, * p<0.1

Table 2.3: Basic ECM estimations with country-industry specific trends: manufacturing industries

VARIABLES	(4) Total capital	(5) Equipment	(6) Structures
Panel A			
$\ln (K/Q)_{t-2}$	-0.100***	-0.159***	-0.057***
	(0.010)	(0.018)	(0.007)
$\ln UC_{t-2}$	-0.067***	-0.132***	-0.021***
	(0.011)	(0.022)	(0.006)
$\triangle \ln K_{t-1}$	0.325***	0.214***	0.399***
	(0.044)	(0.076)	(0.039)
$\triangle \ln Q_t$	0.093***	0.145***	0.040***
	(0.011)	(0.019)	(0.007)
$\triangle \ln Q_{t-1}$	0.094***	0.144***	0.050***
	(0.009)	(0.015)	(0.007)
$\triangle \ln UC_t$	-0.079***	-0.134***	-0.010**
	(0.009)	(0.020)	(0.005)
$\triangle \ln UC_{t-1}$	-0.069***	-0.118***	-0.019***
	(0.009)	(0.017)	(0.005)
Panel B: LR coefficients			
α_2	-0.667***	-0.831***	-0.376***
	(0.079)	(0.090)	(0.102)
Panel C: Test (p-value)			
$\alpha_2 = -1$	0.000	0.061	0.000
Country-industry trends	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
No. of country-industries	143	143	143
Observations	2882	2882	2879
R^2	0.537	0.482	0.500

[1]Standard errors robust and clustered over time within country-industry pairs are in parentheses

[2]*** p<0.01, ** p<0.05, * p<0.1

Table 2.4: Basic ECM estimations: 19 industries

VARIABLES	(7) Total capital	(8) Equipment	(9) Structures
Panel A			
$\ln(K/Q)_{t-2}$	-0.019***	-0.050***	-0.014***
	(0.003)	(0.006)	(0.002)
$\ln UC_{t-2}$	-0.011***	-0.056***	-0.010***
	(0.003)	(0.006)	(0.002)
$\triangle \ln K_{t-1}$	0.591***	0.459***	0.613***
	(0.024)	(0.041)	(0.023)
$\triangle \ln Q_t$	0.058***	0.112***	0.024***
	(0.007)	(0.013)	(0.005)
$\triangle \ln Q_{t-1}$	0.042***	0.080***	0.032***
	(0.006)	(0.010)	(0.005)
$\triangle \ln UC_t$	-0.030***	-0.113***	-0.006
	(0.007)	(0.017)	(0.004)
$\triangle \ln UC_{t-1}$	-0.019***	-0.069***	-0.021***
	(0.005)	(0.010)	(0.004)
Panel B: LR coefficients			
α_2	-0.574***	-1.116***	-0.716***
	(0.149)	(0.105)	(0.153)
Panel C: Test (p-value)			
$\alpha_2 = -1$	0.005	0.270	0.064
Year dummies	Yes	Yes	Yes
No. of country-industries	247	246	247
Observations	4943	4960	4994
R^2	0.487	0.425	0.475

[1]Standard errors robust and clustered over time within country-industry pairs are in parentheses

[2]*** p<0.01, ** p<0.05, * p<0.1

Table 2.5: Basic ECM estimations: 27 industries

VARIABLES	(10) Total capital	(11) Equipment	(12) Structures
Panel A			
$\ln(K/Q)_{t-2}$	-0.020***	-0.053***	-0.013**
	(0.002)	(0.005)	(0.006)
$\ln UC_{t-2}$	-0.010***	-0.060***	-0.007**
	(0.002)	(0.005)	(0.003)
$\triangle \ln K_{t-1}$	0.591***	0.466***	0.617***
	(0.020)	(0.033)	(0.052)
$\triangle \ln Q_t$	0.056***	0.114***	0.023***
	(0.007)	(0.013)	(0.005)
$\triangle \ln Q_{t-1}$	0.046***	0.077***	0.038***
	(0.006)	(0.009)	(0.009)
$\triangle \ln UC_t$	-0.029***	-0.120***	-0.008*
	(0.007)	(0.015)	(0.004)
$\triangle \ln UC_{t-1}$	-0.024***	-0.066***	-0.025***
	(0.006)	(0.009)	(0.007)
Panel B: LR coefficients			
α_2	-0.498***	-1.132***	-0.538***
	(0.121)	(0.082)	(0.172)
Panel C: Test (p-value)			
$\alpha_2 = -1$	0.000	0.107	0.008
Year dummies	Yes	Yes	Yes
No. of country-industries	325	323	325
Observations	6518	6473	6572
R^2	0.486	0.445	0.465

[1]Standard errors robust and clustered over time within country-industry pairs are in parentheses
[2]*** p<0.01, ** p<0.05, * p<0.1

Table 2.6: Decomposing the user cost of capital

VARIABLES	(13) Total capital	(14) Equipment	(15) Structures
Panel A			
$\ln (K/Q)_{t-2}$	-0.025***	-0.055***	-0.014***
	(0.004)	(0.008)	(0.002)
$\ln (P^K/P)_{t-2}$	-0.027***	-0.061***	-0.016***
	(0.005)	(0.010)	(0.002)
$\ln TAX_{t-2}$	-0.025***	-0.098***	0.001
	(0.009)	(0.021)	(0.005)
$\triangle \ln K_{t-1}$	0.483***	0.380***	0.535***
	(0.035)	(0.067)	(0.031)
$\triangle \ln Q_t$	0.070***	0.117***	0.024***
	(0.010)	(0.017)	(0.006)
$\triangle \ln Q_{t-1}$	0.055***	0.089***	0.030***
	(0.007)	(0.011)	(0.006)
$\triangle \ln (P^K/P)_t$	-0.082***	-0.148***	-0.016***
	(0.010)	(0.021)	(0.005)
$\triangle \ln (P^K/P)_{t-1}$	-0.051***	-0.096***	-0.023***
	(0.009)	(0.014)	(0.005)
$\triangle \ln TAX_t$	-0.022*	-0.034	0.008
	(0.011)	(0.024)	(0.006)
$\triangle \ln TAX_{t-1}$	-0.032**	-0.071**	0.002
	(0.014)	(0.032)	(0.006)
Panel B: LR coefficients			
$\ln (P^K/P)$	-1.090***	-1.110***	-1.128***
	(0.153)	(0.109)	(0.207)
$\ln TAX$	-1.029***	-1.794***	0.042
	(0.337)	(0.367)	(0.326)
Panel C: Test (p-value)			
Equal LR elasticities	0.871	0.069	0.005
Year dummies	Yes	Yes	Yes
No. of country-industries	143	143	143
Observations	2882	2882	2879
R^2	0.465	0.391	0.430

[1]Standard errors robust and clustered over time within country-industry pairs are in parentheses

[2]*** p<0.01, ** p<0.05, * p<0.1

Table 2.7: EATR and the statutory corporate income tax rate

VARIABLES	(16) Equipment	(17) Equipment	(18) Structures	(19) Structures
$\ln(K/Q)_{t-2}$	-0.055***	-0.055***	-0.014***	-0.016***
	(0.008)	(0.008)	(0.002)	(0.002)
$\ln(P^K/P)_{t-2}$	-0.060***	-0.060***	-0.016***	-0.018***
	(0.010)	(0.010)	(0.003)	(0.002)
$\ln TAX_{t-2}$	-0.134***	-0.121***	-0.022	-0.029***
	(0.040)	(0.023)	(0.026)	(0.009)
$EATR_{t-2}$	0.035		0.034	
	(0.041)		(0.041)	
τ_{t-2}		0.022		0.051***
		(0.016)		(0.010)
$\triangle \ln K_{t-1}$	0.380***	0.380***	0.535***	0.527***
	(0.067)	(0.067)	(0.031)	(0.031)
$\triangle \ln Q_t$	0.118***	0.119***	0.024***	0.025***
	(0.017)	(0.017)	(0.006)	(0.006)
$\triangle \ln Q_{t-1}$	0.090***	0.090***	0.030***	0.031***
	(0.011)	(0.011)	(0.006)	(0.006)
$\triangle \ln(P^K/P)_t$	-0.148***	-0.148***	-0.016***	-0.017***
	(0.021)	(0.021)	(0.005)	(0.005)
$\triangle \ln(P^K/P)_{t-1}$	-0.095***	-0.095***	-0.024***	-0.025***
	(0.013)	(0.014)	(0.005)	(0.005)
$\triangle \ln TAX_t$	-0.116	-0.065*	-0.077**	-0.019**
	(0.074)	(0.035)	(0.035)	(0.008)
$\triangle \ln TAX_{t-1}$	-0.098	-0.097**	0.021	-0.014*
	(0.070)	(0.041)	(0.038)	(0.008)
$\triangle EATR_t$	0.085		0.136**	
	(0.064)		(0.057)	
$\triangle EATR_{t-1}$	0.030		-0.032	
	(0.062)		(0.059)	
$\triangle\tau_t$		0.044**		0.053***
		(0.021)		(0.014)
$\triangle\tau_{t-1}$		0.035		0.031**
		(0.025)		(0.015)
Year dummies	Yes	Yes	Yes	Yes
No. of country-industry	143	143	143	143
Observations	2882	2882	2879	2879
R^2	0.391	0.392	0.431	0.434

[1]Standard errors in parentheses [2]*** p<0.01, ** p<0.05, * p<0.1

Table 2.8: Investment financed by different sources (LR elasticities)

VARIABLES	Total capital		Equipment		Structures	
a. Combined UC						
$\ln UC^{Debt}$	-0.916***	-0.089	-0.870***	-0.080	-0.720***	-0.313***
	(0.218)	(0.101)	(0.155)	(0.081)	(0.236)	(0.092)
$\ln UC$		-1.031***		-1.271***		-0.757***
		(0.166)		(0.150)		(0.169)
b. Decomposed UC						
$\ln (P^K/P)$	-1.142***	-1.074***	-1.201***	-1.083***	-1.127***	-1.126***
	(0.169)	(0.163)	(0.127)	(0.113)	(0.206)	(0.206)
$\ln TAX^{Debt}$	0.055	-0.231	0.096	-0.042	-0.149	-0.188
	(0.140)	(0.159)	(0.102)	(0.100)	(0.093)	(0.116)
$\ln TAX$		-1.572***		-2.363***		-0.235
		(0.456)		(0.453)		(0.404)

[1]Standard errors robust and clustered over time within country-industry pairs in parentheses.

[2]*** p<0.01, ** p<0.05, * p<0.1.

[3]Year dummies included

[4]Short-run dynamics included.

Table 2.9: Adding country-specific year dummies

VARIABLES	(20) Total capital	(21) Equipment	(22) Structures
Panel A			
$\ln{(K/Q)_{t-2}}$	-0.039***	-0.060***	-0.020***
	(0.005)	(0.010)	(0.003)
$\ln{UC_{t-2}}$	-0.039***	-0.069***	-0.021***
	(0.005)	(0.013)	(0.003)
$\triangle\ln{K_{t-1}}$	0.396***	0.307***	0.451***
	(0.042)	(0.077)	(0.030)
$\triangle\ln{Q_t}$	0.055***	0.085***	0.018***
	(0.011)	(0.018)	(0.006)
$\triangle\ln{Q_{t-1}}$	0.051***	0.079***	0.021***
	(0.008)	(0.013)	(0.006)
$\triangle\ln{UC_t}$	-0.067***	-0.112***	-0.015***
	(0.010)	(0.020)	(0.005)
$\triangle\ln{UC_{t-1}}$	-0.051***	-0.098***	-0.027***
	(0.010)	(0.014)	(0.005)
Panel B: LR coefficients			
α_2	-1.013***	-1.148***	-1.030***
	(0.110)	(0.116)	(0.142)
Panel C: Test (p-value)			
$\alpha_2 = -1$	0.908	0.206	0.832
Country-specific year dummies	Yes	Yes	Yes
No of country-industries	143	143	143
Observations	2882	2882	2879
R^2	0.583	0.508	0.564

[1]Standard errors robust and clustered over time within country-industry pairs are in parentheses.
[2]*** p<0.01, ** p<0.05, * p<0.1.

Table 2.10: Instrumenting the user cost by its tax component

IVs	$\triangle \ln TAX_t$, $\ln TAX_{t-1}$, $\ln TAX_{t-2}$			$\ln TAX_{t-1}$, $\ln TAX_{t-2}$		
	(23)	(24)	(25)	(26)	(27)	(28)
VARIABLES	Total capital	Equipment	Structures	Total capital	Equipment	Structures
Panel A						
$\ln (K/Q)_{t-2}$	-0.025***	-0.052***	-0.013***	-0.024***	-0.044***	-0.018***
	(0.004)	(0.008)	(0.002)	(0.004)	(0.009)	(0.003)
$\ln UC_{t-2}$	-0.026***	-0.057***	-0.012***	-0.026***	-0.043***	-0.020***
	(0.004)	(0.010)	(0.002)	(0.005)	(0.013)	(0.004)
$\triangle \ln K_{t-1}$	0.486***	0.395***	0.538***	0.486***	0.413***	0.547***
	(0.036)	(0.069)	(0.031)	(0.037)	(0.076)	(0.031)
$\triangle \ln Q_t$	0.056***	0.086***	0.019***	0.055***	0.036	0.036***
	(0.009)	(0.014)	(0.006)	(0.012)	(0.026)	(0.010)
$\triangle \ln Q_{t-1}$	0.055***	0.091***	0.027***	0.055***	0.092***	0.031***
	(0.008)	(0.012)	(0.006)	(0.008)	(0.013)	(0.006)
$\triangle \ln UC_t$	-0.026**	-0.023	0.002	-0.022	0.179**	-0.073**
	(0.011)	(0.022)	(0.006)	(0.036)	(0.089)	(0.032)
$\triangle \ln UC_{t-1}$	-0.050***	-0.098***	-0.015***	-0.050***	-0.110***	-0.024***
	(0.007)	(0.012)	(0.004)	(0.007)	(0.015)	(0.006)
Panel B:						
α_2	-1.071***	-1.108***	-0.942***	-1.068***	-0.972***	-1.122***
	(0.155)	(0.118)	(0.209)	(0.167)	(0.189)	(0.165)
Panel C: Test (p-value)						
$\alpha_2 = -1$	0.647	0.359	0.785	0.683	0.882	0.460
Hansen test	0.752	0.022	0.008	0.461	0.252	0.183
Under-identification test	0.000	0.000	0.000	0.000	0.000	0.000
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
No. of country-industries	143	143	143	143	143	143
Observations	2882	2882	2879	2882	2882	2879

[1]Standard errors robust and clustered over time within country-industry pairs are in parentheses.

[2]*** p<0.01, ** p<0.05, * p<0.1.

Table 2.11: Instrumenting the user cost by its lags

IVs	$\ln UC_{t-3}$, $\ln UC_{t-4}$, $\ln UC_{t-5}$, $\ln UC_{t-6}$					
	(29)	(30)	(31)	(32)	(33)	(34)
VARIABLES	Total capital	Equipment	Structures	Total capital	Equipment	Structures
Panel A						
$\ln{(K/Q)_{t-2}}$	-0.034***	-0.061***	-0.059*	-0.046***	-0.062***	-0.029***
	(0.006)	(0.012)	(0.032)	(0.006)	(0.016)	(0.006)
$\ln UC_{t-2}$	-0.038***	-0.068***	-0.098*	-0.047***	-0.065***	-0.034***
	(0.006)	(0.015)	(0.056)	(0.009)	(0.025)	(0.011)
$\triangle \ln K_{t-1}$	0.453***	0.346***	0.528***	0.379***	0.255***	0.416***
	(0.038)	(0.080)	(0.070)	(0.054)	(0.091)	(0.037)
$\triangle \ln Q_t$	0.093***	0.109***	0.144	0.080***	0.065	0.047**
	(0.017)	(0.039)	(0.096)	(0.029)	(0.066)	(0.020)
$\triangle \ln Q_{t-1}$	0.061***	0.085***	0.092	0.054***	0.071***	0.032***
	(0.010)	(0.013)	(0.056)	(0.011)	(0.016)	(0.010)
$\triangle \ln UC_t$	-0.184***	-0.125	-0.583	-0.163	-0.031	-0.133*
	(0.066)	(0.193)	(0.431)	(0.110)	(0.279)	(0.076)
$\triangle \ln UC_{t-1}$	-0.050***	-0.096***	-0.110	-0.049***	-0.088***	-0.052***
	(0.009)	(0.026)	(0.082)	(0.011)	(0.026)	(0.020)
Panel B						
α_2	-1.110***	-1.119***	-1.653***	-1.026***	-1.043***	-1.195***
	(0.148)	(0.128)	(0.431)	(0.151)	(0.198)	(0.220)
Panel C: Test (p-value)						
$\alpha_2 = -1$	0.459	0.354	0.130	0.861	0.830	0.374
Hansen test	0.220	0.055	0.878	0.672	0.479	0.264
Underidentification test	0.001	0.051	0.740	0.028	0.039	0.086
Year dummies	Yes	Yes	Yes			
Country-year dummies				Yes	Yes	Yes
No. of country-industries	143	143	143	143	143	143
Observations	2310	2310	2306	2310	2310	2306

[1]Standard errors robust and clustered over time within country-industry pairs are in parentheses.
[2]*** p<0.01, ** p<0.05, * p<0.1.

Table 2.12: LR elasticities and convergence rates: PMG and outlier robust MG estimations with combined user cost

	13 countries		10 countries	
	PMG	MG	PMG	MG
VARIABLES	Trend	Trend	CCE+Trend	CCE+Trend
Total capital				
$-\phi$	-0.111*** (0.009)	-0.134*** (0.024)	-0.136*** (0.013)	-0.150*** (0.027)
$\ln UC$	-0.403*** (0.018)	-0.443*** (0.156)	-0.489*** (0.026)	-0.288*** (0.115)
Equipment				
$-\phi$	-0.168*** (0.011)	-0.189*** (0.027)	-0.154*** (0.018)	-0.167*** (0.032)
$\ln UC$	-0.803*** (0.031)	-0.680*** (0.085)	-0.428*** (0.029)	-0.666*** (0.182)
Structures				
$-\phi$	-0.072*** (0.006)	-0.085*** (0.019)	-0.074*** (0.010)	-0.078*** (0.022)
$\ln UC$	-0.332*** (0.022)	-0.318*** (0.116)	-0.206*** (0.022)	-0.297 (0.268)

Notes:[1] For the Pooled Mean Group (PMG) estimators, we report the common long-run elasticity of the capital stock with respect to the user cost of capital, and the mean estimate of the convergence rate ($-\phi$) across country-industry pairs. For the Mean Group (MG) estimators, we report outlier-robust estimates of the mean for each of these parameters across country-industry pairs.

[2] Robust standard errors in parentheses

[3] *** p<0.01, ** p<0.05, * p<0.1

[4] Short-run dynamics included

Table 2.13: LR elasticities and convergence rates: PMG and outlier robust MG estimations with decomposed user cost

VARIABLES	PMG Trend	MG Trend
Total capital		
-ϕ	-0.108*** (0.010)	-0.143*** (0.027)
$\ln{(P^K/P)}$	-0.374*** (0.022)	-0.479*** (0.196)
$\ln TAX$	-0.357*** (0.045)	-0.027 (0.364)
Equipment		
-ϕ	0.135*** (0.024)	-0.217*** (0.030)
$\ln{(P^K/P)}$	-0.357*** (0.023)	-0.715*** (0.115)
$\ln TAX$	-0.723*** (0.057)	-0.453 (0.297)
Structures		
-ϕ	-0.069*** (0.008)	-0.0808*** (0.021)
$\ln{(P^K/P)}$	-0.397*** (0.027)	-0.529*** (0.247)
$\ln TAX$	-0.011 (0.038)	0.431 (0.407)

[1]Robust standard errors in parentheses

[2]*** p<0.01, ** p<0.05, * p<0.1

[3]Short-run dynamics included

Appendix D: Derivation of the user cost of capital for debt-financed investment

In this Appendix, we show the derivation of the tax-adjusted user cost of capital in the case of debt-financed investment. From Equation (3.20), we have

$$D_t - N_t = \Pi_t + P_t^K I_t (1 - \phi_t) \tag{D.1}$$

$$D_{t+1} - N_{t+1} = \Pi_{t+1} - P_t^K I_t (1 - \phi_t) [1 + i_{t+1} (1 - \tau_{t+1})] \tag{D.2}$$

We obtain the following equations:

$$\frac{\partial (D_t - N_t)}{\partial K_{t-1}} = \frac{\partial \Pi_t}{\partial K_{t-1}} \tag{D.3}$$

$$\frac{\partial (D_{t+1} - N_{t+1})}{\partial K_t} = \frac{\partial \Pi_{t+1}}{\partial K_t} - P_t^K (1 - \phi_t) [1 + i_{t+1} (1 - \tau_{t+1})] \tag{D.4}$$

$$\frac{\partial (D_t - N_t)}{\partial I_t} = \frac{\partial \Pi_t}{\partial I_t} + P_t^K (1 - \phi_t) \tag{D.5}$$

$$\frac{\partial (D_{t+1} - N_{t+1})}{\partial I_{t+1}} = \frac{\partial \Pi_{t+1}}{\partial I_{t+1}} \tag{D.6}$$

Define Π_t^* and V_t^* as in Equations (3.16) and (3.17). Differentiating V_t^* with respect to I_t, we have

$$\frac{\partial V_t^*}{\partial I_t} = \frac{\partial \Pi_t^*}{\partial I_t} + P_t^K (1 - \phi_t) + E_t \left[\beta_{t+1} \frac{\partial V_{t+1}^*}{\partial K_t} \right] = 0 \tag{D.7}$$

and differentiating V_t^* with respect to K_{t-1}, we have

$$\frac{\partial V_t^*}{\partial K_{t-1}} = \frac{\partial \Pi_t^*}{\partial K_{t-1}} + (1 - \delta) E_t \left[\beta_{t+1} \frac{\partial V_{t+1}^*}{\partial K_t} \right] \tag{D.8}$$

Multiplying Equation (D.7) by $(1 - \delta)$ and subtracting Equation (D.8) gives

$$\frac{\partial V_t^*}{\partial K_{t-1}} = \frac{\partial \Pi_t^*}{\partial K_{t-1}} - (1 - \delta) (\frac{\partial \Pi^*}{\partial I})_t - P_t^K (1 - \phi_t) (1 - \delta) \tag{D.9}$$

Similarly, we can obtain the expression for $\frac{\partial V_{t+1}^*}{\partial K_t}$ as

$$\frac{\partial V_{t+1}^*}{\partial K_t} = \frac{\partial \Pi_{t+1}^*}{\partial K_t} - P_t^K (1 - \phi_t) [1 + i_{t+1} (1 - \tau_{t+1})] - (1 - \delta) (\frac{\partial \Pi^*}{\partial I})_{t+1} \tag{D.10}$$

Substituting the expression for $\frac{\partial V_{t+1}^*}{\partial K_t}$ into Equation (D.8) and rearranging the resulting equation, using $\frac{\partial \Pi_t^*}{\partial I_t} = -P_t^K(1-A_t)$ and $\frac{\partial \Pi_t^*}{\partial K_{t-1}} = (1-\tau_t)\, P_t \left(1-\frac{1}{\eta}\right) \frac{\partial F}{\partial K_{t-1}}$, we obtain the expression for the tax-adjusted user cost of capital in the case of debt-financed investment as in Equation (3.21) under the assumption of static expectation for the relative (tax-adjusted) price of investment goods

$$C_t^{Debt} = \frac{\partial F}{\partial K} = \frac{P_t^K}{P_t\left(1-\frac{1}{\eta}\right)} \left\{ \frac{(1-A_t)}{(1-\tau_t)} (r_{t+1}+\delta) - \frac{[r_{t+1} - i_{t+1}(1-\tau_t)](1-\phi_t)}{1-\tau_t} \right\}$$

Appendix E: List of industries and countries

- **Sample 1**: 11 manufacturing industries

This sample includes the following manufacturing industries: 1) Basic metals and fabricated metal; 2) chemicals, rubber, plastics and fuel; 3) electrical and optical equipment; 4) food, beverages and tobacco; 5) machinery not elsewhere classified; 6) manufacturing not elsewhere classified and recycling; 7) other non-metallic minerals; 8) pulp, paper and printing; 9) textiles, leather and footwear; 10) transport equipment; 11) wood and cork.

- **Sample 2**: 19 industries

This sample includes the 11 manufacturing industries in sample 1, plus the following sectors: 12) agriculture, hunting, forestry and fish; 13) mining and quarrying; 14) construction; 15) wholesale and retail trade; 16) hotels and restaurants; 17) transport and storage; 18) real estate; 19) post and telecommunications.

- **Sample 3**: 27 industries.

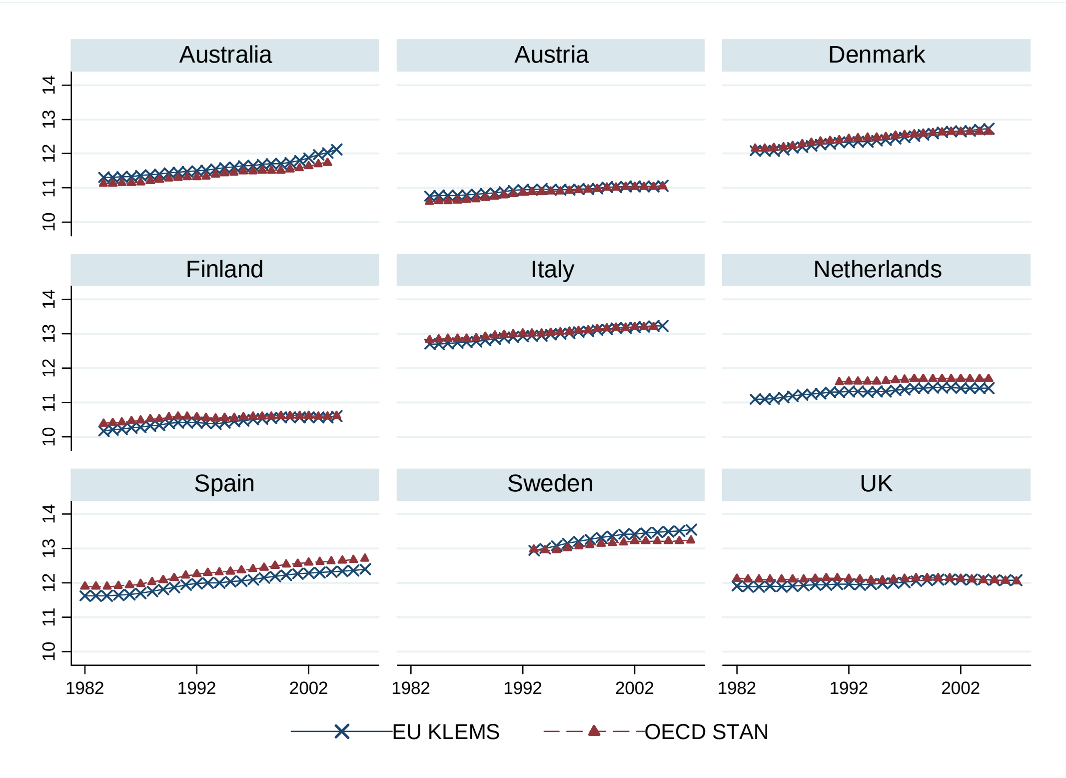
In addition to the 19 industries included in sample 2, we include the following sectors: 20) electricity, gas and water supply; 21) financial intermediation; 22) education; 23) public administration, defence and compulsory social security; 24) health and social work; 25) other community, social and personal services; 26) private households with employed persons; 27) extra-territorial organisations and bodies.

- **Countries and time coverage**

Name	Coverage
Australia	1982-2007
Austria	1982-2007
Czech Republic	1995-2007
Denmark	1986-2007
Finland	1995-2007
Germany	1991-2007
Italy	1982-2007
Japan	1982-2006
Netherlands	1982-2007
Spain	1982-2007
Sweden	1993-2007
UK	1982-2007
US	1982-2007

Appendix F: EU KLEMS and OECD STAN

Figure F.1: Total real capital stock (in logs): total manufacturing industry



Appendix G: Time-series plots for individual countries

Figure G.1: Average K/Q ratio (in logs): country-by-country

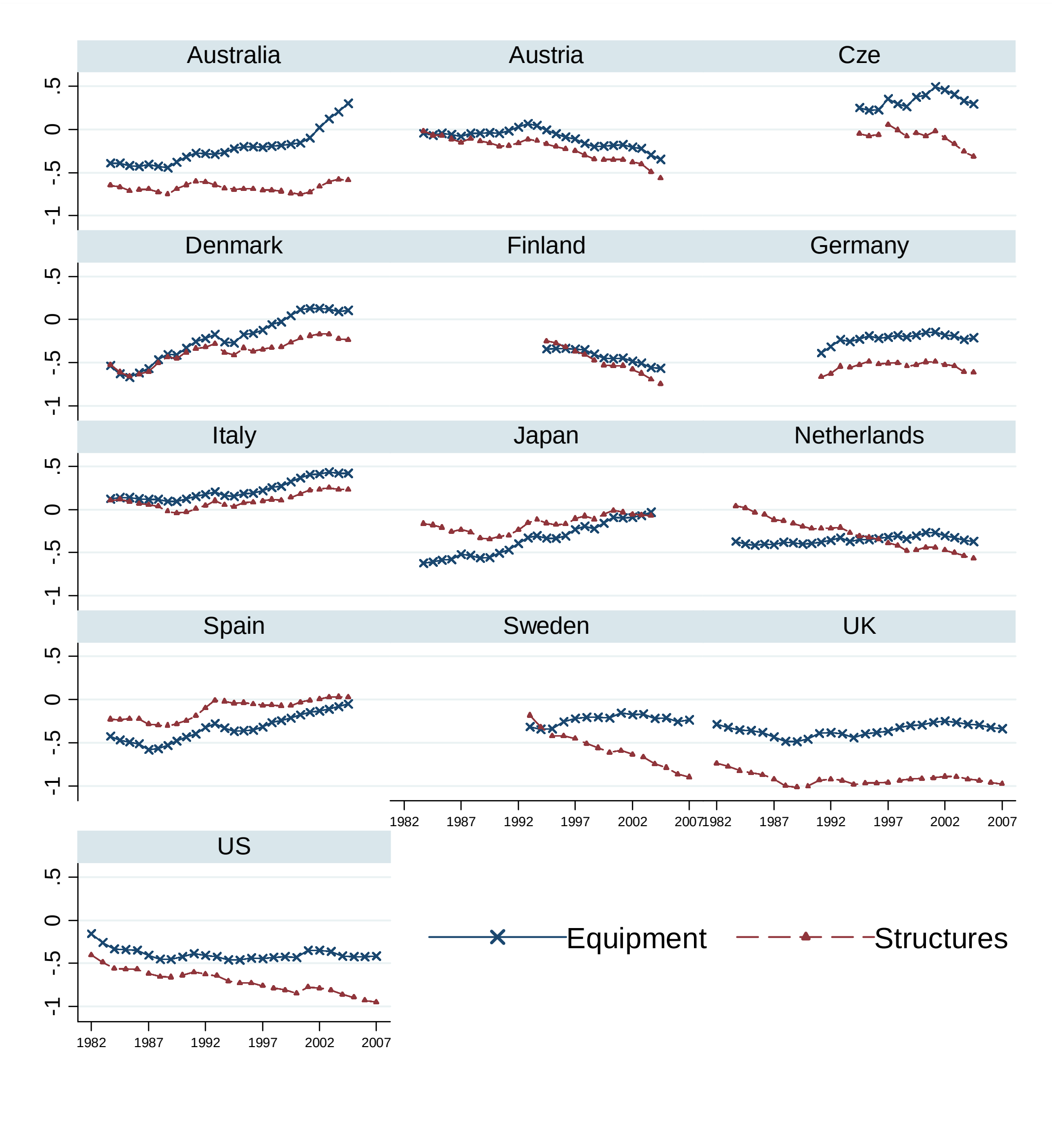


Figure G.2: Average relative prices of assets (in logs): country-by-country

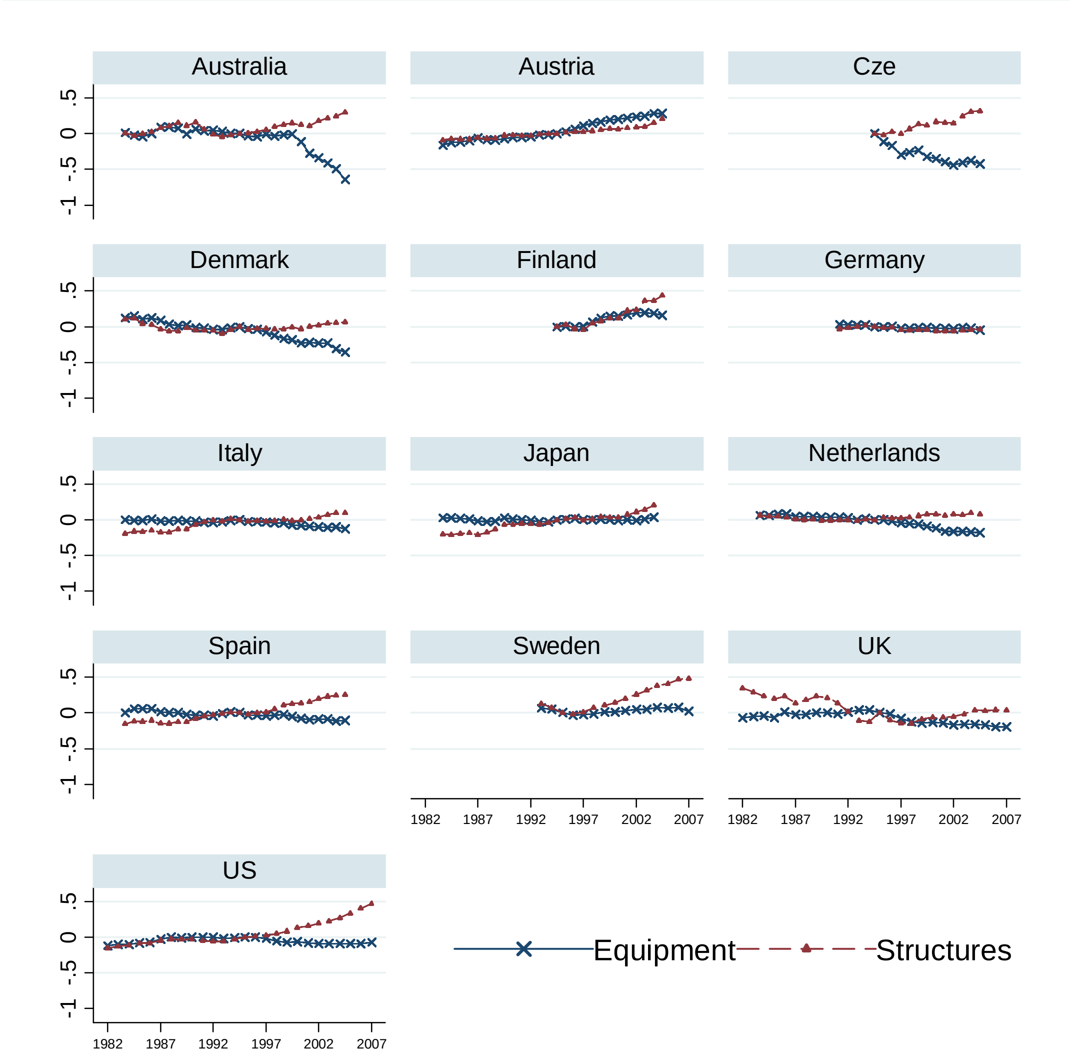
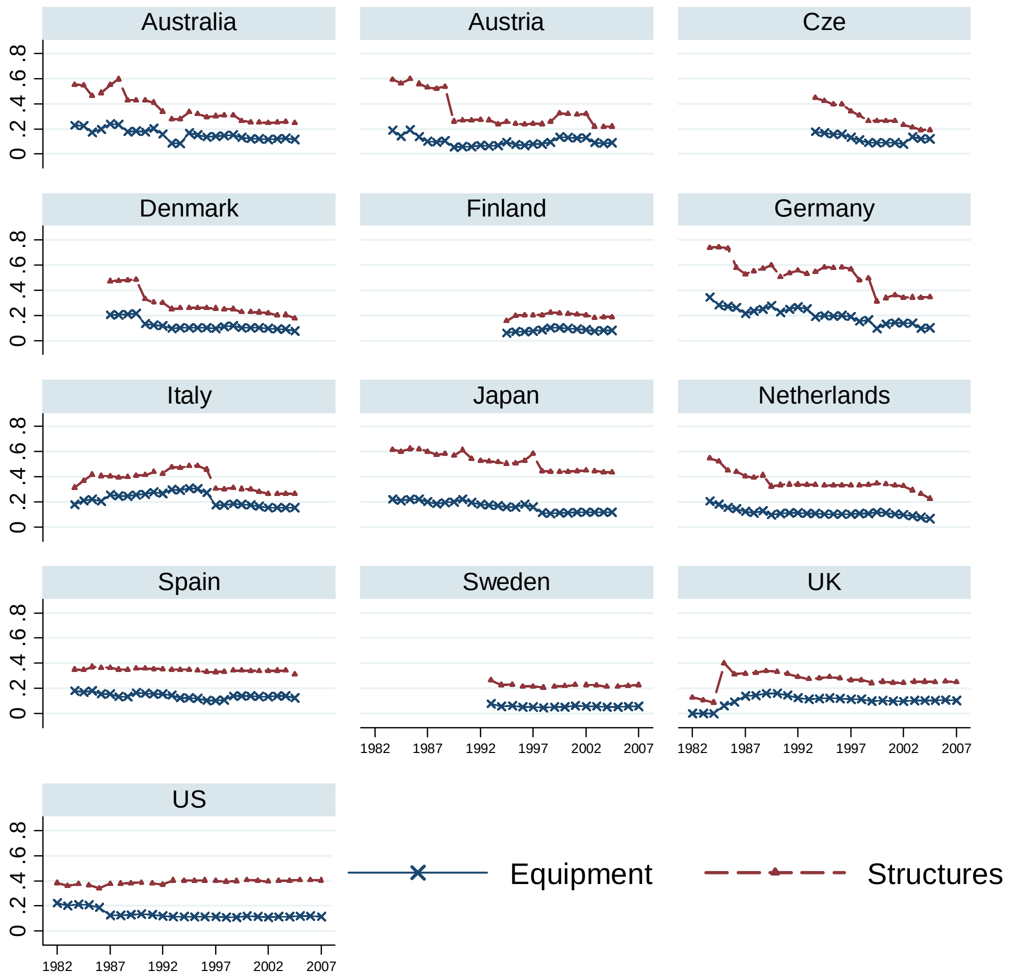


Figure G.3: Average tax component of the user cost of capital (in logs): country-by-country



Appendix H: Estimations without imposing CRS

In this Appendix, we report a set of estimation results when we do not impose the restriction that α_1 equals one. It is worth noting that we need to be cautious when interpreting the results based on the unrestricted model due to the possible non-stationarity of the output and capital stock series.

In the benchmark model estimations where the combined user cost of capital is used, the null hypothesis that α_1 equals one is formally rejected (Table H. 1). Nevertheless, the estimated α_1 is substantial for the case of total capital ($\widehat{\alpha}_1 = 0.710$) and for the case of equipment ($\widehat{\alpha}_1 = 0.820$). Crucially, the null hypothesis that the long-run user cost elasticity is zero ($\alpha_2 = 0$) is strongly rejected, both for total capital and for equipment and structures separately. For total capital and equipment, we do not reject the null hypothesis that the long-run user cost elasticity is -1.0, although the estimated long-run user cost elasticity is smaller for the case of structures.

When we decompose the user cost, the results based on the unrestricted model (Table H. 2) are similar to the results in Table 2.6. When additional tax variables are included (Table H. 3), we continue to find the EATR uninformative for both equipment and structures, but now we estimate a significantly positive coefficient on the statutory corporate income tax rate for both equipment and structures.

When we deal with the possible endogeneity of the user cost by including a full set of country-specific year dummies (Table H. 4) and by using IV estimation based on the unrestricted model (Table H. 5 and Table H. 6), we obtain broadly similar results to those reported in Tables 2.8, 2.9 and 2.10.

Again we find no evidence that the cost of capital for investment financed by debt is informative for either total capital or equipment, but some indication that the cost of capital for debt finance is more informative for structures (Table H.7).

Table H.1: Basic estimations (Manufacturing industries)

VARIABLES	Total capital	Equipment	Structures
Panel A			
$\ln K_{t-2}$	-0.032***	-0.060***	-0.022***
	(0.005)	(0.009)	(0.003)
$\ln Q_{t-2}$	0.023***	0.049***	0.009***
	(0.004)	(0.008)	(0.003)
$\ln UC_{t-2}$	-0.027***	-0.061***	-0.009***
	(0.005)	(0.010)	(0.002)
$\triangle \ln K_{t-1}$	0.484***	0.386***	0.538***
	(0.035)	(0.068)	(0.031)
$\triangle \ln Q_t$	0.065***	0.110***	0.020***
	(0.010)	(0.016)	(0.006)
$\triangle \ln Q_{t-1}$	0.053***	0.086***	0.026***
	(0.007)	(0.012)	(0.006)
$\triangle \ln UC_t$	-0.070***	-0.127***	-0.008***
	(0.009)	(0.019)	(0.004)
$\triangle \ln UC_{t-1}$	-0.047***	-0.088***	-0.014***
	(0.007)	(0.012)	(0.004)
Panel B: LR coefficients			
α_1	0.710***	0.820***	0.389***
	(0.097)	(0.086)	(0.118)
α_2	-0.836***	-1.021***	-0.389***
	(0.110)	(0.121)	(0.120)
Panel C: Test (p-value)			
$\alpha_1 = 1$	0.003	0.038	0.000
$\alpha_2 = -1$	0.236	0.860	0.000
Year dummies	Yes	Yes	Yes
No. of country-industries	143	143	143
Observations	2882	2882	2879

[1]S.E robust and clustered over time within country-industry pairs are in parentheses in this and subsequent tables.

[2]*** p<0.01, ** p<0.05, * p<0.1

Table H.2: Decomposing the user cost of capital

VARIABLES	Total capital	Equipment	Structures
Panel A			
$\ln K_{t-2}$	-0.031***	-0.060***	-0.022***
	(0.005)	(0.009)	(0.003)
$\ln Q_{t-2}$	0.021***	0.048***	0.009***
	(0.004)	(0.008)	(0.003)
$\ln (P^K/P)_{t-2}$	-0.025***	-0.057***	-0.011***
	(0.005)	(0.010)	(0.003)
$\ln TAX_{t-2}$	-0.026***	-0.096***	0.000
	(0.009)	(0.021)	(0.005)
$\triangle \ln K_{t-1}$	0.484***	0.380***	0.535***
	(0.035)	(0.068)	(0.031)
$\triangle \ln Q_t$	0.068***	0.114***	0.022***
	(0.010)	(0.017)	(0.006)
$\triangle \ln Q_{t-1}$	0.053***	0.085***	0.028***
	(0.007)	(0.012)	(0.006)
$\triangle \ln (P^K/P)_t$	-0.081***	-0.146***	-0.013***
	(0.010)	(0.021)	(0.005)
$\triangle \ln (P^K/P)_{t-1}$	-0.048***	-0.092***	-0.019***
	(0.009)	(0.014)	(0.005)
$\triangle \ln TAX_t$	-0.021*	-0.028	0.008
	(0.011)	(0.024)	(0.006)
$\triangle \ln TAX_{t-1}$	-0.030**	-0.063*	0.002
	(0.014)	(0.033)	(0.006)
Panel B: LR coefficients			
$\ln (P^K/P)$	-0.788***	-0.949***	-0.487***
	(0.148)	(0.118)	(0.145)
$\ln TAX$	-0.839***	-1.598***	0.019
	(0.271)	(0.344)	(0.213)
Panel C: Test (p-value)			
Equal LR elasticities	0.869	0.065	0.052
Year dummies	Yes	Yes	Yes
No. of country-industries	143	143	143
Observations	2882	2882	2879
R^2	0.467	0.393	0.434

[1]Standard errors are in parentheses.[2]*** p<0.01, ** p<0.05, * p<0.1

Table H.3: Additional tax variables

VARIABLES	Equipment	Equipment	Structures	Structures
$\ln K_{t-2}$	-0.060***	-0.060***	-0.022***	-0.025***
	(0.009)	(0.009)	(0.003)	(0.003)
$\ln Q_{t-2}$	0.047***	0.047***	0.010***	0.011***
	(0.008)	(0.008)	(0.003)	(0.003)
$\ln (P^K/P)_{t-2}$	-0.056***	-0.055***	-0.011***	-0.012***
	(0.010)	(0.010)	(0.003)	(0.003)
$\ln TAX_{t-2}$	-0.153***	-0.123***	-0.029	-0.034***
	(0.042)	(0.024)	(0.025)	(0.008)
$EATR_{t-2}$	0.061		0.044	
	(0.043)		(0.040)	
τ_{t-2}		0.032**		0.059***
		(0.016)		(0.010)
$\triangle \ln K_{t-1}$	0.380***	0.379***	0.536***	0.526***
	(0.068)	(0.068)	(0.032)	(0.031)
$\triangle \ln Q_t$	0.115***	0.115***	0.023***	0.024***
	(0.017)	(0.017)	(0.006)	(0.006)
$\triangle \ln Q_{t-1}$	0.086***	0.086***	0.028***	0.028***
	(0.012)	(0.011)	(0.006)	(0.006)
$\triangle \ln (P^K/P)_t$	-0.146***	-0.145***	-0.014***	-0.015***
	(0.021)	(0.021)	(0.005)	(0.005)
$\triangle \ln (P^K/P)_{t-1}$	-0.092***	-0.091***	-0.020***	-0.021***
	(0.014)	(0.014)	(0.005)	(0.005)
$\triangle \ln TAX_t$	-0.113	-0.058*	-0.079**	-0.021***
	(0.075)	(0.035)	(0.034)	(0.008)
$\triangle \ln TAX_{t-1}$	-0.094	-0.086**	0.019	-0.017**
	(0.067)	(0.041)	(0.037)	(0.008)
$\triangle EATR_t$	0.091		0.139**	
	(0.066)		(0.057)	
$\triangle EATR_{t-1}$	0.038		-0.029	
	(0.060)		(0.058)	
$\triangle \tau_t$		0.045**		0.056***
		(0.022)		(0.014)
$\triangle \tau_{t-1}$		0.037		0.035**
		(0.025)		(0.014)
No. of country-industries	143	143	143	143
Observations	2882	2882	2879	2879
R^2	0.394	0.394	0.435	0.440

[1]S.Es are in parentheses.[2]*** p<0.01, ** p<0.05, * p<0.1 [3]Year dummies included.

Table H.4: Adding country-specific year dummies

VARIABLES	Total capital	Equipment	Structures
Panel A			
$\ln K_{t-2}$	-0.056***	-0.065***	-0.039***
	(0.007)	(0.012)	(0.005)
$\ln Q_{t-2}$	0.036***	0.054***	0.017***
	(0.005)	(0.010)	(0.003)
$\ln UC_{t-2}$	-0.037***	-0.064***	-0.016***
	(0.005)	(0.012)	(0.003)
$\triangle \ln K_{t-1}$	0.386***	0.306***	0.443***
	(0.043)	(0.078)	(0.031)
$\triangle \ln Q_t$	0.054***	0.083***	0.016**
	(0.011)	(0.018)	(0.006)
$\triangle \ln Q_{t-1}$	0.049***	0.077***	0.019***
	(0.008)	(0.013)	(0.006)
$\triangle \ln UC_t$	-0.065***	-0.109***	-0.012**
	(0.010)	(0.020)	(0.005)
$\triangle \ln UC_{t-1}$	-0.048***	-0.095***	-0.023***
	(0.010)	(0.014)	(0.005)
Panel B: LR coefficients			
α_1	0.646***	0.835***	0.429***
	(0.055)	(0.077)	(0.070)
α_2	-0.664***	-0.986***	-0.414***
	(0.084)	(0.125)	(0.083)
Panel C: Test			
$\alpha_1 = 1$	0.000	0.034	0.000
$\alpha_2 = -1$	0.000	0.909	0.000
Country-specific year dummies	Yes	Yes	Yes
No. of country-industries	143	143	143
Observations	2882	2882	2879
R^2	0.589	0.509	0.572

[1]Standard errors are in parentheses.

[2]*** p<0.01, ** p<0.05, * p<0.1

Table H.5: Instrumenting the user cost by its tax component

IVs	$\triangle \ln TAX_t$, $\ln TAX_{t-1}$, $\ln TAX_{t-2}$			$\ln TAX_{t-1}$, $\ln TAX_{t-2}$		
VARIABLES	Total	Equipment	Structures	Total	Equipment	Structures
$\ln K_{t-2}$	-0.032***	-0.057***	-0.022***	-0.032***	-0.052***	-0.023***
	(0.005)	(0.009)	(0.003)	(0.005)	(0.009)	(0.003)
$\ln Q_{t-2}$	0.021***	0.043***	0.008***	0.020***	0.031***	0.012***
	(0.004)	(0.008)	(0.003)	(0.004)	(0.011)	(0.005)
$\ln UC_{t-2}$	-0.024***	-0.052***	-0.007***	-0.023***	-0.035**	-0.014**
	(0.005)	(0.010)	(0.003)	(0.006)	(0.014)	(0.006)
$\triangle \ln K_{t-1}$	0.487***	0.396***	0.536***	0.488***	0.414***	0.543***
	(0.037)	(0.070)	(0.031)	(0.038)	(0.078)	(0.031)
$\triangle \ln Q_t$	0.053***	0.081***	0.018***	0.048***	0.027	0.029***
	(0.009)	(0.014)	(0.006)	(0.013)	(0.028)	(0.011)
$\triangle \ln Q_{t-1}$	0.052***	0.086***	0.025***	0.052***	0.085***	0.028***
	(0.008)	(0.012)	(0.006)	(0.008)	(0.014)	(0.006)
$\triangle \ln UC_t$	-0.022**	-0.017	0.004	-0.005	0.195**	-0.046
	(0.011)	(0.023)	(0.006)	(0.040)	(0.093)	(0.039)
$\triangle \ln UC_{t-1}$	-0.047***	-0.094***	-0.012***	-0.047***	-0.104***	-0.019***
	(0.007)	(0.013)	(0.004)	(0.007)	(0.016)	(0.006)
α_1	0.646***	0.753***	0.341***	0.622***	0.604***	0.539***
	(0.103)	(0.100)	(0.123)	(0.121)	(0.161)	(0.196)
α_2	-0.749***	-0.915***	-0.321***	-0.717***	-0.680***	-0.601***
	(0.149)	(0.134)	(0.124)	(0.185)	(0.223)	(0.262)
$\alpha_1 = 1$	0.000	0.012	0.000	0.002	0.014	0.019
$\alpha_2 = -1$	0.091	0.528	0.000	0.126	0.151	0.128
Hansen test	0.596	0.017	0.083	0.388	0.178	0.142
Underidentification test	0.000	0.000	0.000	0.000	0.000	0.001
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
No. of country-industries	143	143	143	143	143	143
Observations	2882	2882	2879	2882	2882	2879

[1]Standard errors are in parentheses. [2]*** p<0.01, ** p<0.05, * p<0.1

Table H.6: Instrumenting the user cost by its lags

VARIABLES	Total	Equipment	Structures	Total	Equipment	Structures
$\ln K_{t-2}$	-0.044***	-0.067***	-0.044***	-0.066***	-0.069***	-0.048***
	(0.007)	(0.013)	(0.013)	(0.009)	(0.016)	(0.006)
$\ln Q_{t-2}$	0.030***	0.053***	0.055*	0.043***	0.053***	0.023***
	(0.006)	(0.013)	(0.032)	(0.006)	(0.018)	(0.006)
$\ln UC_{t-2}$	-0.036***	-0.065***	-0.086*	-0.046***	-0.057**	-0.026**
	(0.006)	(0.016)	(0.047)	(0.010)	(0.027)	(0.011)
$\triangle \ln K_{t-1}$	0.452***	0.347***	0.527***	0.369***	0.254***	0.404***
	(0.039)	(0.081)	(0.062)	(0.055)	(0.094)	(0.037)
$\triangle \ln Q_t$	0.091***	0.106***	0.122	0.081***	0.054	0.038*
	(0.018)	(0.039)	(0.078)	(0.028)	(0.070)	(0.020)
$\triangle \ln Q_{t-1}$	0.058***	0.081***	0.081*	0.053***	0.067***	0.027***
	(0.010)	(0.013)	(0.048)	(0.012)	(0.016)	(0.010)
$\triangle \ln UC_t$	-0.181***	-0.122	-0.474	-0.167	0.006	-0.097
	(0.065)	(0.193)	(0.331)	(0.109)	(0.295)	(0.076)
$\triangle \ln UC_{t-1}$	-0.048***	-0.095***	-0.093	-0.047***	-0.088***	-0.041**
	(0.009)	(0.025)	(0.065)	(0.011)	(0.026)	(0.020)
α_1	0.681***	0.797***	1.249***	0.655***	0.765***	0.466***
	(0.094)	(0.122)	(0.555)	(0.068)	(0.162)	(0.104)
α_2	-0.821***	-0.969***	-1.935***	-0.700***	-0.824***	-0.528***
	(0.124)	(0.154)	(0.879)	(0.139)	(0.299)	(0.211)
$\alpha_1 = 1$	0.001	0.098	0.654	0.000	0.146	0.000
$\alpha_2 = -1$	0.150	0.839	0.288	0.032	0.542	0.025
Hansen test	0.232	0.046	0.707	0.678	0.464	0.273
Underidentification test	0.000	0.052	0.681	0.027	0.051	0.112
Year dummies	Yes	Yes	Yes			
Country-specific year dummies				Yes	Yes	Yes
No. of country-industries	143	143	143	143	143	143
Observations	2882	2882	2879	2882	2882	2879

[1]Standard errors are in parentheses. [2]*** p<0.01, ** p<0.05, * p<0.1

Table H.7: Investment financed by different sources (LR elasticities)

VARIABLES	Total capital		Equipment		Structures	
a. Combined UC						
$\ln UC^{Debt}$	-0.531***	-0.073	-0.614***	0.054	-0.225***	-0.162***
	(0.132)	(0.081)	(0.115)	(0.075)	(0.069)	(0.058)
$\ln UC$		-0.778***		-1.104***		-0.305***
		(0.154)		(0.156)		(0.117)
b. Decomposed UC						
$\ln (P^K/P)$	-0.816***	-0.773***	-1.012***	-0.855***	-0.485***	-0.484***
	(0.166)	(0.158)	(0.140)	(0.120)	(0.146)	(0.143)
$\ln TAX^{Debt}$	0.019	-0.219*	0.051	-0.084	-0.104*	-0.134*
	(0.107)	(0.120)	(0.092)	(0.090)	(0.062)	(0.077)
$\ln TAX$		-1.320***		-2.075***		-0.180
		(0.360)		(0.414)		(0.261)

[1]Standard errors are in parentheses.

[2]*** p<0.01, ** p<0.05, * p<0.1.

[3]Common year dummies included

[4]Short-run dynamics included

Appendix I: Estimations with country-industry specific trends

Table I.1: Decomposing the user cost

VARIABLES	Total	Equipment	Structures
Panel A			
$\ln (K/Q)_{t-2}$	-0.099***	-0.158***	-0.057***
	(0.010)	(0.018)	(0.007)
$\ln(P^K/P)_{t-2}$	-0.070***	-0.128***	-0.029***
	(0.012)	(0.024)	(0.007)
$\ln TAX_{t-2}$	-0.039***	-0.122***	-0.005
	(0.012)	(0.027)	(0.009)
$\triangle \ln K_{t-1}$	0.323***	0.207***	0.396***
	(0.044)	(0.076)	(0.039)
$\triangle \ln Q_t$	0.096***	0.151***	0.041***
	(0.012)	(0.020)	(0.007)
$\triangle \ln Q_{t-1}$	0.095***	0.145***	0.051***
	(0.009)	(0.016)	(0.007)
$\triangle \ln(P^K/P)_t$	-0.090***	-0.153***	-0.017***
	(0.010)	(0.022)	(0.006)
$\triangle \ln(P^K/P)_{t-1}$	-0.075***	-0.125***	-0.028***
	(0.011)	(0.020)	(0.007)
$\triangle \ln TAX_t$	-0.025**	-0.020	0.006
	(0.012)	(0.026)	(0.007)
$\triangle \ln TAX_{t-1}$	-0.033**	-0.056	0.002
	(0.015)	(0.035)	(0.007)
Panel B: LR coefficients			
$\ln(P^K/P)$	-0.711***	-0.813***	-0.514***
	(0.093)	(0.103)	(0.131)
$\ln TAX$	-0.400***	-0.775***	-0.086
	(0.013)	(0.171)	(0.163)
Panel C: Test (p-value)			
Equal LR coefficients	0.032	0.853	0.044
No. of country-industries	143	143	143
Observations	2882	2882	2879
R^2	0.540	0.486	0.502

[1]Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

[2]Common year dummies and country-industry specific trends included

Table I.2: Additional tax variables

VARIABLES	Equipment	Equipment	Structures	Structures
$\ln(K/Q)_{t-2}$	-0.158***	-0.158***	-0.057***	-0.057***
	(0.018)	(0.019)	(0.007)	(0.007)
$\ln(P^K/P)_{t-2}$	-0.129***	-0.129***	-0.032***	-0.031***
	(0.024)	(0.024)	(0.008)	(0.007)
$\ln TAX_{t-2}$	-0.020	-0.123***	-0.085**	-0.022*
	(0.078)	(0.033)	(0.033)	(0.011)
$EATR_{t-2}$	-0.119		0.131**	
	(0.082)		(0.053)	
τ_{t-2}		-0.012		0.035**
		(0.030)		(0.014)
$\Delta \ln K_{t-1}$	0.206***	0.207***	0.393***	0.394***
	(0.076)	(0.076)	(0.039)	(0.038)
$\Delta \ln Q_t$	0.150***	0.151***	0.041***	0.041***
	(0.020)	(0.020)	(0.007)	(0.007)
$\Delta \ln Q_{t-1}$	0.145***	0.145***	0.052***	0.051***
	(0.015)	(0.016)	(0.007)	(0.007)
$\Delta \ln(P^K/P)_t$	-0.153***	-0.153***	-0.019***	-0.018***
	(0.022)	(0.022)	(0.006)	(0.006)
$\Delta \ln(P^K/P)_{t-1}$	-0.125***	-0.125***	-0.030***	-0.029***
	(0.020)	(0.020)	(0.007)	(0.007)
$\Delta \ln TAX_t$	-0.016	-0.041	-0.110***	-0.011
	(0.080)	(0.036)	(0.035)	(0.008)
$\Delta \ln TAX_{t-1}$	-0.028	-0.085*	-0.038	-0.008
	(0.078)	(0.045)	(0.038)	(0.009)
$\Delta EATR_t$	-0.012		0.186***	
	(0.071)		(0.058)	
$\Delta EATR_{t-1}$	-0.043		0.067	
	(0.069)		(0.059)	
$\Delta\tau_t$		0.026		0.037***
		(0.025)		(0.013)
$\Delta\tau_{t-1}$		0.026		0.023
		(0.029)		(0.014)
No. of country-industries	143	143	143	143
Observations	2882	2882	2879	2879
R^2	0.487	0.487	0.504	0.504

[1]Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

[2]Common year dummies and country-industry specific trends included

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Chapter 3

Corporate taxation and capital accumulation: evidence from firm-level data

1 Introduction

In Chapter 2, we estimate the long-run elasticity of the capital stock with respect to the tax-adjusted user cost of capital using aggregate data at the industry level from 13 OECD countries. We identify a substantial long-run user cost elasticity, which is significantly different from zero. We also find that the user cost elasticity for equipment is close to -1.0, which is consistent with the basic neoclassical investment model with Cobb-Douglas production technology. The aim of this chapter is to estimate the long-run user cost elasticity using firm-level data.

Results obtained from firm-level data could be different from those obtained from aggregate data for a number of reasons. First, the available sample of firms may not be representative of the whole economy and therefore, we may reach different conclusions purely because we use less representative firm-level data. Second, as the elasticity of the capital stock with respect to the user cost of capital corresponds to the substitution elasticity between capital and labour in the standard neoclassical investment model, it is not implausible to expect different substitution elasticities at the industry level and at the firm level. For example, if in response to a fall in the user cost, capital intensive firms grow faster than labour intensive firms within an industry, or if there are more entries (or fewer exits) of capital intensive firms over time, in the most extreme case we may observe a substantial substitution elasticity between capital and labour at the industry level even if the production technology for individual firms is Leontief. Therefore, it remains an empirical question whether we will reach similar or different conclusions as those in Chapter 2.

One benefit of using firm-level data is that we can directly compare our results with existing micro-level studies on the responses of investment to tax incentives based on the user cost approach (for example, Cummins, Hassett, and Hubbard 1994; Caballero, Engel and Haltiwanger 1995; Chirinko, Fazzari and Meyer 1999). Similar to aggregate-level studies, it proves to be no easy task to obtain precise and consistent estimates of the user cost elasticity using firm-level data. As most existing studies use data from a single country, notably the United States, there is often limited variation in the tax-adjusted user cost, either across firms or over a short period of time. The lack of variation in the user cost may contribute to the empirical difficulty in identifying the user cost elasticity at the firm(plant) level. One novelty of the current study is that we pool together data for firms in different countries, which is one way to introduce more variation to the user cost of capital. By matching firm-level data with the tax-adjusted user cost measured at the country-industry level, we estimate a substantial long-run user cost elasticity which is close to -1.0.

Another benefit of using firm-level data is that we can take into account firm-specific characteristics which may have important implications for a firm's investment behaviour. For example, in contrast with Modigliani and Miller's (1958) irrelevance theorem, Fazzari, Hubbard and Petersen (1988) and many subsequent studies suggest that firm-level investment is sensitive to the firm's financial status. In particular, it is often found that there is a strong residual sensitivity of investment to cash flow (i.e. after controlling for standard determinants of investment suggested by the basic neoclassical investment theory). It is also suggested in the investment literature that a firm's investment behaviour can be affected by its size, age and tax status. All these kinds of firm-level heterogeneities can be better addressed with firm-level data.

Although using micro-level data brings many benefits, it also sets a number of new challenges. First, firm-level data may be plagued with more serious measurement errors than aggregate data. For example, the measurement of both the capital stock and output in company accounts may be less accurate. Second, in contrast to Chapter 2 where we use panel data at the industry level with small N and large T, we now use firm-level panel data with the number of firms being large and the length of the time series available for each firm being short (large N and small T). This data property brings new econometric issues when we estimate a dynamic investment model.

The structure of this chapter is as follows. Section 2 reviews existing micro-level studies. Section 3 describes the firm-level data used in this study. Section 4 describes the empirical model. The benchmark estimation results are presented in Section 5. In Section 6, we check the robustness of the benchmark results. We first deal with the potential endogeneity of explanatory variables (Section 6.1). Then we check whether there is additional explanatory power from tax variables other than the tax-adjusted user cost (Section 6.2). We also examine whether the benchmark results differ across firms with different sizes, ages, financial status (Section 6.3) and tax status (Section 6.4). Section 7 concludes.

2 Previous micro-level studies

There is only a small number of micro-level studies which attempt to estimate the user cost elasticity and no consensus has been reached on its magnitude. Cummins, Hassett, and Hubbard (1994) point out that tax reforms are infrequent and hence, there is limited variation in the user cost in most years within a single country. Other factors, such as cyclical output fluctuations, may then have greater explanatory power for the variation in investment. This poses an identification difficulty when traditional econometric tools such as the Ordinary Least Squares (OLS) and the fixed-effects (FE) regressions are applied. Moreover, if tax policy is endogenous and such endogeneity problem is not properly dealt with, the estimated user cost elasticity will be biased and the related inference will be invalid.

To address these two issues, Cummins, Hassett, and Hubbard (1994) use US tax reforms as natural experiments to estimate the user cost elasticity.[1] The authors argue that during tax reform periods, the deviation of actual investment from what it would have been without the tax reform is proprotional to the deviation of the actual tax-adjusted user cost from its projected value.[2] Most importantly, the effect of tax policy changes may dominate that of other factors during major tax reform periods and hence, it may be easier to identify their impact on investment. Furthermore, the authors argue that if the precise impact of tax reforms on different firms is difficult to predict, the "surprise" to the user cost is likely to be exogenous and therefore, their approach can potentially mitigate the problem of endogenous tax policy faced by many previous time-series studies. Focusing on major business tax reforms between the early 1960s and the early 1990s, the authors estimate the user cost elasticity to be substantial (between -0.5 and -1.0) and significantly different from zero in the years just following a major tax reform, but not during non-reform years.[3]

[1] The authors also estimate an investment equation based on the q model.

[2] The authors forecast post-reform investment and user cost with information available in the year before the reform using linear projections.

[3] Similar results are found using the same approach in their subsequent study (Cummins, Hassett, and Hubbard, 1996) based on firm-level panel data collected from 14 OECD countries.

Caballero, Engel and Haltiwanger (1995) also find that investment is highly responsive to changes in the cost of capital by examining a large sample of plants in the US manufacturing sector over the period 1972-1988. The authors argue that the log of the capital-output ratio and the log of the user cost are both likely to be non-stationary series, but the difference between the two series is likely to be stationary. Hence, they estimate the cointegrated relationship between the log of the capital-output ratio (for investment in equipment only) and the log of the user cost of capital. Their estimates of the long-run user cost elasticity for different sectors range from -0.01 to -2.0, with an average about -1.0, the predicted long-run elasticity in the standard neoclassical investment model with Cobb-Douglas technology.

In contrast, Chirinko, Fazzari and Meyer (1999) estimate a much smaller long-run user cost elasticity than those in the previous two studies. The authors merge the user cost of capital defined at the industry level with Compustat firm-level data for 4,905 US manufacturing firms over the period 1981-1991. By estimating an Autoregressive-Distributive Lag (ADL) model relating the capital stock to output and the user cost, Chirinko, Fazzari and Meyer (1999) obtain a range of estimates of the long-run user cost elasticity from close to zero to roughly -0.50. Their preferred Instrumental Variables estimates of the long-run user cost elasticity are in a narrow range around -0.25, with a standard error of 0.03 to 0.06.

The estimated long-run user cost elasticity is much smaller in Chirinko, Fazzari and Meyer (1999) compared with those reported by Cummins, Hassett, and Hubbard (1994) and Caballero, Engel and Haltiwanger (1995). There are several possible explanations for these different results. First, the econometric tools used in these three studies are different as previously discussed. Second, Chirinko, Fazzari and Meyer (1999) focus on the total capital which is a mix of equipment and structures, while the other two studies focus on investment in equipment only. If investment in structures is less sensitive to changes in the user cost of capital, the overall response of the total capital stock to tax changes is likely to be smaller.

Most existing micro-level studies which attempt to estimate the user cost elasticity rely on firm or plant-level data from a single country, notably the United States. As rightly pointed out by Cummins, Hassett, and Hubbard (1994), there is often limited variation in the user cost in samples based on a single country. This makes the identification of the user cost elasticity difficult, particularly when we control for firm-level fixed effects as identification would then crucially rely on time-series variation in the user cost for individual firms. One possible solution is to pool together firms from different countries, with the hope that we may observe more tax reforms in the cross-country sample.

It is worth noting that other than estimating a model based on the user cost approach, there has been a large number of micro-level studies based on the q model (for example, Hayashi and Inoue 1991, Blundell et al. 1992, and Devereux, Keen and Schiantarelli 1994). It is suggested that the q model is well suited to company data because stock market valuations of publicly traded companies are readily reported. Nonetheless, similar disappointing results that have been found in aggregate-level studies are also reported in these micro-level studies based on the q model. For example, the estimated coefficient on the average q ratio is often unreasonably low, indicating implausibly high adjustment costs. As our sample includes both unquoted companies and individual subsidiaries of quoted groups, for which stock market valuations are not available, we focus on estimating a dynamic investment model based on the user cost approach. This also enables us to compare and contrast the results with those obtained in the previous chapter.

3 Data

3.1 The firm-level data from Amadeus

Our firm-level data are from Bureau van Dyck's Amadeus database, which provides basic information for over 18 million European companies (such as location, industry classifications, legal status, and ownership) as well as information from their balance sheets and profit and loss accounts. For each company, the data is available for up to ten years in Amadeus. We focus on the unconsolidated accounts of large firms in the manufacturing sector.[4] The

[4] To be classified as a large firm, the firm's annual operating revenue must be no less than 10 million EUR (14 million USD), its total assets must be no less than 20 million EUR (28 million USD), and its number of employees must be no less than 150.

key firm-level variables for our benchmark models are real tangible fixed assets (K) and real value-added (Q). Nominal tangible fixed assets are deflated using the sector-level price indices of investment goods obtained from EU KLEMS. Value-added for each firm is obtained by adding depreciation and staff costs to earnings before interest and taxes. Nominal value-added is deflated using the sector-level price indices of value-added also obtained from EU KLEMS. Both price indices have their base year in 1995. We adjust these series to 1995 US dollars using PPP exchange rates between national currency units and US dollars.[5]

Mismeasurement can be a serious problem with firm-level data and estimations could be sensitive to observations with extreme values.[6] Therefore, for our benchmark estimations we drop observations in the top or the bottom one percentile of the distributions of the growth rate of the capital-output ratio, the growth rate of real capital stock, and the growth rate of real value-added. We only keep firms with at least three consecutive years of observations.[7] We also drop firm-year observations where the number of months is different from 12. We also drop firm-year observations that do not report the basic information used to construct our measures of capital and value-added. Consequently there are no missing observations in terms of these key variables in the result-

[5]The PPP exchange rates for 1995 are obtained from the Penn World Table.

[6]For example, balance sheet measures of the stock of capital are generally at historic purchase cost rather than at current replacement cost, and our measure of value-added neglects the distinction between sales and production. As the available time series for each firm are short and lack information about changes in inventories,we have not attempted to adjust the basic measures obtained from company accounts in this study.

[7]We do not allow gaps between year in the panel data estimations. Therefore, if a firm reports two sequences of at least three consecutive years of observations, we retain the longest sequence or the earlier of the two sequences in the case of ties.

ing sample, which covers 30,901 large firms from 9 OECD countries over the period 1999-2008.[8]

The distribution of the number of firms in different countries in each year is summarised in Appendix J. As Figure J.1 shows, for each country, there are relatively fewer firms at the beginning and at the end of the sample period. The number of firms usually peaks in the middle of the sample period. There are considerably more firms located in Italy, France and Germany than in other countries in our sample. In Figure J.2, we plot the distribution of the number of firms and observations by the length of consecutive observations, which ranges from three to nine years. It shows that more than 77 per cent of firms in our sample report data for at least five consecutive years, which accounts for around 87 per cent of total observations. The largest group consists of firms with seven consecutive years of observations (around 47 per cent of the firms in our sample belong to this group).

Table J.1 in Appendix J provides some basic descriptive statistics of the key variables for the full sample and sub-samples by firm age and firm size. The age of a firm is defined as the difference between the year of its incorporation and the year when it first appears in our sample. We classify a firm to be a young firm if its age is below the median firm age in the whole sample, which is 23 years.[9] We classify a firm to be small or large according to its average level

[8]The nine countries are: Czech Republic, Finland, France, Germany, Italy, Netherlands, Spain, Sweden and the UK. Data for 2008 is only used for Czech Republic, Finland and France, due to the availability of price indices.

[9]There are 180 firms for which we do not know about their date of incorporation from Amadeus. As a result, the total number of observations in the "Young firms" and "Old

of real capital stock throughout its sampled period. A small firm's average level of real capital stock is below the median level of real capital stock in the full sample. It is worth noting that the dummy variables indicating firm size and age constructed in this way are time-invariant for individual firms. There is some evidence for younger firms to be also smaller firms, and *vice versa*.[10] Table J.1 shows that on average, small (young) firms grow faster in both capital and output (approxied by $\Delta \ln K$ and $\Delta \ln Q$) than large (old) firms. An average small firm is less capital-intensive (with a lower capital-output ratio) than an average large firm, while an average young firm is more capital-intensive than an average old firm. The average growth rate of the capital-output ratio (approxied by $\Delta \ln \frac{K}{Q}$) is negative for both small firms and young firms, almost zero for large firms and positive for old firms. Overall both capital and value-added are growing at similar rates (around 5% per year), which is consistent with a Constant Returns to Scale CES or a Cobb-Douglas production function.

3.2 Comparing with aggregate data

In this section, we compare our firm-level data with the industry-level data for the same countries from EU KLEMS. We need to bear in mind that there could be major discrepancies between data obtained from company accounts

firms" sub-samples is different from that in the full sample.

[10] In Table J.1, the average levels of real capital stock and real value-added for younger firms are both smaller than those for older firms. The correlation between the two dummy variables indicating firm size and age is positive but small (around 0.062).

and that from EU KLEMS, which may lead to different estimation results.

With respect to the measurement of real capital stock, the differences arise in both the measurement of the depreciable basis and the methods of depreciation. For the measurement of the depreciable basis, tangible fixed assets in company accounts are generally measured at historical costs when these assets are first acquired.[11] On the other hand, EU KLEMS measures real capital stock at replacement cost using the Perpetual Inventry Method, which uses the level of the capital stock in the distant history for a certain country-industry pair as the benchmark.[12]

In terms of the methods of depreciation, tangible fixed assets in company accounts are depreciated according to specific accounting rules which differ across countries and asset types, such as the straight-line and declining-balance depreciation methods. In contrast, EU KLEMS assumes the depreciation of capital follows a geometric pattern, which implies that a given vintage of investment loses a fixed percentage of its productive capacity each year. The depreciation rates in EU KLEMS are assumed to vary across industries and asset types but remain common across countries. These assumptions may be very different from those underlying the company accounts.

[11] Asset revaluation is often a last resort for companies in a difficult position as it would enable them to improve their solvency. Countries may have different practices regarding the revaluation of assets in company accounts. For example, France, Netherlands, and the UK authorise revaluation under certain conditions. Spain and Italy allow this possibility only periodically. On the other hand, Germany forbids the revaluation of assets.

[12] In EU KLEMS, the benchmark capital stock are reported back in the 1940s or earlier for some countries, and are reported in the 1950s, 1970s or 1990s for other countries. See *EU KLEMS Growth and Productivity Accounts* for more detail.

Furthermore, it is problematic to separate measured changes in the value of assets over time into price and quality components. Ideally, we would need to adjust the nominal capital stock using quality-constant price indices, in particular for assets which are subject to rapid technological change, notably computers and related equipment. Although we can deflate the nominal series of tangible fixed assets from company accounts using price indices for the flow of new investment, we do not have proper indices to adjust the stock data to reflect changes in asset quality over time. On the other hand, EU KLEMS uses the US Bureau of Economic Analysis (BEA) estimates of asset depreciation rates, which are based on the re-sale prices of assets on second-hand markets. This can be regarded as adjusting the nominal capital stock by a quality-constant price index.[13]

Moreover, our firm-level data based on large firms in Amadeus may not be representative of the whole manufacturing sector. Also, information provided in company accounts may differ from that reported to the national statistical agencies, especially for countries where the primary purpose of disclosure of financial statements is not to provide the authorities with information for taxation and statistics.[14]

To compare the firm-level data with the industry-level data, we calculate

[13] See Fraumeni, B. (1997).

[14] For countries like the UK and the US, the primary purpose of disclosure of financial statements is to provide shareholders with a true and fair view of the company, and the taxation on profit is calculated separately. For continental Europe, on the other hand, the primary purpose of disclosure of financial statements is to provide the government with information for taxation and statistical purposes.

the growth rate of the capital-output ratio ($\frac{K}{Q}$) in manufacturing for individual countries using data from Amadeus and EU KLEMS, separately. The growth rate of the capital-output ratio reveals the time-series property of this variable, which is essential to the identification of the user cost elasticity once we control for firm-level fixed effects. Figure K.1 plots the growth rates of manufacturing $\frac{K}{Q}$ for each country measured in three ways. First, we calculate the growth rate of aggregate capital stock as a ratio of aggregate output based on the firm-level data without controlling for compositional changes in the data. As previously shown in Figure K.1, there are considerably fewer firms at the beginning and at the end of the sample period, which indicates changes over time in the composition of firms in our samples. To address this issue, the second method also measures the growth rate of $\frac{K}{Q}$ with the firm-level data, but we control for compositional changes. The third measure of the growth rate of the capital-output ratio is based on the industry-level data from EU KLEMS. Detailed explanations of the three measurements are provided in Appendix K.

As Figure K.1 shows, comparing the growth rate of the capital-output ratio computed by the first and the third methods, we observe discrepancies between the two series and the differences are more apparent at the beginning of the sample period. Nevertheless, adjusting for changes in the composition of the firm samples brings the time series of the growth rate of manufacturing $\frac{K}{Q}$ based on the firm-level data somewhat closer to that based on EU KLEMS. In some cases (for example, Sweden), the magnitudes of the growth rates of the capital-output ratio and their time-series patterns become rather similar.

3.3 The industry-level user cost data

We allocate firms in the sample into 11 manufacturing industries by their NACE 2 industry classifications.[15] Tangible fixed assets in company accounts are a mixture of different asset types and limited by the available information, we cannot distinguish between different asset types. Assuming investment is totally financed by retained earnings, we calculate the tax-adjusted user cost of capital for each type of asset located in a certain country-industry combination in year t using the formula derived in Chapter 2:

$$C_{mt} = \frac{P^K_{mt}}{P_t}\left(r_{t+1} + \delta\right)\frac{(1 - A_{mt})}{(1 - \tau_t)} \tag{3.1}$$

where the subscript m stands for different types of assets.[16]

The non-tax component of the user cost corresponds to the relative price $\frac{P^K}{P}$, where P^K is the industry-level price of investment goods and P is the industry-level price of output. Both price indices are provided by EU KLEMS and are only available until the year 2007. To keep firm-level observations in the year 2008, we update the price indices from 2007 to 2008 by using information from OECD STAN.[17] By matching the industry-level relative prices

[15] The 11 manufucturing industries are: basic metals and fabricated metal; chemicals, rubber, plastics and fuel; electrical and optical equipment; food, beverages and tobacco; machinery not elsewhere classified; manufacturing not elsewhere classified and recycling; other non-metallic mineral; pulp, paper and printing; textiles, leather and footwear; transport equipment; and wood and cork. This industry classification corresponds to the one used in Chapter 2.

[16] The different types of assets include: equipment and machinery, buildings and structures, and other types of assets.

[17] For Czech, Finland and France, OECD STAN provides price indices of value-added and of gross fixed assets formation from 2007 to 2008. To update the price indices in EU KLEMS

of investment goods with the firm-level data, we implicitly assume that firms within the same industry in the same country face the same relative prices of investment goods. As in Chapter 2, we do not directly measure the real discount rate r and therefore, we control for the time-series variation in the term $(r_{t+1} + \delta)$ by including time effects in the estimated models.

We measure the tax-component of the user cost of capital, $\frac{(1-A_{mt})}{(1-\tau_t)}$, at the country-industry level using data provided by the Oxford University Centre for Business Taxation. Information on the statutory corporate income tax rate (τ_t) and the net present value of depreciation allowances (A_t) for different types of assets are available from 1999 to 2008 for most countries in our sample.

With this information, we first compute the user cost for different types of capital for each country-industry pair.[18] Then, we calculate the user cost of total capital as a weighted average, where the weights are the proportions of different types of assets in total capital stock within each country-industry pair. As we do not directly observe asset portfolios held by individual firms, we use information from EU KLEMS to construct the weights under the assumption that there is no cross-sectional variation in the asset mix held by firms within the same country-industry pair. The country-industry specific tax-adjusted user cost is then matched with the firm-level capital and output data and by doing so, we assume implicitly that firms within the same industry in the same

from 2007 to 2008, we first compute the growth rates of the price indices provided by STAN. Then, we multiply corresponding price indices in EU KLEMS by the growth rates obtained in the first step.

[18]For assets defined as "other assets", we measure the user cost by taking the average of the user cost of equipment asset and that of structures.

country face the same cost of capital.

4 The empirical model

As shown in the previous chapter, according to the basic neoclassical investment model, the relationship between the long-run optimal capital stock (K^*), output (Q) and the user cost of capital (C) for a profit-maximising firm can be written down as Equation (3.23) in Chapter 2:

$$K^* = \alpha Q^{\left(\sigma+\frac{1-\sigma}{v}\right)} C^{-\sigma}$$

where σ measures the elasticity of substitution between capital and labour, and v measures the returns to scale. We allow for short-run adjustment dynamics using an Error Correction Model as in Equation (3.26) in Chapter 2:

$$\alpha (L) \bigtriangleup \ln K_t = \beta (L) \bigtriangleup \ln K_t^* + \phi \left(\ln K_{t-k}^* - \ln K_{t-k}\right)$$

where $-\phi$ measures the speed of convergence of the actual capital stock towards its optimal level. $\alpha (L)$ and $\beta (L)$ are polynomials in the lag operator, and the order of differencing and the lag structures are left to be empirically determined. For example, assuming $\alpha (L) = \beta (L) = 1$, we obtain a simple dynamic investment model as Equation (4.1)

$$\begin{aligned}\triangle \ln K_{i,t} &= -\phi \left(\ln K_{i,t-1} - \alpha_1 \ln Q_{i,t-1} - \alpha_2 \ln C_{i,t-1}\right) \\ &\quad +\beta_1 \Delta \ln Q_{i,t} + \delta_1 \Delta \ln UC_{i,t} + j_t + u_i + \epsilon_{it} \qquad (4.1)\end{aligned}$$

where the dependent variable is the growth rate of the real capital stock. We assume that the error term has additive components j_t a time-specific effect, u_i a firm-specific effect and ϵ_{it} is the residual component. In this setting, α_1 corresponds to $(\sigma + \frac{1-\sigma}{v})$ and α_2 corresponds to $-\sigma$, the elasticity of substitution between capital and labour. If the production technology is Constant Returns to Scale CES, we would obtain $\alpha_1 = 1$. If the production technology is Cobb-Douglas, we would obtain $a_1 = 1$ and $a_2 = -1$.

By increasing the order of the lag polynomials $\alpha(L)$ and $\beta(L)$, we can obtain an investment model with richer dynamics, for example as Equation (4.2)

$$\begin{aligned}\Delta \ln K_{it} &= -\phi(\ln K_{i,t-3} - a_1 \ln Q_{i,t-3} - a_2 \ln C_{i,t-3}) + \gamma_1 \Delta \ln K_{i,t-1} + \gamma_2 \Delta \ln K_{i,t-2} \\ &\quad +\beta_1 \Delta \ln Q_{i,t} + \beta_2 \Delta \ln Q_{i,t-1} + \beta_3 \Delta \ln Q_{i,t-2} + \delta_1 \Delta \ln UC_{i,t} \\ &\quad +\delta_2 \Delta \ln UC_{i,t-1} + \delta_3 \Delta \ln UC_{i,t-2} + j_t + u_i + \epsilon_{it} \qquad (4.2)\end{aligned}$$

We can also impose long-run constant returns to scale on the technology by restricting α_1 to be unity. For example, we can replace the two terms involving $\ln K_{i,t-3}$ and $\ln Q_{i,t-3}$ in Equation (4.2) by the single term $\ln(\frac{K}{Q})_{i,t-3}$

and effectively we then estimate Equation (4.3)

$$\begin{aligned}\Delta \ln K_{it} &= -\phi[\ln(\frac{K}{Q})_{i,t-3} - a_2 \ln C_{i,t-3}] + \gamma_1 \Delta \ln K_{i,t-1} + \gamma_2 \Delta \ln K_{i,t-2} \\ &\quad +\beta_1 \Delta \ln Q_{i,t} + \beta_2 \Delta \ln Q_{i,t-1} + \beta_3 \Delta \ln Q_{i,t-2} + \delta_1 \Delta \ln UC_{i,t} \\ &\quad +\delta_2 \Delta \ln UC_{i,t-1} + \delta_3 \Delta \ln UC_{i,t-2} + j_t + u_i + \epsilon_{it} \qquad (4.3)\end{aligned}$$

5 Results

5.1 OLS and Fixed-effects estimates

The presence of lagged dependent variables in these dynamic investment models suggests that consistent estimates in short panels may be obtained using the Generalised Method of Moments (GMM) estimators discussed in Arellano and Bond (1991). It is however useful to compare the results obtained using least squares estimators. For this reason, Table 3.1 reports the Ordinary Least Squares (OLS) and fixed-effects within-groups (WG) estimation results based on Equation (4.1) (Columns 1 and 3) and Equation (4.2) (Columns 2 and 4), respectively, with constant returns to scale imposed. To control for the effects of common business cycles, we include a set of common year dummies in these specifications.

The upper panel of Table 3.1 presents the basic results. The estimated coefficient on $\ln(\frac{K}{Q})_{i,t-1}$ (or $\ln(\frac{K}{Q})_{i,t-3}$) corresponds to the speed of convergence of the actual capital stock towards its long-run target. We can see that while the OLS estimations suggest a rather slow convergence rate around -0.03, the WG estimations suggest a much faster speed of convergence around -0.58. Comparing the two models based on the restricted versions of Equations (4.1) and (4.2), we observe that the coefficients on the longer lags of the variables in first differences in Columns 2 and 4 are all significant at the 1 per cent level except in one case.[19] The fit of the models indicated by the R^2 statistics also increases when longer lags are included. Therefore, we base our subsequent estimations on Equation (4.3).

The lower panel of Table 3.1 reports the implied long-run elasticity of the capital stock with respect to the user cost of capital (α_2). The OLS estimates in Columns 1 and 2 suggest a long-run user cost elasticity around -0.5, which is significantly different from zero but also significantly different from -1.0. However, with the presence of firm-specific fixed effects, these OLS estimates are biased and inconsistent. As we can see in Columns 3 and 4, the WG estimates suggest a much larger point estimate of the long-run user cost elasticity. In Column 4, the WG estimates of the model based on Equation (4.3) provides a substantial long-run user cost elasticity which is insignificantly different from -1.0.

How do these results in Table 3.1 compare with those obtained from the industry-level data? In Table 3.2, we present the WG estimation results of these two dynamic specifications using the industry-level data from EU KLEMS for comparison. We use two samples. The first sample corresponds to

[19] The OLS estimate of the coefficient on $\Delta \ln UC_{i,t-2}$ in Column 2.

the one used in Chapter 2, which covers manufacturing industries in 13 OECD countries over the period 1982-2007. The second sample consists of the same nine countries as in our firm-level data set, over the shorter period 1999-2007. The WG estimates based on these two samples also suggest that the long-run elasticity of the total capital stock with respect to the user cost is substantial and close to -1.0,[20] which is broadly in line with the findings in Table 3.1.[21] The results using the industry-level data do however suggest much slower adjustment than the results using the firm-level data - this is evident both from the estimates of the convergence rate $-\phi$ (i.e. the coefficients on $\ln(\frac{K}{Q})_{i,t-1}$ or $\ln(\frac{K}{Q})_{i,t-3}$) and the estimates of the impact elasticities (i.e. the coefficients on $\Delta \ln Q_{i,t}$ and $\Delta \ln \mathrm{UC}_{i,t}$).

5.2 GMM estimates

It is known that with the presence of individual fixed effects, for dynamic panel estimations with the lagged dependent variable on the right-hand side, the OLS estimate of the coefficient on the lagged dependent variable is likely to be biased upwards. On the other hand, the WG estimate of the coefficient on the lagged dependent variable is likely to be biased downwards in short panels due to the within-groups transformation. To illustrate this inconsistency of

[20] In Column (7), the point estimate of the long-run user cost elasticity is -2.302, however, it is associated with a big standard error. Asthe parameter is estimated imprecisely, the null hypothesis that α_2 equals -1.0 is not rejected even at the 10 per cent level.

[21] The specification reported in Column (5) of Table 3.2 differs from that reported in Column 1 of Table 2.2 in the previous chapter only by the omission of the $\Delta \ln K_{i,t-1}$, $\Delta \ln Q_{i,t-1}$ and $\Delta \ln UC_{i,t-1}$ terms. We can note that the main features of the results using the industry-level data are not sensitive to the inclusion or omission of this and longer lagged terms.

the WG estimator, let us consider a simple dynamic regression model

$$
\begin{aligned}
y_{it} &= \alpha y_{i,t-1} + u_i + \epsilon_{it} && (5.1)\\
i &= 1, 2, ..N,\ t = 2, ...T
\end{aligned}
$$

where u_i is the individual-specific fixed effect and ϵ_{it} is a serially uncorrelated error term. The WG estimator applies Ordinary Least Squares to the transformed model

$$\widetilde{y}_{it} = \alpha \widetilde{y}_{i,t-1} + \widetilde{\epsilon}_{it} \tag{5.2}$$

where $\widetilde{y}_{it} = y_{it} - \frac{1}{T-1}\sum_{t=2}^{T} y_{it}$, $\widetilde{y}_{i,t-1} = y_{i,t-1} - \frac{1}{T-1}\sum_{t=1}^{T-1} y_{it}$, and $\widetilde{\epsilon}_{it} = \epsilon_{it} - \frac{1}{T-1}\sum_{t=2}^{T} \epsilon_{it}$. We can see that the WG estimator, $\widehat{\alpha}_{WG}$, is inconsistent as N becomes large with T fixed, as $Corr(y_{i,t-1}, -\frac{1}{T-1}\epsilon_{i,t-1})$ and $Corr(-\frac{1}{T-1}y_{it}, \epsilon_{it})$ are both negative and, consequently, $E(\widetilde{y}_{i,t-1}\widetilde{\epsilon}_{it}) < 0$. Only when T becomes large does this bias in the WG estimator become negligible (i.e. $E(\widetilde{y}_{i,t-1}\widetilde{\epsilon}_{it}) \rightarrow 0$ as $T \rightarrow \infty$). We relied on this property in Chapter 2, where we had 26 years of data for many of the country-industry pairs. Howver we cannot do so in the current study as T is at most 10 for individual firms and, as a result, the WG estimator is likely to be seriously biased.

One alternative is to use the first-differencing transformation to remove any firm-level fixed effects. Nevertheless, by first-differencing Equation (4.3), we introduce on the right-hand side the lagged error term $\epsilon_{i,t-1}$, which is correlated with $\Delta \ln K_{i,t-1}$.[22] As a result, the OLS estimate of the coefficient on this

[22] Thsi can be seen more easily by writing the first-differenced transformation of Equation

variable would be biased. Depending on whether or not output and the user cost of capital are also correlated with the first-differenced error term, there may be further sources of bias. To address the issue of endogenous variables in the setting of a dynamic investment model like Equation (4.3), we need to find valid instruments for any endogenous variable.

Arellano and Bond (1991) suggest to use lagged levels of endogenous variables as instruments for the set of equations in first-differences by applying the generalised method of moments (GMM). If the error term ϵ_{it} in Equation (4.3) is simply a white noise process, we can use lags of $\ln K$ dated $(t-2)$ and earlier as instruments for each of these first-differenced equations. More of these lagged instruments become available as we consider later equations, and these additional instruments are used in the estimation procedure. We can instrument any other endogenous variable in the same way. Furthermore, as mentioned previously, firm-level data on output and capital stock are likely to be mismeasured. If the model includes several lagged values of an explanatory variable that is measured with error, we would then need to use only the longer lagged values of this variable to obtain valid instruments.

We start by estimating Equation (4.3) assuming there is no measurement error and the residual component of the error term (ϵ_{it}) is serially uncorrelated. Initially, we only treat the capital stock as endogenous while treating both output and the user cost of capital as exogenous. This requires us to use the

(5.1) explicitly as $(y_{i,t} - y_{i,t-1}) = \alpha(y_{i,t-1} - y_{i,t-2}) + (\epsilon_{i,t} - \epsilon_{i,t-1})$ and noting that $y_{i,t-1}$ is necessarily correlated with $\epsilon_{i,t-1}$.

lags of $\ln K$ dated $(t-2)$ and earlier as the instruments for the capital stock terms, and allows us to use $\ln Q$ and $\ln UC$ dated t and earlier as instruments for the output and user cost terms.

Table 3.3 reports the GMM estimation results under these assumptions.[23] In Column 9, we include a set of common year dummies to control for the effects of common business cycles. In Column 10, we include country-specific year dummies to control for idiosyncratic shocks at the country level - as explained in Section 6.2.1 of Chapter 2, this specification allows for possible correlation between tax policy and country-specific business cycles. The estimated speed of convergence in these two models is very small and insignificantly different from zero and as a result, the estimated long-run user cost elasticity becomes extremely imprecise. In panel C, the validity of the restriction that α_1 equals 1 is rejected at the 1 per cent level.[24] However, the Hansen test rejects the null hypothesis that the instrumental variables are exogenous at the 1 per cent level, indicating that the set of instruments used here may be invalid. As expected, the null hypothesis that there is no first-order serial correlation in the error term of the first-differenced equations is rejected at the 1 per cent level, while the null hypothesis that there is no second-order serial correlation in the first-differenced errors is not rejected at the 10 per cent level.[25]

[23] We report one-step GMM estimates with robust standard errors computed using the xtabond2 command in Stata (see Roodman, 2006).

[24] The test results regarding the restriction on α_1 in Table 3.3 are obtained from the corresponding GMM estimations based on the unrestricted Equation (4.2), which are reported in Appendix K. These show that once we treat output as endogenous (Columns 11-14), relaxing or imposing the restriction on α_1 does not significantly affect the estimated long-run user cost elasticity, which remains close to -1.0.

[25] As $\Delta\epsilon_{it} = \epsilon_{it} - \epsilon_{i,t-1}$, and $\Delta\epsilon_{i,t-1} = \epsilon_{i,t-1} - \epsilon_{i,t-2}$, we should expect $\Delta\epsilon_{it}$ to be correlated

In Columns 11 and 12, we treat both capital stock and output as endogenous variables and use the lags of $\ln K$ and $\ln Q$ dated $(t-2)$ and earlier as instruments. We continue to treat the user cost of capital as exogenous and to assume no measurement errors in variables. A set of common year dummies is included in Column 11 and country-specific year dummies are included in Column 12. Now, the GMM estimations yield significant estimates of both the convergence rate and the long-run user cost elasticity. Moreover, we no longer reject the null hypothesis that α_1 equals 1. Nonetheless, the Hansen test of over-identifying restrictions still rejects the null hypothesis of valid instruments at the 1 per cent level.

In Columns 13 and 14, we continue to treat both capital stock and output as endogenous while treating the user cost as exogenous. Now, we allow for serially uncorrelated measurement error in both the capital and output variables. This requires us to use only the lags of $\ln K$ and $\ln Q$ dated $(t-5)$ and earlier as instruments for the equations in first-differences.[26] In Column 13, common year dummies are included. The validity of the instruments is still rejected by the Hansen test at the 1 per cent level. In Column 14, we use the same set of instruments but include country-specific year dummies. Now, the Hansen test of the over-identifying restrictions has a p-value of 0.032 and hence, the validity of our instruments is no longer rejected at the 1 per cent level. The

with $\Delta\epsilon_{i,t-1}$ if ϵ_{it} is serially uncorrelated, but not with $\Delta\epsilon_{i,t-q}$, where q are integers greater than 1. We only report the AR(1) and AR(2) test results in Table 3.3 and subsequent tables, but we do not detect higher order autocorrelation in the first-differenced error terms.

[26] We also estimated specifications including shorter lags of both $\ln K$ and $\ln Q$ in the instrument set, and the results were similar to those reported in Columns 13 and 14. However, the Hansen test always rejected the null hypothesis of valid instruments in these cases.

main results remain similar to those in Columns 11 and 12. In both columns, the null hypothesis that α_1 equals 1 is not rejected. The estimated long-run user cost elasticity is significantly different from zero and close to -1.0. The estimated speed of convergence is significantly different from zero, and lies in between those suggested by the OLS and WG estimates. This is reassuring as the OLS estimate of this parameter is likely to be biased upwards, while the WG estimate of this parameter is likely to be biased downwards.[27]

6 Robustness checks

6.1 Endogeneity of the user cost of capital

So far, we have maintained the assumption that the user cost of capital is uncorrelated with current or lagged values of the error term (ϵ_{it}) in Equation (4.3). Arguably, it is unlikely for the tax component of the user cost measured at the industry level to be correlated with idiosyncratic shocks at the firm level.[28] Even if there are systematic shocks at the industry or country level, it may take a long time for the government to adjust its corporate income tax system in response to such shocks. Similarly, the non-tax component of the user cost, the relative price of investment goods, measured at the industry-level is also unlikely to be endogenous to firm-specific shocks. Nevertheless,

[27] The convergence parameter $-\phi$ in our Error Correction Specification behaves like the sum of estimated coefficients on the lagged dependent variables in an Autoregressive-Distributed Lag specification.

[28] Recall that we assume firms within the same industry in the same country face the same tax-adjusted user cost of capital.

the Hansen test results in Table 3.3 reject the validity of the instruments used there, at least at the 5% level. Therefore, in this section we consider treating the user cost as endogenous in the GMM estimations.

One strategy is to instrument the current user cost of capital by its lags. Table 3.4 reports the GMM estimation results when capital stock, output and the user cost of capital are all assumed to be endogenous variables. We keep using $\ln K$ and $\ln Q$ dated $(t-5)$ and earlier as instruments for the capital stock and output terms. Implicitly, we assume there are serially uncorrelated measurement errors in these two variables. Country-specific year dummies are also included. One rationale to keep country-specific year dummies in Table 3.4 is that the Hansen test in Column 14 in the previous table yields a higher p-value than that in Column 13 when common year dummies are included, suggesting that it may be important to allow for correlation between tax policy and country-specific business cycles.

In Column 15, we assume the user cost of capital is endogenous but not measured with error. We thus use $\ln UC$ dated $t-2$ and earlier as instruments for the first-differenced equations. The point estimate of the long-run user cost elasticity is around -0.965, which is significantly different from zero at the 5 per cent level. The null hypothesis that this parameter is -1.0 is not rejected by a standard Wald test at the 10 per cent level. Now, the Hansen test yields a p-value of 0.041 and again we do not reject the validity of our instruments at the 1 per cent level.

Next, in Columns 16-18, we consider using only longer lags of $\ln UC$ as instruments for the equations in first-differences. In Column 16, we use $\ln UC$ dated $t-3$ and earlier; in Column 17, we use $\ln UC$ dated $t-4$ and earlier; and in Column 18, we use $\ln UC$ dated $t-5$ and earlier, which allows for the possibility of serially uncorrelated measurement error in the user cost variable. As the Table shows, the Hansen test no longer rejects the validity of the instruments even at the 10 per cent level once we use only these longer lags of $\ln UC$ as instruments. The estimated long-run user cost elasticity remains negative in all these three columns, and is significantly different from zero at least at the 10 per cent level in Columns 16 and 17. Nonetheless, these estimates become more and more imprecise as we use only the more distant lags of the user cost in the set of instruments. In fact, although the point estimates of the long-run user cost elasticity in Columns 16-18 become much larger in absolute value, they are sufficiently imprecise that we do not reject the null hypothesis that α_2 equals -1.0 in any of these columns.

6.2 Additional tax variables

In this section, we investigate whether the effective average tax rate ($EATR$) and the statutory corporate income tax rate have additional explanatory power for firm-level investment. Table 3.5 presents the GMM estimation results. Here we treat both capital and output as endogenous with serially uncorrelated measurement errors, and use $\ln K$ and $\ln Q$ dated t-5 and earlier as instruments.

We treat the user cost of capital and the additional tax variables as exogenous.[29]

Consistent with our findings at the industry level in the previous chapter, the results in Column 19 suggest that the $EATR$ has no significant effect on the capital-output ratio in the long run once we control for the user cost of capital. Here we also find that the statutory corporate tax rate has no significant effect in either the short run or in the long run. With respect to the EATR, this result may not be surprising because the estimation is based on unconsolidated accounts data for companies or their subsidiaries in individual countries and therefore, we have already implicitly controlled for a firm's location choice for investment.

6.3 Sensitivity to firm size, age and cash flow

In the investment literature, it has been pointed out that capital markets for equity and debt may be imperfect. According to the pecking-order theory, firms prefer internal to external funds. Underlying this line of research is the premise that capital market imperfections cause a divergence between the cost of internal and external funds. Moreover, firms may not have equal access to external funds for investment. If it is too costly to raise external funds by issuing new debt or equity, a firm's investment may be strongly affected by the availability of internal funds.

[29] Broadly similar results to those in Table 3.5 were obtained when using only longer lags of the user cost and additional tax variables.

Using panel data on US manufacturing firms, Fazzari, Hubbard and Petersen (1988) find that investment is sensitive to cash flow, and more so for groups of firms that are more likely to face internal finance constraints, such as for developing firms in rapidly growing industries. Gilchrist and Himmelberg (1995) also find that investment is highly sensitive to cash flow and such "excess sensitivity" is not spuriously generated by cash flow's ability to predict future investment returns.[30] Based on a sample of Japanese firms, Hoshi, Kashyap and Sharfstein (1991) find that investment by Japanese firms that belong to a corporate group is less sensitive to cash flow than investment by independent firms, and they suggest a group affiliation alleviates underinvestment problems caused by capital market imperfections. The "excess sensitivity" of investment to cash flow is also documented in Bond and Meghir (1994) based on the Euler equation approach.

There remains an on-going debate about how to identify whether a firm that is financially constrained. In Fazzari, Hubbard and Petersen (1988), firms are classified as more or less financially constrained primarily by their retention behavior measured by the ratio of dividends to income. Other studies find that the sensitivity of investment to cash flow varies across firms with different sizes or ages. For example, Devereux and Schiantarelli (1990) find that cash flow's impact on a firm's investment behaviour is more prominant for larger

[30] The term "excess sensitivity" refers primarily to the q model, which relates a firm's investment behaviour to the marginal q ratio. If marginal q summarises all information about the value of additional investment then investment should not respond to other variables such as cash flow. Therefore, the empirical finding of a significant link between invesment and cash flow conditional on measures of q is referred to as "excess sensitivity".

firms than for smaller firms, and for newer firms than for older firms. Nevertheless, it remains controversial whether the (excess) sensitivity of investment to cash flow should be interpreted as a reliable indicator of a firm's access to capital markets. In particular, using a different classification scheme, Kaplan and Zingales (1997) suggest that less financially constrained firms exhibit significantly greater sensitivity to cash flow than firms which appear to be more financially constrained.[31]

The emphasis of the current study is not on detecting the "excess sensitivity" of investment to cash flow, however, it remains important to check whether our estimated long-run user cost elasticity would be affected by including cash flow as an additional explanatory variable. In the spirit of the literature on the "excess sensitivity" of investment to cash flow, we first split the original sample by firm age and firm size.[32] Table 3.6 summarises the GMM estimation results based on four sub-samples before we control for cash flow. We continue to treat capital and output as endogenous with serially uncorrelated measurement errors, and to treat the user cost as exogenous.[33] Country-specific year dummies are included. The results suggest that firms of different sizes or ages do not appear to have different long-run user cost elasticities, which are all significantly different from zero and close to -1.0.

[31] Kaplan and Zingales (1997) use qualitative information in the annual reports and quantitative information in the companies' financial statements to classify each firm-year observation into five different groups according to the likelihood of being financially constrained.

[32] The definitions of our firm size and firm age classifications are provided in Section 3.1.

[33] We use $\ln K$ and $\ln Q$ dated t-5 and earlier, as well as $\ln UC$ dated t and earlier, as instruments for the equations in first-differences.

Next, we add cash flow variables into the investment model. We define cash flow as net income plus depreciation. The nominal series of cash flow is converted into a real series using the price indices of value-added from EU KLEMS. In Table 3.7, we include $\frac{CF}{K}_{i,t-3}$, $\Delta\frac{CF}{K}_{i,t}$, $\Delta\frac{CF}{K}_{i,t-1}$ and $\Delta\frac{CF}{K}_{i,t-2}$ as additional explanatory variables in Equation (4.3). We treat capital, output and the user cost in the same way as in Table 3.6. We treat $\frac{CF}{K}$ as endogenous with serially uncorrelated measurement error, and hence use $\frac{CF}{K}$ dated $t-5$ and earlier in our set of instruments. Panel B presents the estimated long-run elasticities of capital with respect to the user cost and cash flow, respectively.[34] For the full sample, the estimated long-run elasticity of the capital stock with respect to $\frac{CF}{K}$ is positive but insignificant. More importantly, we find that controlling for cash flow does not affect the estimated long-run user cost elasticity, which remains close to -1.0. In the sub-sample estimations presented in Columns 26-29, we do not find any evidence for a significant link between cash flow and investment in the long run in any of these sub-samples. Surprisingly, we find a negative and significant link between investment and cash flow in the short run, as indicated by the negative coefficient on $\Delta\frac{CF}{K}_{i,t}$ in all five columns.

[34] The sample size in Table 3.7 becomes smaller due to missing observations on the cash flow variable. We clean the original sample to guarantee that there are no missing observations in terms of key variables and no gaps in the panel data. We also further clean the estimation sample by removing the top and the bottom 1 percentile of observations in the distribution of $\frac{CF}{K}$.

6.4 The effects of tax asymmetries

One general feature of the corporate income tax system is the asymmetric treatment of profits and losses. In the derivation of the user cost of capital in Chapter 2, we assume that taxable profit is always positive. In reality, firms may experience tax losses (i.e. negative values of taxable profit). When this occurs, the tax loss in a particular year may be carried forward or backward. Nevertheless, when tax losses are carried forward, there is usually no interest markup, and this may only be allowed for a limited period of time. This delay before tax allowances can be utilised reduces their present value, so that the value of tax incentives for investment will differ across firms with different tax status. Based on COMPUSTAT data for US firms in the early 1980s, Auerbach and Poterba (1987) document that around 15 per cent of firms in their sample report loss carryforwards. Their calculation suggests that tax asymmetries are an important source of inter-industry differences in effective tax rates.

This aspect of the corporate income tax system has been analysed in studies such as Auerbach and Poterba (1987), Altshuler and Auerbach (1990), and Mintz (1988). In particular, Devereux, Keen and Schiantarelli (1994) incorporate tax asymmetries into the firm's optimisation problem and derive the implied tax-adjusted q ratio and user cost of capital. They find that accounting for tax asymmetries generally decreases the value of q and increases the user cost of capital. Nonetheless, their empirical models based on these alternative measures of q and user cost lead to similar results to those using the unadjusted measures of q and user cost.

We do not have accurate information to identify each firm's tax status and hence, we rely on data from company accounts to construct an indicator for which firms are more likely to be in a tax loss position. More specifically, we define a firm to be in a loss-making status in a particular year if its reported profit before tax is negative.[35] As shown in Figure J.1 in Appendix J, around 12 per cent of firms in our sample were loss-making in 1999. Subsequently, the percentage of loss-making firms remains around 15 per cent in most years before it reaches a peak of about 22 per cent in 2008. The average percentage of loss-making firms in the sample period is higher in Czech, France and the UK than in the other countries.[36] Figure J.2 shows that among the loss-making firm-year observations, slightly more than 30 per cent are making losses for only one year. Around 20 percent of the loss-making firm-years are in a sequence of continuous loss making for two years, around 15 percent for three years and around 27 percent for at least 4 years.

Essentially, the existence of tax asymmetries introduces measurement error in our standard measure of the user cost of capital and as a result, it may confound the estimation of the user cost elasticity. The importance of this measurement problem is an empirical question that we begin to explore in this section. Table 3.8 presents the GMM estimation results for extended model

[35] Profit (loss) before tax in Amadeus is defined as the sum of operating profit and financial profit. Interest charges are included in the calculation of financial profit.

[36] The average percentage of loss-making firms is around 19 per cent in both Czech and France and more than 20 per cent in the UK.

specifications where we account for the presence of tax losses in two simple ways. We treat capital and output as endogenous with serially uncorrelated measurement errors, and we treat the user cost as exogenous.

In Column 30, we use a time-invariant dummy variable (LS_i) which equals 1 in each year for a firm if it ever reports negative profit before tax during the sample period. We then interact this dummy variable with all our explanatory variables, so allowing all coefficients in Equation (4.3) to take different values for the two sets of observations. Panel A presents the estimated coefficients on the level of the capital-output ratio, the level and the first-difference of the user cost of capital, and on the additional variables formed by interacting these terms with the dummy variable (LS_i).[37] The GMM estimation results suggest no significant difference in terms of the estimated long-run user cost elasticity, or any other coefficients, between firms that never report any losses and those that report losses for at least one year.[38] The same is found for all the remaining interaction terms included in the specification.

In Column 31, we use a time-varying dummy variable ($LS'_{i,t}$) which equals 1 when firm i reports negative profit before tax in year t, and equals 0 otherwise. We interact this dummy variable with all the original regressors in Equation 4.3.[39] Now, the estimated coefficient on $\ln(K/Q)_{i,t-3}$ interacted with the

[37] All other variables as in Equation (4.3) and their interactions with the dummy variable (LS_i) are also included in the estimated model.

[38] The set of instruments used in Column 30 includes this time-invariant dummy variable multiplied by all of the original instruments. For example, $LS_i \ln K_{i,t-5}$ is used in addition to $\ln K_{i,t-5}$; $LS_i \ln UC_{i,t}$ is used in addition to $\ln UC_{i,t}$; and so on.

[39] The set of instruments used in Column 31 includes current or lagged values of this dummy variable multiplied by any of the original instruments. For example, $LS'_{i,t-5} \ln K_{i,t-5}$

dummy variable $LS'_{i,t}$ is insignificantly different from zero, but the estimated coefficients on $\ln UC_{i,t-3}$ and $\Delta \ln UC_{i,t}$ interacted with the dummy variable $LS'_{i,t}$ are both positive and significantly different from zero. The estimated long-run user cost elasticity for profit-making firm-year observations remains close to -1.0. In contrast, the estimated long-run user cost elasticity for loss-making firm-year observations is lower, around -0.619, which is significantly different from zero but also significantly different from -1.0. The absolute value of the estimated coefficient on $\Delta \ln UC_{i,t}$ for loss-making firm-year observations is also smaller than that for profit-making firm-year observations. These findings indicate that tax incentives may have different effects on the behaviour of firms that are not currently in a tax-paying position. Further investigation of this heterogeneity is left for future research.

7 Conclusions

In this chapter, we estimate the long-run elasticity of the capital stock with respect to the user cost of capital using firm-level data from Amadeus which covers 30,901 large manufacturing firms in 9 countries over the period 1999-2008. Previous micro-level studies on this topic usually rely on data from a single country and the limited variation in the user cost of capital may help to explain the range of estimates found in this literature. This study contributes to this research by pooling data for a large number of firms across countries

is used in addition to $\ln K_{i,t-5}$; $LS'_{i,t} \ln UC_{i,t}$ is used in addition to $\ln UC_{i,t}$; and so on.

and industries, which is one way to introduce more variation in the user cost of capital. This chapter also complements the previous chapter which estimates the long-run user cost elasticity at the industry level.

Consistent with the results based on the industry-level data in the previous chapter, we find that capital intensity at the firm level is strongly responsive to changes in the tax-adjusted user cost of capital. The implied long-run user cost elasticity is close to -1.0 in within-groups estimations. This result remains robust when we deal with short panel issues and the endogeneity of explanatory variables using the Generalised Methods of Moments estimator suggested by Arellano and Bond (1991).

We find little evidence that the effective average tax rate or the statutory corporate income tax rate matter for these firms' investment behaviour once we control for the user cost of capital. We also check the robustness of our benchmark GMM estimation results by exploring firm-level heterogeneities. We find no evidence that the long-run user cost elasticity varies across firms with different sizes or ages. Moreover, these results are robust to including a measure of liquidity (as proxied by cash flow) in our model of investment. Furthermore, we consider the effects of tax asymmetries on a firm's investment behaviour. Our preliminary investigation suggests that firms with different tax status may respond differently to corporate tax incentives. Most importantly, allowing for these firm-level heterogeneities does not affect the estimated long-run user cost elasticity, which remains close to -1.0 in different model specifications.

Table 3.1: OLS and Fixed-effects within-groups estimations

	OLS			WG
VARIABLES	(1)	(2)	(3)	(4)
Panel A				
$\ln(K/Q)_{i,t-1}$	-0.031***	-0.031***	-0.380***	-0.576***
	(0.001)	(0.001)	(0.003)	(0.007)
$\ln UC_{i,t-1}$	-0.016***	-0.018***	-0.351***	-0.586***
	(0.004)	(0.004)	(0.014)	(0.025)
$\Delta \ln K_{i,t-1}$		0.076***		-0.479***
		(0.004)		(0.006)
$\Delta \ln K_{i,t-2}$		-0.022***		-0.565***
		(0.004)		(0.006)
$\Delta \ln Q_{i,t}$	0.204***	0.182***	0.277***	0.253***
	(0.004)	(0.005)	(0.004)	(0.006)
$\Delta \ln Q_{i,t-1}$		0.126***		0.358***
		(0.004)		(0.006)
$\Delta \ln Q_{i,t-2}$		0.098***		0.461***
		(0.004)		(0.007)
$\Delta \ln UC_{i,t}$	-0.739***	-0.776***	-0.821***	-0.853***
	(0.008)	(0.009)	(0.009)	(0.010)
$\Delta \ln UC_{i,t-1}$		0.120***		-0.455***
		(0.016)		(0.022)
$\Delta \ln UC_{i,t-2}$		-0.006		-0.555***
		(0.015)		(0.023)
Panel B				
α_2	-0.521***	-0.558***	-0.923***	-1.017***
	(0.113)	(0.138)	(0.035)	(0.042)
$\alpha_2 = -1$	0.000	0.001	0.029	0.691
Year dummies	Yes	Yes	Yes	Yes
No. of firms	30901	27222	30901	27222
Observations	154193	92391	154193	92391
R^2	0.088	0.138	0.280	0.337

[1] $\ln(K/Q)_{i,t-1}$ and $\ln UC_{i,t-1}$ are replaced by $\ln(K/Q)_{i,t-3}$ and $\ln UC_{i,t-3}$ in Columns 2 and 4.

[2] In Panel B, we report the estimated long-run user cost elasticity α_2 and the p-values of the Wald test of the null hypothesis that $\alpha_2 = -1$.

[3] Robust standard errors clustered over time within firms are in parentheses.

[4] *** p<0.01, ** p<0.05, * p<0.1

Table 3.2: Fixed-effects within-groups estimations: EU KLEMS

	13 countries (WG)		9 countries (WG)	
VARIABLES	(5)	(6)	(7)	(8)
Panel A				
$\ln(K/Q)_{i,t-1}$	-0.039***	-0.025***	-0.030**	-0.043***
	(0.006)	(0.004)	(0.012)	(0.013)
$\ln UC_{i,t-1}$	-0.056***	-0.025***	-0.069***	-0.049**
	(0.007)	(0.005)	(0.017)	(0.021)
$\Delta \ln K_{i,t-1}$		0.439***		0.105*
		(0.047)		(0.054)
$\Delta \ln K_{i,t-2}$		0.036		-0.168***
		(0.031)		(0.049)
$\Delta \ln Q_{i,t}$	0.062***	0.069***	0.010	0.020
	(0.011)	(0.011)	(0.019)	(0.015)
$\Delta \ln Q_{i,t-1}$		0.059***		0.020
		(0.007)		(0.014)
$\Delta \ln Q_{i,t-2}$		0.041***		0.025
		(0.007)		(0.018)
$\Delta \ln UC_{i,t}$	-0.078***	-0.071***	-0.052***	-0.053***
	(0.010)	(0.009)	(0.018)	(0.019)
$\Delta \ln UC_{i,t-1}$		-0.051***		-0.047**
		(0.007)		(0.020)
$\Delta \ln UC_{i,t-2}$		-0.037***		-0.033
		(0.008)		(0.021)
Panel B				
α_2	-1.443***	-1.008***	-2.302**	-1.141**
	(0.209)	(0.129)	(1.174)	(0.489)
$\alpha_2 = -1$	0.034	0.948	0.270	0.774
Year dummies	Yes	Yes	Yes	Yes
No. of industries	143	143	99	99
Observations	3025	2739	792	594
R^2	0.245	0.469	0.281	0.163

[1] $\ln{(K/Q)}_{i,t-1}$ and $\ln UC_{i,t-1}$ are replaced by $\ln{(K/Q)}_{i,t-3}$ and $\ln UC_{i,t-3}$ in Columns 6 and 8.

[2]Robust standard errors clustered over time within country-industry pairs are in parentheses [3]***p<0.01, **p<0.05, * p<0.1

Table 3.3: GMM estimations with exogenous user cost of capital

VARIABLES	(9)	(10)	(11)	(12)	(13)	(14)
Panel A						
$\ln (K/Q)_{i,t-3}$	-0.003	0.014	-0.200***	-0.184***	-0.207***	-0.285***
	(0.018)	(0.020)	(0.031)	(0.032)	(0.055)	(0.065)
$\ln UC_{i,t-3}$	-0.150***	-0.183***	-0.228***	-0.249***	-0.199***	-0.279***
	(0.032)	(0.037)	(0.038)	(0.042)	(0.051)	(0.064)
$\Delta \ln K_{i,t-1}$	0.086***	0.107***	-0.136***	-0.115***	-0.363***	-0.439***
	(0.020)	(0.021)	(0.032)	(0.032)	(0.096)	(0.133)
$\Delta \ln K_{i,t-2}$	0.004	0.023	-0.188***	-0.172***	-0.396***	-0.693***
	(0.019)	(0.020)	(0.030)	(0.031)	(0.097)	(0.136)
$\Delta \ln Q_{i,t}$	0.069***	0.061***	0.758***	0.700***	0.904***	0.853***
	(0.009)	(0.009)	(0.054)	(0.059)	(0.058)	(0.065)
$\Delta \ln Q_{i,t-1}$	0.016	0.006	0.255***	0.241***	0.561***	0.589***
	(0.013)	(0.013)	(0.027)	(0.027)	(0.109)	(0.113)
$\Delta \ln Q_{i,t-2}$	0.006	-0.009	0.215***	0.200***	0.414***	0.518***
	(0.016)	(0.017)	(0.030)	(0.030)	(0.108)	(0.124)
$\Delta \ln UC_{i,t}$	-0.858***	-0.920***	-0.908***	-0.924***	-0.927***	-0.913***
	(0.012)	(0.018)	(0.013)	(0.018)	(0.014)	(0.019)
$\Delta \ln UC_{i,t-1}$	-0.156***	-0.172***	-0.188***	-0.175***	-0.394***	-0.398***
	(0.029)	(0.034)	(0.036)	(0.039)	(0.085)	(0.103)
$\Delta \ln UC_{i,t-2}$	-0.203***	-0.184***	-0.247***	-0.232***	-0.382***	-0.554***
	(0.030)	(0.035)	(0.035)	(0.040)	(0.083)	(0.112)
Panel B: LR coefficients						
α_2	-49.245	12.926	-1.140***	-1.353***	-0.957***	-0.979***
	(292.002)	(18.993)	(0.169)	(0.224)	(0.181)	(0.157)
Panel C: Test (p-values)						
$\alpha_1 = 1$	0.000	0.000	0.220	0.584	0.374	0.636
$\alpha_2 = -1$	0.868	0.463	0.408	0.115	0.812	0.895
Hansen test	0.000	0.000	0.000	0.000	0.001	0.032
AR(1)	0.000	0.000	0.000	0.000	0.000	0.000
AR(2)	0.263	0.161	0.446	0.309	0.725	0.061
Year dummies	Yes		Yes		Yes	
Country-year dummies		Yes		Yes		Yes
No. of firms	23938	23938	23938	23938	20923	20923
Observations	65169	65169	65169	65169	62154	62154

Notes: See next page.

Notes:

[1]Robust standard errors clustered over time within firms are in parentheses.

[2]*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

[3]In this table and subsequent tables, the one-step GMM estimates are reported.

[4]In Columns 9 and 10, we treat the capital stock as endogenous while treating both output and the user cost as exogenous. We use $\ln K$ dated $t-2$ and earlier, $\ln Q$ and $\ln UC$ dated t and earlier as instruments; in Columns 11 and 12, we treat both the capital stock and output as endogenous while treating the user cost as exogenous. We use $\ln K$ and $\ln Q$ dated $t-2$ and earlier, and $\ln UC$ dated t and earlier as instruments; in Columns 13 and 14, we treat both the capital stock and output as endogenous with serially uncorrelated measurement error while treating the user cost as exogenous. We use $\ln K$ and $\ln Q$ dated $t-5$ and earlier, and $\ln UC$ dated t and earlier as instruments.

[5]In Panel C, we report the p-values associated with the Hansen test of the null hypothesis of valid instruments. We also report the p-values associated with the test of the null hypothesis of no first or second-order serial correlation in the first-differenced error terms.

Table 3.4: GMM estimations with endogenous user cost of capital

VARIABLES	(15)	(16)	(17)	(18)
Panel A				
$\ln{(K/Q)}_{i,t-3}$	-0.249***	-0.216***	-0.175**	-0.174*
	(0.069)	(0.074)	(0.078)	(0.093)
$\ln UC_{i,t-3}$	-0.240**	-0.489***	-0.672***	-0.657*
	(0.115)	(0.160)	(0.213)	(0.343)
$\Delta \ln K_{i,t-1}$	-0.397***	-0.476***	-0.365**	-0.240
	(0.141)	(0.147)	(0.161)	(0.189)
$\Delta \ln K_{i,t-2}$	-0.509***	-0.524***	-0.489***	-0.473**
	(0.146)	(0.156)	(0.173)	(0.186)
$\Delta \ln Q_{i,t}$	0.683***	0.581***	0.547***	0.503***
	(0.106)	(0.111)	(0.125)	(0.138)
$\Delta \ln Q_{i,t-1}$	0.436***	0.327**	0.344**	0.389**
	(0.145)	(0.167)	(0.174)	(0.191)
$\Delta \ln Q_{i,t-2}$	0.569***	0.382**	0.291*	0.211
	(0.143)	(0.162)	(0.173)	(0.216)
$\Delta \ln UC_{i,t}$	-0.953***	-1.011***	-1.033***	-1.051***
	(0.027)	(0.031)	(0.038)	(0.040)
$\Delta \ln UC_{i,t-1}$	-0.321**	-0.541***	-0.366	-0.703**
	(0.145)	(0.161)	(0.228)	(0.282)
$\Delta \ln UC_{i,t-2}$	-0.483***	-0.699***	-0.612**	-1.165***
	(0.158)	(0.206)	(0.240)	(0.402)
Panel B: LR coefficients				
α_2	-0.965**	-2.262***	-3.846*	-3.773
	(0.420)	(0.843)	(1.978)	(2.456)
Panel C: Test (p-values)				
$\alpha_2 = -1$	0.933	0.134	0.150	0.259
Hansen test	0.041	0.144	0.237	0.278
AR(1)	0.000	0.004	0.002	0.001
AR(2)	0.123	0.323	0.266	0.183
Country-year dummies	Yes	Yes	Yes	Yes
No. of firms	20923	20923	20923	20923
Observations	62154	62154	62154	62154

Notes: See next page.

Notes:

[1]Robust standard errors clustered over time within firms are in parentheses.

[2]*** p<0.01, ** p<0.05, * p<0.1.

[3]In Columns 15-18, we treat the capital stock and output as endogenous with serially uncorrelated measurement error and use $\ln K$ and $\ln Q$ dated $t-5$ and earlier for the capital stock and output terms. We also treat the user cost as endogenous. In Column 15, we use $\ln UC$ dated $t-2$ and earlier; In Column 16, we use $\ln UC$ dated $t-3$ and earlier; in Column 17, we use $\ln UC$ dated $t-4$ and earlier; and in Column 18, we use $\ln UC$ dated $t-5$ and earlier as instruments for the equations in first-differences.

Table 3.5: GMM estimations with additional tax variables

VARIABLES	(19)	(20)
Panel A		
$\ln(K/Q)_{i,t-3}$	-0.272***	-0.233***
	(0.046)	(0.055)
$\ln UC_{i,t-3}$	-0.270***	-0.273***
	(0.058)	(0.059)
$EATR_{i,t-3}$	0.102	
	(0.524)	
$\tau_{i,t-3}$		0.127
		(0.481)
$\Delta \ln K_{i,t-1}$	-0.497***	-0.451***
	(0.082)	(0.088)
$\Delta \ln K_{i,t-2}$	-0.499***	-0.343***
	(0.085)	(0.090)
$\Delta \ln Q_{i,t}$	0.683***	0.699***
	(0.065)	(0.072)
$\Delta \ln Q_{i,t-1}$	0.465***	0.404***
	(0.079)	(0.094)
$\Delta \ln Q_{i,t-2}$	0.539***	0.474***
	(0.074)	(0.095)
$\Delta \ln UC_{i,t}$	-0.922***	-0.924***
	(0.017)	(0.020)
$\Delta \ln UC_{i,t-1}$	-0.420***	-0.440***
	(0.076)	(0.083)
$\Delta \ln UC_{i,t-2}$	-0.487***	-0.452***
	(0.070)	(0.080)
$\Delta EATR_{i,t}$	0.709***	
	(0.258)	
$\Delta EATR_{i,t-1}$	-0.396	
	(0.431)	
$\Delta EATR_{i,t-2}$	-0.716	
	(0.466)	
$\Delta \tau_{i,t}$		0.080
		(0.323)
$\Delta \tau_{i,t-1}$		-0.337
		(0.433)
$\Delta \tau_{i,t-2}$		-0.050
		(0.401)

To be continued next page

Table 3.5 continued

	(19)	(20)
Hansen test	0.003	0.002
AR(1)	0.000	0.000
AR(2)	0.110	0.130
Year dummies	Yes	Yes
No. of firms	20923	20923
Observations	62154	62154

[1]Robust standard errors clustered over time within firms are in parentheses.

[2]*** p<0.01, ** p<0.05, * p<0.1.

[3]In both columns, we treat the capital stock and output as endogenous with serially uncorrelated measurement error while treating the user cost, the $EATR$ and τ as exogenous. In Column 19, we use $\ln K$ and $\ln Q$ dated $t-5$ and earlier, $\ln UC$ and $EATR$ dated t and earlier as instruments. In Column 20, we use $\ln K$ and $\ln Q$ dated $t-5$ and earlier, $\ln UC$ and τ dated t and earlier as instruments.

Table 3.6: Sub-sample GMM estimations by firm age and firm size

	(21)	(22)	(23)	(24)
VARIABLES	Young firms	Old firms	Small firms	Large firms
Panel A				
$\ln{(K/Q)}_{i,t-3}$	-0.362***	-0.263***	-0.370***	-0.307***
	(0.081)	(0.082)	(0.072)	(0.064)
$\ln UC_{i,t-3}$	-0.364***	-0.276***	-0.349***	-0.330***
	(0.085)	(0.087)	(0.085)	(0.067)
$\Delta \ln K_{i,t-1}$	-0.524***	-0.500***	-0.529***	-0.319**
	(0.141)	(0.115)	(0.145)	(0.131)
$\Delta \ln K_{i,t-2}$	-0.782***	-0.455***	-0.624***	-0.550***
	(0.143)	(0.139)	(0.144)	(0.120)
$\Delta \ln Q_{i,t}$	0.784***	0.792***	0.814***	0.732***
	(0.075)	(0.087)	(0.085)	(0.073)
$\Delta \ln Q_{i,t-1}$	0.708***	0.568***	0.526***	0.465***
	(0.134)	(0.129)	(0.125)	(0.127)
$\Delta \ln Q_{i,t-2}$	0.623***	0.363***	0.547***	0.460***
	(0.141)	(0.129)	(0.138)	(0.123)
$\Delta \ln UC_{i,t}$	-0.925***	-0.898***	-0.927***	-0.893***
	(0.026)	(0.025)	(0.027)	(0.023)
$\Delta \ln UC_{i,t-1}$	-0.524***	-0.468***	-0.489***	-0.296***
	(0.120)	(0.095)	(0.120)	(0.106)
$\Delta \ln UC_{i,t-2}$	-0.642***	-0.394***	-0.545***	-0.504***
	(0.130)	(0.113)	(0.130)	(0.102)
Panel B: LR coefficient				
α_2	-1.006***	-1.047***	-0.943***	-1.074***
	(0.156)	(0.274)	(0.179)	(0.152)
Panel C: Tests (p-values)				
$\alpha_2 = -1$	0.971	0.864	0.749	0.623
Hansen test	0.135	0.080	0.006	0.014
AR(1)	0.002	0.006	0.001	0.000
AR(2)	0.105	0.621	0.275	0.140
Country-year dummies	Yes	Yes	Yes	Yes
No. of firms	10100	10720	10382	10541
Observations	30419	31432	30667	31487

[1]Robust standard errors clustered over time within firms are in parentheses.
[2]***p<0.01, **p<0.05,*p<0.1 [3]In all four columns, we treat the capital stock and output as endogenous with serially uncorrelated measurement error while treating the user cost as exogenous. We use $\ln K$ and $\ln Q$ dated $t-5$ and earlier, and $\ln UC$ dated t and earlier as instruments for the equations in first-differences.

Table 3.7: GMM estimations with cash flow

VARIABLES	(25) Full sample	(26) Young firms	(27) Old firms	(28) Small firms	(29) Large firms
Panel A					
$\ln{(K/Q)}_{i,t-3}$	-0.248***	-0.278***	-0.219**	-0.324***	-0.328***
	(0.060)	(0.069)	(0.089)	(0.068)	(0.069)
$\ln UC_{i,t-3}$	-0.271***	-0.299***	-0.288***	-0.300***	-0.329***
	(0.059)	(0.073)	(0.081)	(0.084)	(0.061)
$(CF/K)_{i,t-3}$	0.061	0.071	0.043	-0.015	-0.078
	(0.058)	(0.069)	(0.077)	(0.059)	(0.121)
$\Delta \ln K_{i,t-1}$	-0.534***	-0.442***	-0.586***	-0.717***	-0.423***
	(0.132)	(0.131)	(0.113)	(0.121)	(0.123)
$\Delta \ln K_{i,t-2}$	-0.674***	-0.586***	-0.464***	-0.585***	-0.584***
	(0.117)	(0.119)	(0.118)	(0.135)	(0.135)
$\Delta \ln Q_{i,t}$	0.795***	0.774***	0.747***	0.813***	0.632***
	(0.058)	(0.066)	(0.084)	(0.077)	(0.066)
$\Delta \ln Q_{i,t-1}$	0.645***	0.647***	0.553***	0.636***	0.495***
	(0.118)	(0.135)	(0.128)	(0.128)	(0.129)
$\Delta \ln Q_{i,t-2}$	0.554***	0.537***	0.389***	0.478***	0.547***
	(0.118)	(0.123)	(0.130)	(0.145)	(0.127)
$\Delta \ln UC_{i,t}$	-0.803***	-0.837***	-0.809***	-0.715***	-0.830***
	(0.032)	(0.039)	(0.038)	(0.045)	(0.031)
$\Delta \ln UC_{i,t-1}$	-0.458***	-0.423***	-0.525***	-0.532***	-0.367***
	(0.096)	(0.107)	(0.092)	(0.103)	(0.096)
$\Delta \ln UC_{i,t-2}$	-0.541***	-0.505***	-0.423***	-0.485***	-0.496***
	(0.093)	(0.103)	(0.099)	(0.119)	(0.092)
$\Delta(CF/K)_{it}$	-0.170***	-0.152***	-0.138***	-0.235***	-0.180**
	(0.041)	(0.047)	(0.046)	(0.043)	(0.073)
$\Delta(CF/K)_{i,t-1}$	-0.080	-0.074	-0.057	-0.180***	-0.194
	(0.078)	(0.075)	(0.082)	(0.067)	(0.143)
$\Delta(CF/K)_{i,t-2}$	-0.029	0.011	-0.046	-0.069	-0.229
	(0.084)	(0.091)	(0.079)	(0.080)	(0.168)
Panel B: LR coefficients					
α_2	-1.093***	-1.077***	-1.316***	-0.927***	-1.004***
	(0.206)	(0.211)	(0.449)	(0.228)	(0.159)
CF/K	0.247	0.254	0.195	-0.047	-0.237
	(0.261)	(0.273)	(0.392)	(0.180)	(0.342)

To be continued next page

Table 3.7 continued

Panel C: Tests (p-values)					
$\alpha_2 = -1$	0.652	0.714	0.482	0.748	0.979
Hansen test	0.005	0.098	0.135	0.024	0.018
AR(1)	0.002	0.002	0.054	0.099	0.000
AR(2)	0.098	0.165	0.381	0.577	0.156
Country-year dummies	Yes	Yes	Yes	Yes	Yes
No. of firms	19763	9617	10049	9547	10216
Observations	58774	28967	29521	28236	30538

[1]Robust standard errors clustered over time within firms in parentheses

[2]*** p<0.01, ** p<0.05, * p<0.1.

[3]In these five columns, we treat the capital stock, output and cash flow as endogenous with serially uncorrelated measurement error while treating the user cost as exogenous. We use $\ln K$, $\ln Q$ and CF/K dated $t-5$ and earlier, and $\ln UC$ dated t and earlier as instruments.

Table 3.8: GMM estimations with tax asymmetries

VARIABLES	(30)	(31)
Panel A		
$\ln{(K/Q)}_{i,t-3}$	-0.326***	-0.334***
	(0.075)	(0.042)
$LS_i \times \ln{(K/Q)}_{i,t-3}$	0.091	
	(0.100)	
$LS'_{i,t} \times \ln{(K/Q)}_{i,t-3}$		0.017
		(0.028)
$\ln UC_{i,t-3}$	-0.303***	-0.392***
	(0.068)	(0.049)
$LS_i \times \ln UC_{i,t-3}$	0.018	
	(0.083)	
$LS'_{i,t} \times \ln UC_{i,t-3}$		0.186***
		(0.055)
$\Delta \ln UC_{i,t}$	-0.913***	-0.997***
	(0.018)	(0.023)
$LS_i \times \Delta \ln UC_{i,t}$	0.016	
	(0.031)	
$LS'_{i,t} \times \Delta \ln UC_{i,t}$		0.428***
		(0.091)
Panel B: Test (p-values)		
Hansen test	0.013	0.005
AR(1)	0.000	0.000
AR(2)	0.276	0.183
Country-year dummies	Yes	Yes
Number of firms	20923	20923
Observations	62154	62154

[1]Differences of $\ln K$, $\ln Q$, $\ln UC$ (as in Equation 4.3) and their interactions with the dummies indicating loss-making firm-years are also included in the specifications.
[2]In both columns, we treat capital and output as endogenous with serially uncorrelated measurement errors, and we treat the user cost as exogenous. The instruments used in these two columns are explained in footnotes 38 and 39.
[3]Robust standard errors clustered over time within firms in parentheses.
[4]*** p<0.01, ** p<0.05, * p<0.1.

Appendix J: Sample distributions and descriptive statistics

Figure J.1: Number of firms

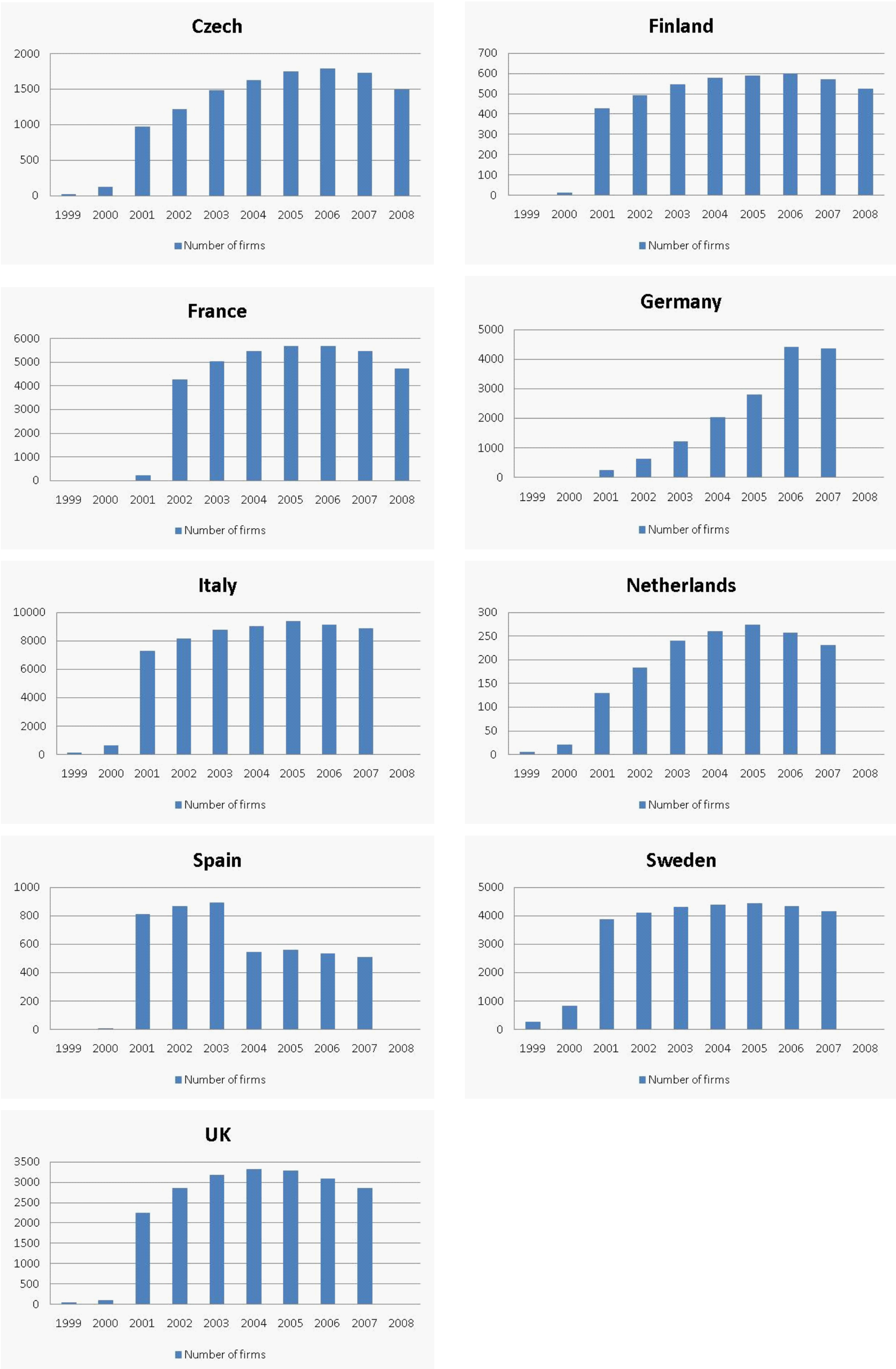


Figure J.2: Distribution of firms by the number of consecutive observations

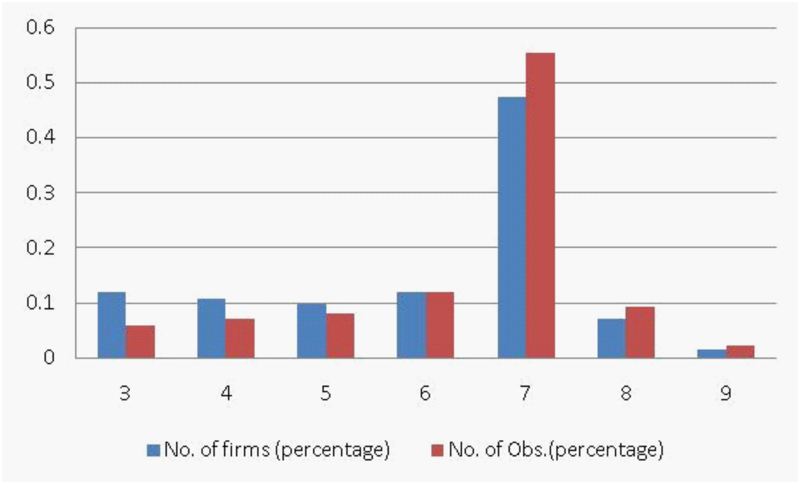


Table J.1: Descriptive statistics of key variables

Variables		Full sample	Small firms	Large firms	Young firms	Old firms
$\ln K$	Mean	8.280	7.080	9.481	8.140	8.411
	S.D	1.582	1.025	1.037	1.650	1.502
$\Delta \ln K$	Mean	0.048	0.058	0.038	0.054	0.042
	S.D	0.279	0.318	0.235	0.300	0.258
$\ln Q$	Mean	8.777	8.138	9.417	8.585	8.960
	S.D	1.187	0.829	1.146	1.171	1.173
$\Delta \ln Q$	Mean	0.050	0.062	0.038	0.066	0.034
	S.D	0.230	0.232	0.227	0.247	0.210
$\ln (K/Q)$	Mean	-0.497	-1.057	0.064	-0.444	-0.549
	S.D	1.095	1.055	0.810	1.163	1.023
$\Delta \ln (K/Q)$	Mean	-0.002	-0.003	0.000	-0.012	0.008
	S.D	0.335	0.365	0.302	0.358	0.311
No. of obs.		185,094	92,545	92,549	89,654	94,412

Appendix K: Comparing the firm-level data with EU KLEMS

Figure K.1 plots the growth rates of the capital-output ratio for the manufacturing sector in each country, computed in three different ways. First, we use the firm-level data to measure the growth rate of $\frac{K}{Q}$ in country j in period t as:

$$\begin{aligned} \frac{\overset{\bullet}{K_{jt}}}{Q_{jt}} &= \frac{X_{j,t} - X_{j,t-1}}{X_{j,t-1}} \times 100 \\ X_{j,t} &= \frac{\sum_i K_{ijt}}{\sum_i Q_{ijt}} \end{aligned} \tag{K.1}$$

where the subscript i indicates the ith firm in country j (labeled as "Amadeus" in Figure K.1 and the series is shown in blue). This is a "naive" way of calculating the growth rate of the aggregate capital-output ratio from the firm data, since it ignores change in the composition of firms in the sample from one year to the next. The second method is designed to control for such compositional changes by restricting the sample of firms used to calculate the growth rate of $\frac{K}{Q}$ between period $t-1$ and period t to be those firms which are present in both periods (labelled as "Amadeus*" in Figure K.1 and the series is shown in red). We calculate the weighted average growth rate of these firms' capital-output ratio using the formula:

$$\begin{aligned} \frac{\overset{\bullet}{K_{jt}}}{Q_{jt}}^{*} &= \sum_i w_{ij,t-1} \overset{\bullet}{X}_{ijt} \\ \text{where } w_{ij,t-1} &= \frac{X_{ij,t-1}}{\sum_j X_{ij,t-1}}, X_{ijt} = \frac{K_{ijt}}{Q_{ijt}}, \text{ and } \overset{\bullet}{X}_{ijt} = \frac{X_{ij,t} - X_{ij,t-1}}{X_{ij,t-1}} \times 100 \end{aligned} \tag{K.2}$$

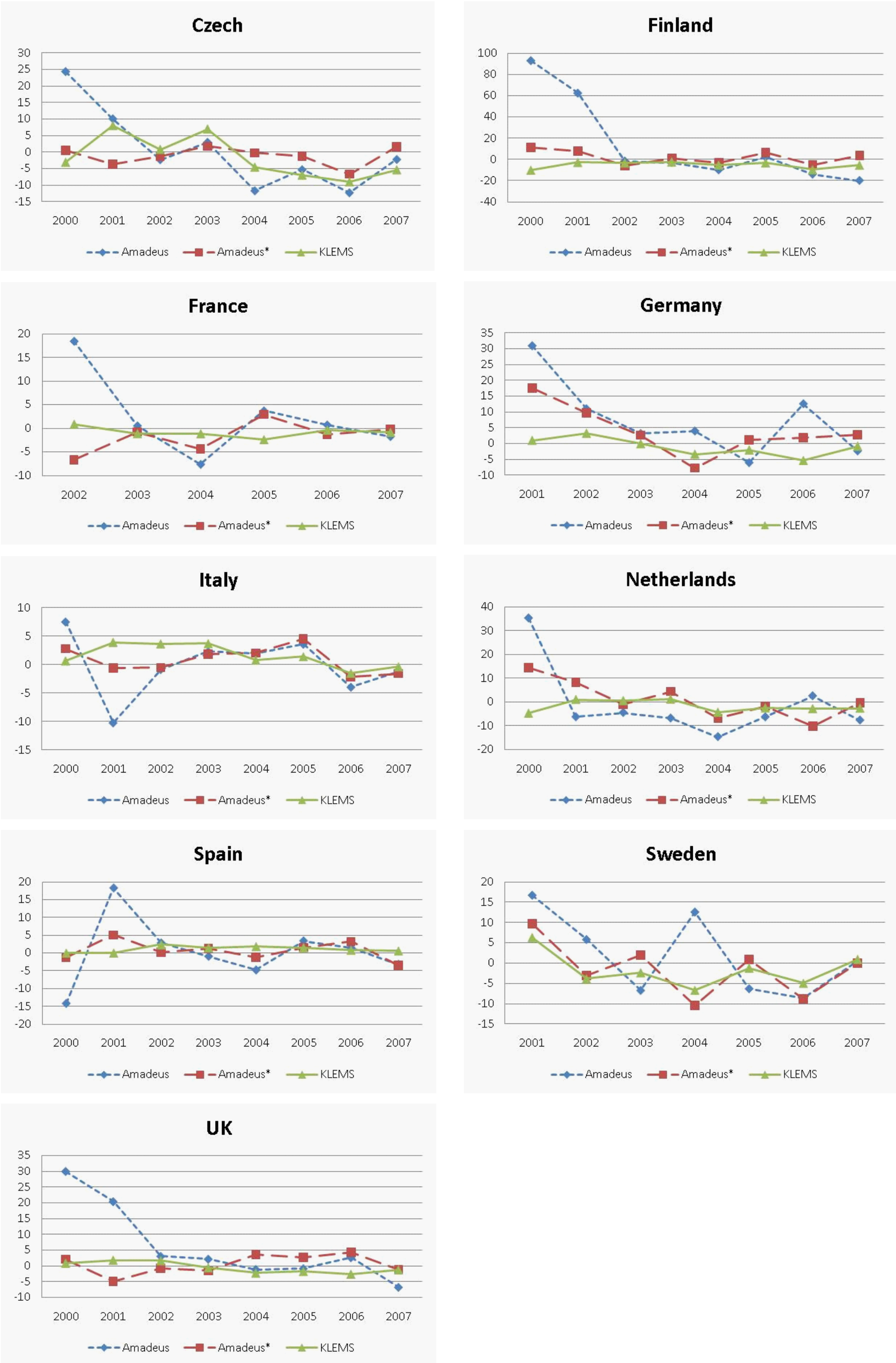
Note that the two measures $\frac{\overset{\bullet}{K_{jt}}}{Q_{jt}}$ and $\frac{\overset{\bullet}{K_{jt}}}{Q_{jt}}^{*}$ would coincide in a balanced panel where each firm i in country j is observed in each year.

Finally, we compute the growth rate of $\frac{K}{Q}$ using the industry-level data from EU KLEMS as:

$$\begin{aligned} \frac{\overset{\bullet}{K_{jt}}}{Q_{jt}}^{KLEMS} &= \frac{X_{j,t} - X_{j,t-1}}{X_{j,t-1}} \times 100 \\ X_{jt} &= \frac{K_{jt}}{Q_{jt}} \end{aligned} \tag{K.3}$$

where K_{jt} and Q_{jt} are total real capital stock and real value-added for the manufacturing sector in country j in year t (labled as "KLEMS" in Figure K.1 and the series is shown in green).

Figure K.1: Growth rate of K/Q: Amadeus and KLEMS



Appendix L: Loss-making firms

Figure L.1: Percentage of loss-making firms by year

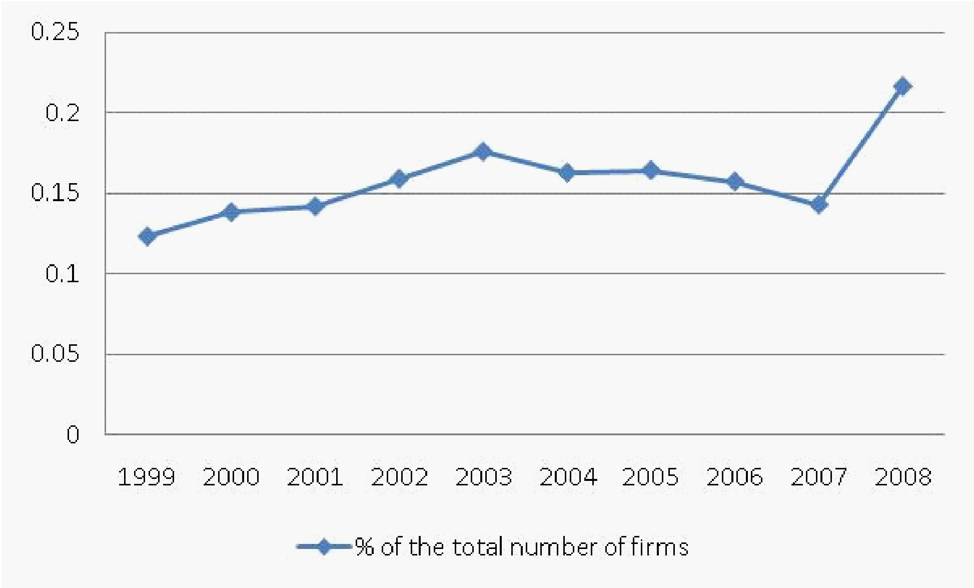
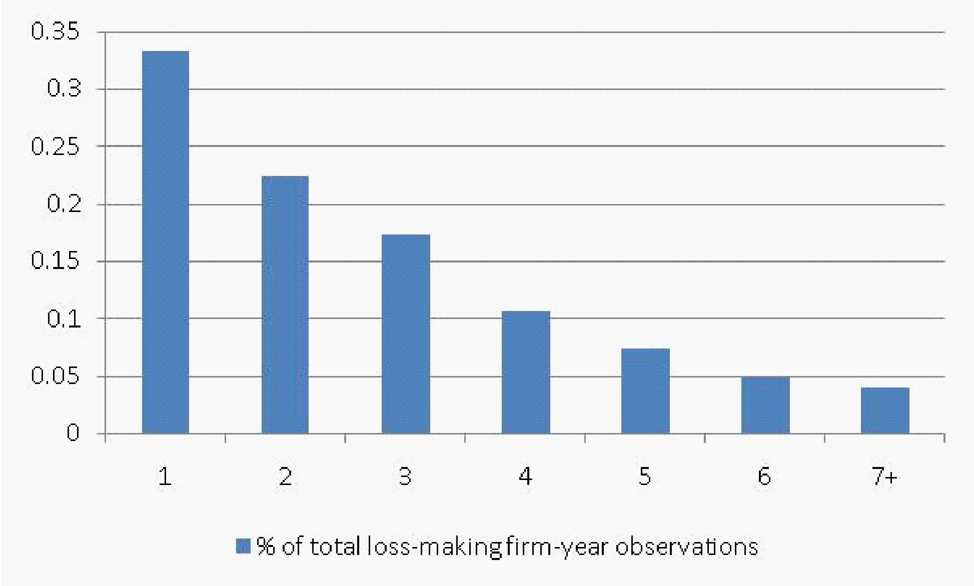


Figure L.2: Distribution of firm-years by the duration of loss making



Appendix M: Table 3.3 without imposing constant returns to scale

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
$\ln K_{i,t-3}$	-0.144***	-0.098***	-0.203***	-0.181***	-0.212***	-0.283***
	(0.028)	(0.030)	(0.032)	(0.033)	(0.055)	(0.065)
$\ln Q_{i,t-3}$	0.035*	0.012	0.157***	0.199***	0.148*	0.312***
	(0.018)	(0.019)	(0.045)	(0.037)	(0.086)	(0.084)
$\ln UC_{i,t-3}$	-0.215***	-0.233***	-0.214***	-0.254***	-0.176***	-0.291***
	(0.031)	(0.037)	(0.039)	(0.043)	(0.057)	(0.068)
$\Delta \ln K_{i,t-1}$	-0.057*	-0.007	-0.145***	-0.111***	-0.371***	-0.432***
	(0.030)	(0.032)	(0.034)	(0.035)	(0.096)	(0.133)
$\Delta \ln K_{i,t-2}$	-0.131***	-0.084***	-0.193***	-0.169***	-0.401***	-0.684***
	(0.028)	(0.029)	(0.031)	(0.032)	(0.097)	(0.137)
$\Delta \ln K_{i,t}$	0.075***	0.066***	0.757***	0.702***	0.892***	0.857***
	(0.008)	(0.008)	(0.054)	(0.059)	(0.059)	(0.065)
$\Delta \ln K_{i,t-1}$	0.041***	0.027**	0.216***	0.254***	0.544***	0.601***
	(0.013)	(0.013)	(0.040)	(0.033)	(0.111)	(0.115)
$\Delta \ln K_{i,t-2}$	0.041***	0.018	0.173***	0.213***	0.377***	0.534***
	(0.016)	(0.017)	(0.043)	(0.035)	(0.117)	(0.128)
$\Delta \ln UC_{i,t}$	-0.855***	-0.915***	-0.906***	-0.924***	-0.923***	-0.913***
	(0.011)	(0.017)	(0.014)	(0.018)	(0.014)	(0.019)
$\Delta \ln UC_{i,t-1}$	-0.232***	-0.236***	-0.177***	-0.176***	-0.393***	-0.398***
	(0.029)	(0.035)	(0.036)	(0.039)	(0.085)	(0.103)
$\Delta \ln UC_{i,t-2}$	-0.267***	-0.238***	-0.234***	-0.235***	-0.368***	-0.557***
	(0.029)	(0.035)	(0.036)	(0.040)	(0.085)	(0.112)
α_1	0.242***	0.123	0.775***	1.095***	0.697***	1.102***
	(0.090)	(0.168)	(0.184)	(0.173)	(0.341)	(0.217)
α_2	-1.489***	-2.386***	-1.055***	-1.402***	-0.832***	-1.032***
	(0.268)	(0.653)	(0.181)	(0.255)	(0.222)	(0.198)
Test (p-values)						
$\alpha_1 = 1$	0.000	0.000	0.220	0.584	0.374	0.636
$\alpha_2 = -1$	0.068	0.034	0.760	0.115	0.448	0.873
Hansen test	0.000	0.000	0.000	0.000	0.001	0.027
AR(1)	0.000	0.000	0.000	0.000	0.000	0.000
AR(2)	0.121	0.084	0.503	0.298	0.753	0.065
Year dummies	Yes		Yes		Yes	
Country-year dummies		Yes		Yes		Yes
No. of firm	23938	23938	23938	23938	20923	20923
Observations	65169	65169	65169	65169	62154	62154

Notes: See next page.

Notes:

[1]Robust standard errors clustered over time within firms are in parentheses.

[2]*** p<0.01, ** p<0.05, * p<0.1.

[3]In this table, we relax the restriction $\alpha_1 = 1$ and the results in these six columns correspond to those presented in Columns 9-14 in Table 3.3.

[4]In Columns 1 and 2, we treat the capital stock as endogenous while treating both output and the user cost as exogenous. We use $\ln K$ dated $t-2$ and earlier, $\ln Q$ and $\ln UC$ dated t and earlier as instruments; in Columns 3 and 4, we treat both the capital stock and output as endogenous while treating the user cost as exogenous. We use $\ln K$ and $\ln Q$ dated $t-2$ and earlier, and $\ln UC$ dated t and earlier as instruments; in Columns 5 and 6, we treat both the capital stock and output as endogenous with serially uncorrelated measurement error while treating the user cost as exogenous. We use $\ln K$ and $\ln Q$ dated $t-5$ and earlier, and $\ln UC$ dated t and earlier as instruments.

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