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THE FIVE DRIVERS: AN EMPIRICAL REVIEW

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The Five Drivers: an empirical review*

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1 Introduction

Productivity, or the amount of output produced by a given number of inputs, can be measured in a number of ways;[1] the focus of Government policy, and much of the theoretical and empirical literature, is on labour productivity, which provides the theme of the discussion in this review.

A central plank of UK Government policy concerning Britain's long run economic performance relates to microeconomic policies aimed at raising the rate of productivity growth. The first major assessment of productivity policy by the Labour Government observed that:

> The productivity challenge for the UK is to have a faster rise in productivity than its main competitors as it closes the productivity gap. This challenge is increasing as major economies, especially the US, continue to have stronger productivity growth than the UK and to widen the productivity gap.
>
> HM TREASURY (2000, p. 8)

In response to this challenge, a policy framework has been developed that identifies five *drivers* of productivity, which comprise the engine of long term economic growth (see Box 2, and HM Treasury(2000, 2001*a*, 2001*b*, 2003, 2004)).

To place this objective in context, a brief overview of recent performance is helpful. Since the end of the Second World War, UK productivity growth has lagged behind that of her major advanced competitors, as shown in panel (a) of the figure on page 4. The UK economy enjoyed a dominant position in the nineteenth century, and conventional growth theory suggests that other economies should have *caught up* with the UK over time, before growing at the same rate. The evidence, however, refutes this prediction: far from converging to UK productivity levels, several advanced economies caught up, and promptly *overtook* the UK, driving a 'productivity gap' which still exists today, and may even be worsening for particular sectors.

Behind this aggregate figure of output per hour lies a number of trends in factor *inputs*. Panel (c) shows that there has been a consistent downward trend in the average number of hours worked per worker in the UK over the post-war period, such that by 1999, the average hours were 20 per cent lower than in 1950. In a comparative context, panel (d) shows that some of the differences between productivity figures are accounted for by cross-country differences in average hours worked. Thus for instance, the fact that French average hours are roughly 8 per cent lower than in the UK implies that the productivity gap between the two measured by output per

[1] Box 1 provides an explanation of the relevant issues.

Box 1: DEFINING PRODUCTIVITY

In general, productivity relates units of outputs to units of inputs. Specifically, this can be represented as:

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}}.$$

In the context of this study, the measure of output is generally national income, or gross domestic product (GDP), whilst a number of inputs appear in the literature. Two approaches are considered here: **Labour productivity**, and **Total Factor Productivity (TFP)**. These are examined in turn.

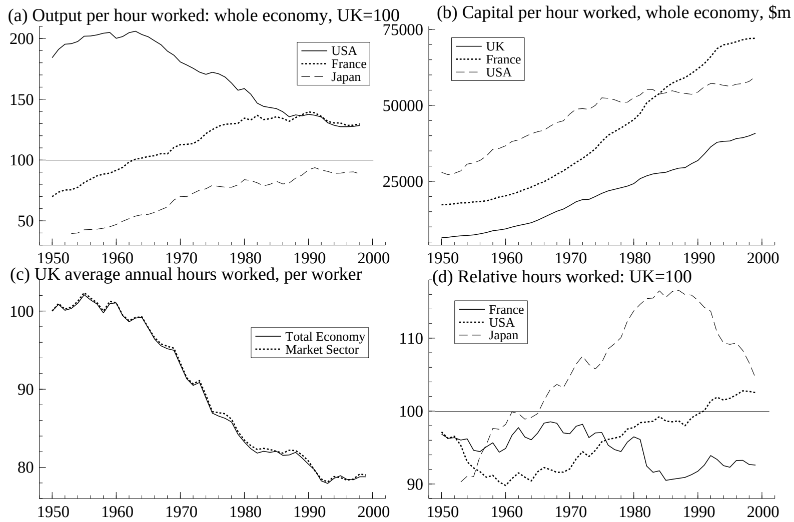
1. **Labour productivity** is measured in various ways, depending on the choice of labour input:

   - OUTPUT PER CAPITA provides a broad indication of the average income per head across the whole population (or just the population of working age)
   - OUTPUT PER WORKER is focussed more specifically on the output generated by people in work. A frequent assumption in the literature on economic growth is that all available labour is fully employed, meaning that output per worker and per capita are equivalent; Aghion and Howitt (1998, Chapter 4) study the effect of relaxing the full employment scenario.
   - OUTPUT PER HOUR WORKED offers one of the most direct measures of productivity performance, since it controls for differences in working hours, which can be significant across countries (see the figure on page 4).

2. **Total Factor Productivity**, or TFP, captures the contribution to output of all inputs together. In an accounting sense, TFP is the 'residual' growth in output that is not accounted for by growth in inputs. Stylistically:

   $$\text{Growth in Output} = \text{Growth in Inputs} + \text{TFP growth}.$$

   TFP in this sense is a measure of what cannot be explained directly by observed inputs; thus whilst it could capture the effect of technological progress (where higher TFP growth would indicate better performance), it could also reflect differences in the *structure* of sectors of the economy, as well as the influence of other factors that have been erroneously omitted from the model.



NOTES: Panel (a) shows output per hour worked, relative to the UK benchmark of 100; (b) shows the total value of capital per hour worked, in millions of US dollars; (c) shows the post-war trend in the average number of hours worked per worker, in the UK, assuming 1950=100; (d) shows the trend in hours worked in relation to the UK benchmark of 100. Data source: NIESR, see O'Mahony and de Boer (2002).

worker rather than output per *hour*, will be smaller than panel (a) implies. Another indication of variations in inputs is suggested in panel (b), which points to substantial differences in capital per hour worked.

Table 1 provides a snapshot of recent relative performance on a total-factor productivity measure which captures the efficiency with which both labour and physical capital are used in the economy. Although the total economy-wide figures point to a smaller productivity gap with respect to the USA and France, this aggregate picture hides differences at a sectoral level. Where the UK is a leader in TFP levels for transport and communications, for example, in other areas such as manufacturing and financial and business services, levels of TFP in competitors are up to 43 per cent higher than the UK. This variation in performance could provide important information about the nature of growth, innovation, enterprise and related activity across the sectors of the economy, with potentially significant implications for policy.

Table 1: TOTAL FACTOR PRODUCTIVITY BENCHMARKS, 1999

	Relative TFP (UK=100)		
	USA	France	Germany
Total Economy	115.0	105.6	103.3
Market Sectors	129.4	103.9	108.8
Transport and Communication	94.3	88.9	72.1
Manufacturing	143.4	110.4	120.5
Financial and Business services	124.1	98.7	122.2

NOTES: Data source: NIESR

2 Productivity Growth in Theory

What does the literature on economic growth have to say about the determinants of productivity performance?[2] Early post-war models developed a 'neo-classical' framework in which output (national income, or GDP) is produced by a function of inputs (in a simple case, labour and capital).[3] Taken in isolation, however, these inputs do not provide a complete explanation for economic growth. The amount of labour in the economy is affected primarily by the population growth rate, and the amount of capital by the aggregate savings rate, but once the effects of changes in each input are transmitted to output, there is no further growth in the economy. Thus a key result of the neo-classical model is that government policy affects the long run *level* of GDP, but not its long run *growth rate*.

Rather, an exogenous factor called technological progress (in a very broad sense), is the source of growth in the long run. It affects the efficiency with which capital and labour inputs enter into the economy's production function, and from a growth accounting perspective, represents the growth in output that is not captured by growth in inputs. As a consequence of its exogeneity, technical progress itself is not explained by the neo-classical model: in the words of one critic, it falls from the sky 'like manna from heaven.'

This implies that any empirical work based on such a model would be able to identify technical progress only as a 'residual'; in reality, this residual could capture a great number of issues besides technology, including measurement error, specification mistakes relating to the variables included, and further errors resulting from the omission of other relevant factors. For these reasons, amongst others, the residual has been termed the measure of our 'ignorance.'

[2]A review of this issue is provided by Freeman (2000). Romer (2001, Chapters 1 and 3) offers a compact review of developments in growth theory, whilst Barro and Sala-i Martin (1995) and Aghion and Howitt (1998) concentrate on the foundations of recent economic growth models.

[3]See, for example, Solow (1956).

Box 2: THE FIVE DRIVERS OF PRODUCTIVITY: A SUMMARY

First discussed in HM Treasury (2000), the Five Driver framework underlies the Government's approach to microeconomic reform of the economy. The drivers offer a useful presentational framework to analyse the most important determinants of long-run productivity performance.

- **Investment** in physical capital, which affects productivity directly, as workers have more equipment to use in production; and indirectly, since new capital may be necessary to **implement new innovations**.
- **Skills** levels of the working population are important, as a flexible and active labour market requires a skilled workforce capable of adapting to new production techniques, etc.
- **Innovation**, principally as a result of research and development spending, generates new ideas, thereby adding to the overall 'stock of knowledge.'
- **Competition**, which is driven by market structure, can affect firms' behaviour by changing their incentives to engage in a particular activity (such as innovation), or by influencing their organisational structure.
- **Enterprise**, which relates to the attitudes and capabilities of managers, amongst other things; this could be relevant to the implementation of new innovations.

The drivers are interdependent, since contribution of each depends upon the support of the others (for example, a skilled and flexible workforce is essential to new discoveries found through innovation), but this delineation offers a useful structure to identify areas of policy intervention, and evaluate its effectiveness.

The response of growth theorists was to develop models that could account for technological progress itself: long run growth was 'endogenised', in that it could be explained by internal, rather than extraneous, factors. From the literature emerged a range of factors that could raise long run productivity performance: from 'learning by doing', productivity improvements gained from production experience (Arrow (1962)); improvements in 'human capital' (i.e. skills) raising long run growth rates (Lucas (1988)); a specific R&D sector increasing the variety of intermediate inputs in the production process (Romer (1990)); to R&D improving the quality of intermediate inputs (Aghion and Howitt (1992, 1998, 2005)).[4]

These recent contributions are among those dispensing with the conventional assumption of perfectly competitive markets, to permit the existence of *imperfect competition*. This offers an attractive solution to the problematic inconsistency of innovating firms reaping the rewards of research spending, when factor inputs are assumed to be paid their marginal product, as is the case within a perfectly competitive framework.

Whenever idea-producing activities such as research and development generate spillover effects (affecting not just the party engaged in research, but other external firms), returns to scale tend to be increasing, if the stock of knowledge (the supply of ideas) is included as a factor of production. However, perfect competition would imply that old ideas should be compensated according to their marginal production cost, which is zero – thereby undermining the incentives for firms to spend money on research at the outset (Barro and Sala-i Martin 1995).

By allowing firms engaged in R&D to protect their discoveries with patents, for example, the imperfect competition framework allows appropriate incentive structures to be constructed, in which research takes place, and where government policies can affect incentives in such a way as to yield an optimal level of R&D activity (Aghion and Howitt 1998).

In summary, the sources of growth in theory are numerous. Whilst developments in post-neoclassical endogenous growth theory have offered more convincing explanations for long run growth than their earlier counterparts, they have failed to deliver the firm policy conclusions heralded by some. As a result, it falls to empirical data to disentangle the sources of recent productivity performance.

3 The Empirical Literature

Many empirical studies are based on specific theoretical models, with the effect that most examine the effect of one factor (e.g. innovation) in isolation from another (e.g. competition). Accordingly, the following sections introduce the empirical evidence relating to each of the Five Drivers of productivity, since this offers a logical structure to consider the findings.

3.1 Physical Investment

Can physical investment raise productivity growth rates? Neoclassical models would suggest not, whether through labour productivity of TFP growth. As a straightforward input into the production function, physical capital can only affect the level of output rather than its long-run growth rate; further, TFP is calculated by adjusting output growth for changes in inputs,

[4] A review of the recent growth literature is provided by Temple (1999).

so physical capital would not be a source of its growth in any conventional sense.

However, dismissing physical capital as unimportant on this basis is unwise since it clearly occupies a central function in production: without an adequate capital stock, there could be no productivity growth in any case. Two further points support this view. First, available data on capital stocks makes little or no correction for improvements in the *quality* of investment over time (that is, its productivity-level enhancing effects). Thus if the productivity of capital increases in time, and this is not captured by available data, then the true contribution of capital to output growth could be understated, with the effect of TFP correspondingly overstated. Since empirical studies such as Mankiw, Romer and Weil (1992) suggest that capital accounts[5] for one-third of the level of output per head before any corrections are made, this suggests a significant and important role for capital in production. Secondly, capital investment may be important in endogenous growth models, where it could be a complement to innovations, whose implementation might require an upgraded capital stock.

A contrasting view to the Mankiw, Romer and Weil estimates of the contribution of capital to output has been suggested by De Long and Summers (see Temple (1998) for a summary). Their argument revolves around the hypothesis that investment in equipment has had a significant positive effect on growth, through the presence of strong externalities which raise TFP growth. There is some evidence to suggest that the social return to equipment investment is high (see Temple), but difficulties remain in the interpretation of this evidence.

Therefore, rather than asking whether investment can raise productivity performance in a direct way, a more prescient question to ask is whether UK firms under- or over-invest relative to a notional 'optimal' investment rate. The direct relevance of this issue to productivity was stated in Section 1, which identified differences in capital intensity as a partial explanation for the productivity gap. Unfortunately, the question is very hard to answer directly, since this would require knowledge of the efficient benchmark level of investment which, as Bond (2000) observes, is 'difficult to pin down.' Of interest, therefore, is whether UK firms face investment constraints imposed by the financial system, or other elements of the economy.

Although there are some indications that finance constraints have restricted investment in UK firms in recent times, the supporting evidence is not overwhelming. Bond and Meghir (1994) find that the sensitivity of investment to cash flow (which could reflect the presence of finance restrictions) is more concentrated in those firms in their sample paying low dividends, pointing to relatively severe constraints. Results presented by Bond, Elston, Mairesse and Mulkay (2003) suggest that the availability of internal

[5] In a purely growth accounting sense, rather than through a direct causal mechanism.

funds was more of a constraint for UK firms than other European firms over the period 1978 to 1989, which could suggest that capital markets, as a source of external funding, were less effective in the UK in providing funds for profitable investment opportunities. However, as the authors note (p. 162), '[these] results are doubtless consistent with other interpretations.' As Bond and van Reenen (2003) and Bond, Klemm, Newton-Smith, Syed and Vlieghe (2004) observe, tests for financing constraints could also be detecting other sources of mis-specification in underlying theoretical models of investment, providing support to the view that the case for capital market imperfections as a constraint on UK investment is by no means certain.

3.2 Skills

How important are skills in determining productivity performance? Early neoclassical models of growth were silent on this question, since they did not take explicit account of improvements in the quality of labour inputs (implying that, like the case of capital stocks above, unadjusted TFP figures would overstate the contribution of technological progress to growth). However, recent models have provided the empirical literature with more promising avenues.

On one hand, the case studies supporting Arrow (1962)-style learning by doing models suggests that where workers perform the same tasks frequently, the skills they acquire by doing so raise their productivity levels significantly. The scope for these kinds of skills having an effect on long-run productivity growth, though, seems limited; and since the skills may be technology- and capital-specific, the advantage they bring could be lost whenever innovation or investment altered the production process.

This would suggest that the kind of skills that might be of interest from a *policy* perspective would be those of a more general (and transferable) nature, captured by levels of educational attainment in the workforce. This approach is taken by Mankiw *et al.* (1992), who use evidence on the proportion of the working-age population in secondary schooling to build a measure of 'human capital', which is then treated as an input in the same way as (say) physical capital. This approach goes some way towards capturing the effect of a better-skilled workforce, and the evidence suggests that the elasticity of output with respect to skills is one-third, equal to that of physical capital.

Whether education can raise the *level* or *growth rate* of productivity is unclear. Within the model of Mankiw *et al.* (1992), the human capital stock exerts only a level effect on output per worker, which contrasts with the framework in Lucas (1988), where educational choice is modelled explicitly with reference to the returns to schooling, and skills can have a growth effect. The empirical literature approaches these issues from many angles, with a cross-country perspective in Barro and Sala-i Martin (1995) analysing the effect of schooling alongside a number of other factors, and a microeconomic perspective in Card (2001), *inter alia*, exploring the returns to education.

The empirical literature on education and productivity is reviewed in an extensive survey by Sianesi and van Reenen (2003), who observe that whilst there is no consensus about the *type* of effect, it is clear that education does have a significant effect of some kind.

3.3 Innovation

What is the effect of innovation on productivity? In seeking to answer this question, the empirical literature has studied the effect of a range of innovation measures on labour productivity and TFP, concentrating broadly on four key issues: what is the elasticity of output to innovation; what is the social rate of return to research and development; what are the spillover effects of research and development; and what is the role of technology transfer, as opposed to primary innovation, in closing a productivity gap.

Studies trying to capture the sensitivity of productivity to innovation have typically focussed on research and development spending, estimating the elasticity of a measure of productivity to the level of R&D spending.[6]

Griliches (1980*b*) is a good example from the literature, where the consensus is that there is a positive and significant link between R&D capital and productivity. Griliches's elasticity estimate of output with respect to R&D of 0.07 – suggesting an increase in R&D of 1% would raise the level of output by 0.07% – is in line with the range of early estimates in the literature, which vary from 0.05% to 0.1%. More recently, Cameron (2003) and Coe and Helpman (1995), amongst others, have found the elasticity to be somewhat higher, at around 0.2-0.3.[7]

An alternative to output elasticities is the social (gross) rate of return to knowledge. This is typically estimated using the growth in output or TFP, regressed against a measure of R&D intensity (such as the ratio of R&D expenditure to value added). As Jones and Williams (1998) discuss, this approach typically yields a lower bound to the social rate of return to R&D; Cameron (1998) reports that the consensus in the literature suggests a social gross rate of 20% to 50%.

Further, as Griliches (1986) observes, while overall and basic R&D contribute to productivity growth, the latter has a higher return. Cameron (1998) also reports differences in returns to process and product R&D, with the former typically yielding higher returns, whilst those in R&D intensive sectors generally appear higher than the average.

[6] See Cameron (1998) and Mairesse and Sassenou (1991) for surveys.

[7] Klette and Griliches (1996) discuss potential sources of downward bias when estimating elasticities using a production function approach; this bias is one possible explanation for the lower estimates in earlier studies.

From a discussion of social rates of return, it is natural to move onto the existence of *spillover* effects of R&D. External effects of R&D can take place through four mechanisms:[8] on the positive front, surplus appropriability (where innovators cannot appropriate the total social benefit of the good they create); standing on shoulders (where existing knowledge contributes to the capacity to innovate); and on the negative front, stepping on toes (new discoveries create negative duplication externalities, arising for example out of patent races); and creative destruction (where a new good supersedes an existing one, rendering it valueless).

These are important because they determine whether too little – or too much – R&D is actually taking place, relative to a socially optimal level. The search for spillovers in the literature has been extensive, although estimates of their extent and nature vary across studies. Nevertheless, as Griliches comments:

> "In spite of [many] difficulties, there has been a significant number of reasonably well done studies all pointing in the same direction: R&D spillovers are present, their magnitude may be quite large, and social rates of return remain significantly above their private rates."

GRILICHES (1992, p. S43)

Accounting for spillovers is possible via a number of channels. One implicit method relies on the differences between varying levels of data aggregation: in the absence of a specific variable to capture externalities (such as other firms' R&D spending), differences between the rate of return to R&D for firm-level and industry-wide studies could reflect spillover effects between firms in an industry.[9] This approach is explored by Griliches (1988), who finds little convincing evidence in support of this hypothesis, a result mirrored in the literature (see Cameron (1998)).

Direct measurement of spillovers is examined by Coe and Helpman (1995) and Bernstein and Mohen (1998), amongst others, who extend the method of estimating elasticities discussed above, to include the effect of foreign R&D capital stocks for a sample of countries. The results presented in Coe and Helpman (1995) point to the existence of significant links between an economy's TFP and not only its domestic R&D capital stock, but also those of its trading partners. Further, this effect appears to be stronger, the more open an economy is to international trade.

This trade dimension opens a major avenue of the innovation and productivity empirical literature. An economy's productivity performance is

[8] See Cameron (1998), or Jones and Williams (2000).

[9] Similarly, differences between industry- and country-wide studies could be driven by cross-industry spillovers.

determined not only by its research and development effort, but also by the extent to which it falls behind the global productivity leader. As Bernard and Jones (1996*a*, 1996*b*) discuss, TFP for a 'follower' country is affected by the size of the TFP gap with the leader, and the speed of catch-up.

Distinguishing between convergence and direct innovation as twin sources of productivity growth makes it possible to disentangle the effects of a number of factors. Cameron (forthcoming) and Cameron, Proudman and Redding (1998, 2005) adopt a flexible structure to examine the mechanisms by which TFP followers catch up with the leader. Using a panel of UK manufacturing sectors, the latter study finds a significant role for international trade in facilitating productivity catch-up (with the US), while R&D expenditure has a direct effect on productivity growth (with a social rate of return of just under 50%). Using this framework, van Reenen, Griffith and Redding (2004) explore the same issues across a panel of OECD countries, finding similar results, and in addition, a role for human capital in aiding both catch-up and productivity growth directly.

3.4 Competition and Market Structure

Does market structure affect productivity performance? Conventional economic models suggest that greater competition can deliver static gains, in the form of higher consumer surplus. However in addition to this, competition can have dynamic effects on an economy, through incentives for innovation, organisational behaviour and investment, and so an assessment of the long-term impact is essential.

In this context, the empirical literature comprises two strands: one attempts to estimate a *direct* effect of competition and entry on TFP, and the other examines an *indirect* effect through the impact of competition on innovation.

As Nickell (1996) observes, there is some theoretical basis for believing that greater competition should raise firm productivity, but 'the basis is not, as yet, a strong one.' (Nickell 1996, p. 728). Nevertheless, there are some suggestions supporting the hypothesis that competition is beneficial. Nickell points to three examples of *prima facie* evidence: first, the fact that liberal Western European economies have enjoyed substantially better productivity growth than their *dirigiste* Eastern European counterparts; secondly, the fact that Japanese industries subject to the greatest domestic competition were also those with the most successful industrial performance; and finally the observation that in general, deregulation is fuelled by significant productivity gains.

More concretely, evidence based on a panel of UK manufacturing firms during the 1970s and early 80s suggests that there is a 'robust and substantial effect of . . . competition on productivity *growth*' (Nickell 1996, p. 739, emphasis in original). Another study (Nickell, Nicolitsas and Dryden 1997) examines the role of three factors in determining a firm's productivity performance: product market competition, financial market pressure (related to high debt servicing costs and risk of bankruptcy) and shareholder control. Looking specifically at total factor productivity, the authors find that all three have an impact. Competition is found to be positively related to TFP growth,[10] whilst interest payments normalised on cash flow are positively related to future productivity growth, and firms with a dominant external shareholder (from the financial sector) have higher productivity growth rates. A significant feature of these results is that the last two elements can act as partial substitutes for competition, implying that the presence of either might attenuate the impact of increased competition on a firm.

Firm entry can reflect competition in a market; this avenue is explored by Aghion, Blundell, Griffith, Howitt and Prantl (2004*a*, 2004*b*), using the policy reforms of the Thatcher Government in the 1980s as a trigger for the entry of more foreign firms into UK markets. Three mechanisms link entry and productivity performance: the 'batting average' effect, in which technologically more advanced entrants have higher productivity growth, leading to a reallocation of inputs from lower productivity firms; the imitation effect, where incumbent firms improve organisation and reduce slack, imitating new entrants' practice; and finally the 'innovate to escape' effect, where incumbents raise innovative effort in response to the threat of entry, in order to escape having to compete. In all three cases, entry, or the threat of it, is predicted to raise productivity growth.

Using a panel of UK manufacturing firms covering 1987 to 1993, the authors find evidence in support of their two main theoretical predictions regarding productivity. First, the threat of entry by foreign firms (which are assumed to be close to the technological frontier) is found to have a positive and significant effect on TFP growth in domestic incumbent plants.[11] Evidence suggests that increasing the entry rate by half a percent (or one standard deviation) raises average TFP growth in domestic incumbent firms by one and a half percentage points.

Secondly, for industries closer to the technological frontier, the effect of firm entry on TFP growth is much stronger than for plants further away. This is consistent with the model of innovation developed by Aghion and others,[12] in which firms close to the technology frontier have an incentive to innovate so as to escape competition with new entrants. Firms far behind the frontier, however, have little incentive to innovate, since even by doing so, they would not progress sufficiently to compete successfully with new

[10] Average rents normalised on value added is used as an inverse measure of competition, and a negative relation between this and TFP growth is estimated.

[11] Lagged actual firm entry is used as the measure of entry threat.

[12] See Aghion, Harris and Vickers (1997), Aghion, Harris, Howitt and Vickers (2001), Acemoglu, Aghion and Zilibotti (2003) and Aghion and Howitt (2005).

firms.

An inverted-U relationship between competition and innovation is also found in empirical evidence examined by Aghion, Bloom, Blundell, Griffith and Howitt (2005), relating to data on UK industries covering 1973 to 1994. This result is based on the same model of innovation and entry discussed above, which represents the 'state of the art' of empirical studies into competition and innovation. Thus the positive link between the two that was found by Geroski (1990), Blundell, Griffith and van Reenen (1995) and Blundell, Griffith and van Reenen (1999), *inter alia*, and the negative link found by Greenhalgh and Rogers (2005), has been supplemented by recent evidence pointing to a more subtle relationship that depends on the relative technological position of each domestic industry.

Stemming from this, an important question to ask is how far the inverted-U style of analysis applies to UK firms. It is not difficult to imagine that within the country, some industries are closer to the global technology frontier in their sector than others. In this case, it would seem appropriate for different competition policies to apply to different industries, based on an assessment of the position of each relative to the frontier. However, a major challenge in this regard is *identifying* which sectors would benefit from strengthened competition, and which would not: this in itself is not straightforward, but would nevertheless be essential if the empirical literature were to lead to any firm policy conclusions. OECD (2005), for example, observes that whilst differences in the industrial mix of firms, and the associated patterns of R&D spending, can explain some of the productivity gap between the UK and leading EU states, it does not explain the UK's gap with the US. Thus it is not inconceivable that comparisons of market structure, and the distance to the technological frontier, depend on the countries examined, in addition to the industries considered.[13]

3.5 Enterprise and Entrepreneurship

The dearth of robust measures of enterprise that capture entrepreneurship, without being affected by other factors, has hindered empirical studies into its direct effect on productivity. In one sense, this stems from the lack of a clear definition of 'enterprise', which is a relatively abstract concept. The principal econometric problem is that variables that might be interpreted as measuring entrepreneurship – such as the number of firms entering a market – are also measures of other factors (in this case, of market competi-

[13] A further section of the literature on industrial organisation, that discusses the endogeneity of sunk costs (see, for example, Sutton (1991)), suggests that the evolution of fixed costs, and through this, market structure, might be determined by firms' investment behaviour directly, rather than by exogenous factors. In this light, the relationship between market structure and innovation, investment and productivity growth becomes even less clear.

tion), and distinguishing between the impact of enterprise specifically and other factors is extremely difficult.

Compounding this problem is the absence of *unambiguous* measures of enterprise. HM Treasury (2004) proposes a range of indicators of each of the Five Drivers, but several enterprise variables raise problems. For example, it is by no means obvious what relationship exists between productivity and the 'fear of failure preventing people from starting a business.' On one hand, potential investors imposing high 'psychological hurdle rates' could be depressing the amount of investment and number of business start-ups below their efficient levels; however, it could also be the case that the fear of failure would ensure that only high-return, high-productivity investments took place, eliminating the tail of underperforming investments without affecting profitable opportunities.

However, despite this rather pessimistic outlook, there are causes for optimism. Entrepreneurs, or individuals who help *implement* innovations, are important, in the same way that for example, a skilled workforce may be essential to implement productivity-enhancing improvements in the capital stock. This avenue is explored by Michelacci (2003), who finds some evidence in support of the hypothesis that entrepreneurs defined in this way are essential to exploit the potential of research and development expenditure.

4 Evaluating the Literature

How can we interpret the empirical evidence? The foregoing discussion has highlighted the myriads of estimates relating to productivity determinants, presenting the problem of determining which one to follow from a policy perspective. As might be expected, the problem is more subtle and complex than simply choosing one particular estimate above all others: the nature and scope of different studies is such that some variation in estimates is inevitable. The task therefore is to disentangle the sources of this variation, to distinguish between more and less robust methodologies and therefore advise on the most relevant range of estimates.

To this end, the discussion below highlights a number of concerns relating to methodology and data reliability, and examines how the literature can be interpreted.

4.1 Assessing the Estimates

A summary of the studies discussed in Section 3 is presented in Tables 2 to 5, which capture the relevant elements of their empirical work, including the estimates of important coefficients (such as the social rate of return). Both the tables and the above discussion highlight the substantial variabil-

Table 2: Selected Drivers: Some Empirical Evidence

PAPER	DRIVER	DATA COVERAGE	EXPLANATORY VARIABLES	COEFFICIENTS
Michelacci (2003)	Enterprise	Aggregate data, US, 1950-1990	Elasticity of patent applications to the proportion of self-employed individuals in economy	0.24-0.53
Nickell (1996)	Competition	Panel of 147 companies, 1972-86, UK	Elasticity of productivity growth to competition	0.11 - 0.16
Aghion, Blundell, Griffith, Howitt and Prantl (2004*b*)	Competition	Panel of manufacturing firms, UK, 1987-1993	Elasticity of TFP growth to the threat of foreign firm entry	3.095 - 3.995
			Elasticity of TFP growth to competition	0.146
Mankiw *et al.* (1992)	Skills	Panel of countries, 1960-1985	Elasticity of GDP per working age person to average percentage of working-age population in secondary school	0.66
			Implied output elasticity with respect to human capital stock	0.28
Barro and Lee (1994)	Skills	Panel of 85 countries, 1965-75, and 95 countries during 1975-85	Elasticity of growth in GDP per worker with respect to the average duration of secondary schooling in adult males	0.014

NOTES: Human capital studies are reported from Sianesi and van Reenen (2003), which also contains results from further studies. Studies may contain more explanatory variables than those listed above; those included here are those relevant to this paper.

Table 3: Innovation and R&D: Some Recent Studies

PAPER	LHS VARIABLE	DATA COVERAGE	RHS VARIABLES	COEFFICIENTS
Cameron (2003)	TFP Level	Aggregate manufacturing,	R&D capital stock elasticity	0.288 (0.11)
		UK, 1960-1995	R&D capital elasticity with trend	0.29 (0.12)
Cameron, Proudman and Redding (2005)	TFP Growth	Panel of 14 manufacturing sectors,	TFP catch-up coefficient	0.138 (0.053)
		UK, 1971-1992	R&D intensity elasticity	0.496 (0.259)
van Reenen *et al.* (2004)	TFP Growth	Panel of 9 manufacturing sectors,	TFP catch-up coefficient	0.024 (0.021)
		12 OECD countries, 1974-1990	R&D intensity elasticity	0.427 (0.174)
Coe and Helpman (1995)	TFP Level	Aggregate data,	Elasticity of domestic R&D capital stock	0.078
		21 OECD countries and Israel, 1971-1990	Elasticity of domestic R&D capital stock for G7 countries	0.234
			Elasticity of foreign R&D capital stock	0.294
			UK elasticity of world R&D	0.315

NOTES: Standard errors of estimates reported in parentheses, where available. LHS VARIABLES refers to the productivity measure used, either as a level or a growth rate; RHS VARIABLES refers to relevant explanatory variables, which explain some of the variation in the productivity measure.

Table 4: R&D elasticities: Selected Earlier Studies

PAPER	ELASTICITY	PAPER	ELASTICITY
USA		**France**	
Griliches (1980*b*)	0.06 *f*	Cuneo and Mairesse (1984)	0.22-0.33 *f*
Griliches (1980*a*)	0.00-0.07 *i*	Mairesse and Cuneo (1985)	0.09-0.26 *f*
Nadiri (1980)	0.06-0.10 *p*	Patel and Soete (1988)	0.13 *t*
Griliches (1986)	0.09-0.11 *f*	Mairesse and Hall (1996)	0.00-0.17 *f*
Patel and Soete (1988)	0.06 *t*	**West Germany**	
Nadiri and Prucha (1990)	0.24 *i*	Patel and Soete (1988)	0.21 *t*
Japan		**United Kingdom**	
Patel and Soete (1988)	0.37 *t*	Patel and Soete (1988)	0.07 *t*
Sassenou (1988)	0.14-0.16 *f*	**G7**	
Nadiri and Prucha (1990)	0.27 *i*	Coe and Helpman (1995)	0.234 *t*

NOTES: Source: adapted from Cameron (1998). Estimates derived from data on: *f*: firm level; *i*: industry level; *p*: private economy.

Table 5: Rates of Return to R&D: Selected earlier studies

PAPER	ELASTICITY	PAPER	ELASTICITY
USA		**France**	
Griliches (1980*b*)	0.27 *f*	Hall and Mairesse (1995)	0.22-0.34 *f*
Griliches (1980*a*)	0.00-0.42 *i*	Griliches and Mairesse (1983)	0.31 *f*
Griliches and Mairesse (1983)	0.19 *f*	**Japan**	
Griliches (1986)	0.33-0.39 *f*	Griliches and Mairesse (1986)	0.20-0.56 *f*
Jaffe (1986)	0.25 *f*	**UK**	
Nadiri and Prucha (1990)	0.24 *i*	O'Mahony (1992)	0.08 *i*

NOTES: as Table 4

Box 3: INTERPRETING THE LITERATURE

From the discussion in Sections 3 and 4, and the data in Tables 2 to 5, it is clear that the literature can only be of assistance in suggesting a likely range for a particular estimate, rather than a single point estimate. This is partly due to the fact that variation in the methodology, data coverage and scope of studies inevitably leads to differences for even the same variable across each. Further, since empirical studies only look at a limited snapshot of a particular country, or sector, it is not hard to imagine that the true figure for a variable (such as the rate of return to R&D) might differ from an estimate.

In light of these observations, what pragmatic response can the literature offer? First, from the point of view of a policy-maker, certain frameworks might be more useful than others; as Hall and Mairesse (1995) comment, '... there is more than one measure of the elasticity of output with respect to R&D capital: which one is preferred depends on the purpose to which it to be put.' Thus as Section 4 observes, where elasticities and rates of return are estimated in the literature, the scope for justified intervention might be more obvious when looking at the latter, to see whether the social rate of return to a particular activity (such as education) exceeds the private rate.

ity that can exist in the estimated coefficient for a particular variable (such as the elasticity of R&D capital) across studies. in many cases, this reflects differences in the time period covered, the countries considered and the scope of industries assessed. To this extent, it may not be possible to conclude that one estimate is particularly more robust than another, especially when studies share a common methodology. Thus for example, van Reenen *et al.* (2004) uses the conceptual framework and estimation technique developed by Cameron *et al.* (2005), suggesting that each study's estimate of the social return to R&D (43% and 49% respectively) is legitimate. In this context, therefore, the most pragmatic response is to advise on a robust *range* for a particular estimate, as reported in Box 3.

Notwithstanding these issues, though, some observations can be made about the robustness of different techniques, and the relevance of various approaches to policy-making. In this regard, the most important point for discussion is the distinction in the literature on R&D and innovation, between elasticities and gross social rates of return.

From a methodological standpoint, elasticity estimates require the construction of a R&D capital stock, which enters either directly into a firm's production function (see Hall and Mairesse (1995)), or into an expression for TFP (see Cameron (2003)). This could be problematic, since only *flows* *into* the capital stock are measurable, necessitating an estimate of a benchmark value of the stock at a particular time. Of particular concern is the fact that little account can be taken for differences in the *quality* of R&D capital over time (see Griliches (1979)). Further, in parallel to the physical capital literature, the R&D capital stock is subject to a rate of depreciation over time. No definitive justification for depreciation in the stock of *knowledge* or ideas exists, although it could be seen within an endogenous growth framework, where the discovery of new ideas by others might reduce the value of a firm's own ideas. In any case, it is not clear why such a depreciation rate would remain constant over time, firms or industries. In addition to these concerns, there is no reason to presume that the problems surrounding the measurement of physical capital stocks (see Biørn, Lindquist and Skjerpen (1999)) are not also relevant to measuring knowledge capital.

In contrast, measuring the rate of return to R&D requires only the research and development spending for a particular year, which represents only the latest *increment* to a national 'R&D capital stock', thereby dispensing with the need to calculate the value of the stock. How can we interpret the rate of return figures? Some authors (see, e.g. Hall and Mairesse (1995)) believe that timing problems and depreciation render estimates of the R&D return unreliable. In the first case, however, it is not clear why the timing of R&D expenditure – capturing how long it takes for new ideas to have an effect on productivity – is any more uncertain than that of the overall capital stock, which affects elasticity estimates. Nor is it obvious why the assumption of no depreciation in the capital stock should fatally undermine estimates of the overall return, when no theoretical, empirical or intuitive reasoning has been presented for any particular rate of depreciation.

What bearing does this have on advising which estimate is the most robust? Several considerations are relevant here. First, from the perspective of identifying areas in which intervention might be justified, a rate of return will be of much greater use then an elasticity. In particular, the degree to which the private and social rates of return to a particular driver differ, is critical. If the returns to tertiary education, say, were captured more or less entirely by the individual, then there would be little case for government subsidies in that sector (ignoring, of course, other possible motivations for subsidies). The general picture in the literature appears to be one in which the biggest divergence between private and social returns exists in innovation, where high gross social rates of return have been consistently estimated.

Spillovers might present further problems for interpretation, since it might not be possible to generalise the results of one study and apply them to a different context. Thus for example, the presence of spillovers between countries in R&D spending, for example, need not point to the existence of the same effects between individual firms within a sector of the economy. This would suggest that policy intervention on a sectoral level, for instance, would need to use sector-specific evidence, rather than aggregate results.

A related point underlines the light that the empirical evidence can shed on interpreting the Five Drivers framework. Whilst the Drivers play an important part in the growth process, they do so in differing ways. Thus the evidence suggests that physical capital affects the level of output per hour, but not its growth rate; in contrast, the literature on the effect of education and skills, though inconclusive, does not deny the possibility that it can raise the long run growth rate of productivity.[14] In any case, the practical distinction between a 'level effect' which takes several years to occur, and a 'growth effect' over the same period, could well be so slight as to make little difference;[15] however, the point still remains that the literature should be interpreted within the context that the Five Drivers can operate in different ways.

As an example of the interdependence of the Drivers, it is interesting to consider the effect of innovation in the service sector. Although the scope for research and development might be low in some service sectors, it is possible that various other innovative activities might interact with other drivers, besides innovation. Thus if ICT leads to changes in working practices in ICT-using sectors (such as retail and financial services), then this could raise labour productivity, and in this context, differences in labour market regulations across countries could be important. This is particularly relevant to the the recent productivity performance of the EU, which Inklaar, O'Mahony, Robinson and Timmer (2003) find has been poor for ICT-using service sectors relative to the US, since 1995. As Gust and Marquez (2004) argue, it is quite plausible that the extent of labour market regulation in Western Europe significantly slows the speed of adoption of new technologies and new ways of doing business. Whilst the UK experience does not necessarily mirror exactly that of the EU, the potential remains for the Drivers to affect each other.

4.2 Remaining Issues in the Literature

How effectively does the empirical literature continue the search for productivity sources, where theory left off? In the opinion of some authors, progress has not fulfilled its potential:

> Endogenous growth theory has sketched the bare bones of an aggregate model of technological change. Firm-level studies of

[14]Cameron (2003) found evidence of a significant effect of the level of R&D on the *level* of UK manufacturing TFP, but not its *growth rate*; this implies that a permanent increase in R&D spending would only generate *short run* growth.

[15]As Temple (1999) observes, 'it is always worth remembering that "the long run growth rate" is a theoretical abstraction, never observable in practice. Debates about whether or not policy affects it will distract us from more questions that are ultimately of more practical importance.' (p.141).

> R&D, productivity, patenting, and firm growth could add flesh to these bones. So far they have not.
>
> KLETTE AND KORTUM (2002, p. 2)

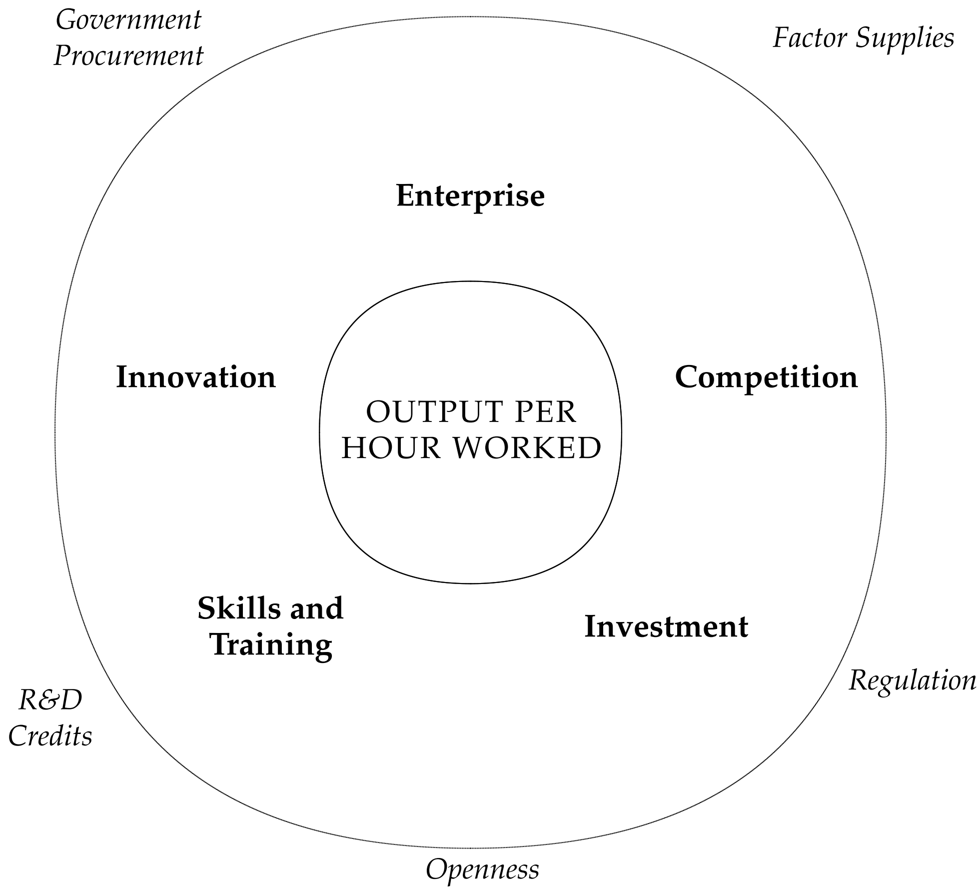
However, in reality the problems facing empirical estimation appear more subtle than the quotation suggests. Section 2 observed that far from constructing a single framework to analyse technological change, theory has presented a vast array of competing models, each placing a different emphasis on the various sources of growth. In truth, there are so many alternative models that the answer to the search for the various sources of productivity growth will inevitably need to come from evidence, rather than theory.

The empirical search for productivity determinants concentrates primarily on labour productivity, and total factor productivity,[16] and several data-related observations can be made in relation to this. First, the quality of data is not consistently uniform across countries or sectors. As O'Mahony (1999) discusses, measuring productivity in the service sector is particularly difficult, due to the absence of a tangible output, and appropriate methods of adjusting for changes in the quality of output. This is somewhat problematic, since a comprehensive strategy to improve whole-economy productivity performance would be undermined if the available literature ignored four-fifths of the economy. This would suggest a need for further research into service sector productivity explicitly, and its determinants.

Additional problems arise in the *interpretation* of public sector productivity data, since an increase in the number of teachers tending to a fixed number of students (for example) would lower productivity in the education sector (if the number of graduating students was used to measure educational output), whilst potentially bringing significant benefits to the quality of education received. It is not difficult to imagine further examples applied to other sectors. In this respect, initiatives such as the Atkinson Review (Atkinson 2005) represent an important step towards implementing productivity policy across a broader section of the economy.

Finally, several studies have discussed sources of error in the measurement of TFP. One basic concern affecting both neoclassical and endogenous growth models is that a TFP index relies on the accurate measurement of factor inputs, which can be difficult, for example in the case of capital stocks. Further, double-counting of factors such as labour used in research and development, could introduce measurement bias (Cameron 2003), as could errors in estimating price indices (Crafts and Mills 2005).

[16] Box 1 provides an explanation of each.



5 Productivity and Policy

How can policy affect long term productivity growth? The figure on page 23 identifies a number of areas in which government policy might influence the Five Drivers, without creating adverse distortions in the economy.

Essential in achieving this, though, is an acknowledgement that government policy is best directed towards creating a suitable *environment* in which the productivity drivers can operate, via the levers identified in the figure. Thus for example, as Hassett and Hubbard (1996) and Hall and van Reenen (1999) discuss, R&D policy is more effectively implemented through the allocation of credits and subsidies, which operate at the margin, rather than the kind of direct targets favoured by some policy-makers: in this regard, the European Commission's objective of raising research and development spending to 3% of GDP appears as an arbitrary goal with relatively little regard to the demand for R&D activity within firms or industries.

What role should economic policy play in raising productivity growth, and what are the major challenges? The foregoing discussion has emphasised the importance of rates of return to different factors as an important guide, but even where an opportunity for policy intervention has been identified, the appropriate set of policies is not obvious. Thus there is no concrete link between one policy level on one hand, and a productivity outcome on the other. For example, a drive to encourage firms to engage in R&D in the UK as opposed to abroad might well increase the amount of domestic innovation taking place, whilst at the same time reducing the spillover effects of foreign R&D on the UK.

6 Concluding Comments

The Five Drivers framework comprises one of the two central plank of the UK Government's microeconomic policy reforms, along with labour market policy. Appealing to a broad range of theory on the sources of economic growth in the short-run and long-run, the Drivers represent five key parts of a central 'engine' of growth. Two of these, physical investment and workforce skills, have traditional interpretations within early post-war models of growth, whilst the remaining three – innovation, competition and enterprise – have a role within more recent endogenous growth models.

Whilst the progression from theoretical models to empirical estimates does entail a range of econometric problems, the evidence on some of the Drivers is relatively clear. Physical investment, skills and innovation do have a positive effect on either the level or growth rate of productivity, although the evidence on the effect of competition remains somewhat inconclusive, and data on enterprise is scarce. Interdependencies among the Drivers pose further problems in the interpretation of the available evidence.

Despite these issues, however, it is possible to draw out a number of policy-related themes in the literature. First, with regard to identifying the scope for justified policy intervention, evidence on the rates of return to different activities, such as investment or innovation, seems to be more appropriate than other evidence based, for example, on elasticities. Empirical estimates suggest that rates of return to research and development in some manufacturing industries are particularly high, which, given the low rates of R&D spending in the same UK sectors, would suggest that there is some scope for encouraging innovation. Similarly, rates of return to different levels of education do point towards an opening for policies to encourage greater skills within the workforce, although the strength of evidence in this regard is somewhat weaker. In any case, it is clear that the most appropriate strategy is to create a climate in which an activity (such as greater innovation by firms) is encouraged, rather than one in which the government intervenes directly to engage in the activity itself. Secondly, the evidence available underlines the importance of the international dimension to economic growth, through technology transfer, and spillovers arising from innovation, amongst other factors.

Finally, it should not be forgotten that knowledge of the channels through which changes in the Drivers affect growth is at best imprecise, and the empirical literature sheds only a partial light on some of the important issues. Further, the links from policy to the Drivers themselves are not fixed, and the interdependent nature of the sources of growth, and its international dimension, only serve to cloud understanding of the effects of policy. However, in view of the fact that the Five Drivers framework offers a pragmatic programme that identifies the principal sources of growth, it provides a structure to consider the theoretical and empirical literature. Although this review has not commented on the links between macroeconomic policy and growth directly, macroeconomic stability must be an integral part of a climate inducive to economic growth. In this context, it is interesting to note that EMU members have somewhat less incentive to make progress on microeconomic reforms when they cannot be sure that the macroeconomic policy response will help to offset any short run costs to such reforms (Duval and Elmeskov 2005).

References

ACEMOGLU, D., AGHION, P. AND ZILIBOTTI, F. (2003), 'Vertical Integration and Distance to Frontier', *Journal of the European Economic Association*, **1** (2-3), 630–638.

AGHION, P. AND HOWITT, P. (1992), 'A model of growth through creative destruction', *Econometrica*, **60** (2), 323–351.

AGHION, P. AND HOWITT, P. (1998), *Endogenous Growth Theory*, MIT, MIT Press.

AGHION, P. AND HOWITT, P. (2005), 'Growth with Quality-Improving Innovations: An Integrated Framework', in P. Aghion and S. N. Durlauf, eds, *Handbook of Economic Growth*, Elsevier, Amsterdam.

AGHION, P., BLOOM, N., BLUNDELL, R., GRIFFITH, R. AND HOWITT, P. (2005), 'Competition and Innovation: An Inverted-U Relationship', *Quarterly Journal of Economics*, **120** (2), 701–728.

AGHION, P., BLUNDELL, R., GRIFFITH, R., HOWITT, P. AND PRANTL, S. (2004*a*), 'Entry and productivity growth: evidence from micro-level panel data', *Journal of the European Economic Association*, **2** (2-3), 265–276.

AGHION, P., BLUNDELL, R., GRIFFITH, R., HOWITT, P. AND PRANTL, S. (2004*b*), 'Firm Entry, Innovation and Growth: Theory and Micro Evidence', mimeo, Harvard University.

AGHION, P., HARRIS, C. AND VICKERS, J. (1997), 'Competition and Growth with Step-by-Step Innovation: an example', *European Economic Review*, **41** (3), 771–782.

AGHION, P., HARRIS, C., HOWITT, P. AND VICKERS, J. (2001), 'Competition, Imitation and Growth with Step-by-Step Innovation', *Review of Economic Studies*, **68** (3), 467–492.

ARROW, K. J. (1962), 'The economic implications of learning by doing', *Review of Economic Studies*, **29** (1), 155–173.

ATKINSON, A. B. (2005), *Measurement of Government Output and Productivity for the National Accounts: The Atkinson Review final report*, London, Palgrave.

BARRO, R. AND SALA-I MARTIN, X. S. (1995), *Economic Growth*, McGraw-Hill.

BARRO, R. J. AND LEE, J.-W. (1994), 'Sources of Economic Growth', *Carnegie-Rochester Conference Series on Public Policy*, **40**, 1–46.

BERNARD, A. B. AND JONES, C. I. (1996*a*), 'Comparing apples to oranges: productivity convergence and measurement across industries and countries', *American Economic Review*, **86** (5), 216–38.

BERNARD, A. B. AND JONES, C. I. (1996*b*), 'Productivity Across Industries and Countries: Time Series Theory and Evidence', *Review of Economics and Statistics*, **78** (1), 135–146.

BERNSTEIN, J. I. AND MOHEN, P. (1998), 'International R& D spillovers between U.S. and Japanese R& D intensive sectors', *Journal of International Economics*, **44**, 315–338.

BIØRN, E., LINDQUIST, K.-G. AND SKJERPEN, T. (1999), 'Micro Data On Capital Inputs: Attempts to Reconcile Stock and Flow Information', *Statistics Norway Discussion Papers*, **268**.

BLUNDELL, R., GRIFFITH, R. AND VAN REENEN, J. (1995), 'Dynamic Count Data Models of Technological Innovation', *Economic Journal*, **105** (March), 333–344.

BLUNDELL, R., GRIFFITH, R. AND VAN REENEN, J. (1999), 'Market Share, Market Value and Innovation in a Panel of British Manufacturing Firms', *Review of Economic Studies*, **66** (3), 529–554.

BOND, S. (2000), 'UK Investment and the Capital Market', mimeo, presented to HM Treasury seminar *Economic Growth and Government Policy*.

BOND, S. AND MEGHIR, C. (1994), 'Dynamic Investment Models and the Firm's Financial Policy', *Review of Economic Studies*, **61** (2), 197–222.

BOND, S. AND VAN REENEN, J. (2003), 'Microeconometric Models of Investment and Employment', mimeo, IFS, London.

BOND, S. R., ELSTON, J. A., MAIRESSE, J. AND MULKAY, B. (2003), 'Financial Factors and Investment in Belgium, France, Germany and the United Kingdom: A Comparison using Company Panel Data', *Review of Economics and Statistics*, **85** (1), 153–165.

BOND, S. R., KLEMM, A., NEWTON-SMITH, R., SYED, M. AND VLIEGHE, G. (2004), 'The roles of expected profitability, Tobin's Q and cash flow in econometric models of company investment', *Bank of England Working Paper Series*, **222**.

CAMERON, G. (1998), 'Innovation and Growth: a survey of the empirical literature', mimeo, Nuffield College, Oxford.

CAMERON, G. (2003), 'Why Did UK Manufacturing Productivity Growth Slow Down in the 1970s and Speed Up in the 1980s?', *Economica*, **70** (2), 121–141.

CAMERON, G. (forthcoming), 'The Sun Also Rises', *Journal of Economic Growth*, .

CAMERON, G., PROUDMAN, J. AND REDDING, S. (1998), 'Productivity convergence and international openness', in J. Proudman and S. Redding, eds, *Openness and Growth*, Bank of England, London.

CAMERON, G., PROUDMAN, J. AND REDDING, S. (2005), 'Technological Convergence, R&D, Trade and Productivity Growth', *European Economic Review*, **49** (3), 775–807.

CARD, D. (2001), 'Estimating the Return to Schooling: Progress on Some Persistent Econometric Problems', *Econometrica*, **69** (5), 1127–1160.

COE, D. AND HELPMAN, E. (1995), 'International R&D Spillovers', *European Economic Review*, **39** (5), 859–88.

CRAFTS, N. F. R. AND MILLS, T. C. (2005), 'TFP Growth in British and German Manufacturing, 1950-1996', *Economic Journal*, **115** (July), 649–670.

CUNEO, P. AND MAIRESSE, J. (1984), 'Productivity and R&D at the Firm Level in French Manufacturing', in Z. Griliches, ed., *R&D, Patents and Productivity*, Chicago University Press, Chicago.

DUVAL, R. AND ELMESKOV, J. (2005), 'The Effects of EMU on Structural Reforms in Labour and Product Markets', *OECD Economics Department Working Paper*, **438**.

FREEMAN, R. (2000), 'How Important is business R & D for economic growth and should the government subsidise it?', mimeo, presented to HM Treasury seminar *Economic Growth and Government Policy*.

GEROSKI, P. (1990), 'Innovation, Technological Opportunity and Market Structure', *Oxford Economic Papers*, **42**, 586–602.

GREENHALGH, C. AND ROGERS, M. (2005), 'The Value of Innovation: The Interaction of Competition, R&D and IP', mimeo, University of Oxford.

GRILICHES, Z. (1979), 'Issues in assessing the contribution of research and development to productivity growth', *Bell Journal of Economics*, **10** (1), 92–116.

GRILICHES, Z. (1980*a*), 'R&D and the productivity slowdown', *American Economic Review*, **70**, 343–348.

GRILICHES, Z. (1980*b*), 'Returns to R&D Expenditures in the Private Sector', in K. W. Kendrick and B. Vaccara, eds, *New Developments in Productivity Measurement*, Chicago University Press, Chicago.

GRILICHES, Z. (1986), 'Productivity, R&D, and Basic Research at the Firm Level in the 1970's', *American Economic Review*, **76** (1), 141–154.

GRILICHES, Z. (1988), 'Productivity Puzzles and R&D: Another Explanation', *Journal of Economic Perspectives*, **2** (4), 9–21.

GRILICHES, Z. (1992), 'The Search for R& D Spillovers', *Scandinavian Journal of Economics*, **94** (Supplement), 29–47.

GRILICHES, Z. AND MAIRESSE, J. (1983), 'Comparing Productivity Growth: an Exploration of French and US Industrial and Firm Data', *European Economic Review*, **61**, 324–9.

GRILICHES, Z. AND MAIRESSE, J. (1986), 'R&D and Productivity Growth: Comparing Japanese and US Manufacturing Firms', *NBER Working Paper Series*, **1778**.

GUST, C. AND MARQUEZ, J. (2004), 'International Comparisons of Productivity Growth: The Role of Information Technology and Regulatory Practices', *Labour Economics*, **11**, 33–58.

HALL, B. H. AND MAIRESSE, J. (1995), 'Exploring the relationship between R& D and productivity in French manufacturing firms', *Journal of Econometrics*, **65**, 263–293.

HALL, B. H. AND VAN REENEN, J. (1999), 'How effective are fiscal incentives for R&D? A review of the evidence', *NBER Working Paper Series*, **7098**.

HASSETT, K. A. AND HUBBARD, R. G. (1996), 'Tax Policy and Investment', *NBER Working Paper Series*, **5683**.

HM TREASURY (2000), *Productivity in the UK: The Evidence and the Government's Approach*, London, HM Treasury.

HM TREASURY (2001*a*), *Productivity in the UK: 2 – Progress towards a productive economy*, London, HM Treasury.

HM TREASURY (2001*b*), *Productivity in the UK: 3 – The Regional Dimension*, London, HM Treasury.

HM TREASURY (2003), *Productivity in the UK: 4 – The Local Dimension*, London, HM Treasury.

HM TREASURY (2004), *Productivity in the UK: 5 – Benchmarking UK productivity performance*, London, HM Treasury.

INKLAAR, R., O'MAHONY, M., ROBINSON, C. AND TIMMER, M. P. (2003), 'Productivity and Competitiveness in the EU and the US', in M. O'Mahony and B. van Ark, eds, *EU Productivity and Competitiveness: An Industry Perspective Can Europe Resume the Catching Up Process?*, Office for Official Publications of the European Communities, Luxembourg.

JAFFE, A. (1986), 'Technological opportunity and spillovers of R&D: Evidence from firms' patents, profits and market value', *American Economic Review*, **76**, 984–1000.

JONES, C. I. AND WILLIAMS, J. (1998), 'Measuring the Social Return to R&D', *Quarterly Journal of Economics*, **113**, 1119–1135.

JONES, C. I. AND WILLIAMS, J. (2000), 'Too Much of a Good Thing? The Economics of Investment in R&D', *Journal of Economic Growth*, **5** (1), 65–85.

KLETTE, T. J. AND GRILICHES, Z. (1996), 'The Inconsistency of Common Scale Estimators when output prices are unobserved and endogenous', *Journal of Applied Econometrics*, **11**, 343–361.

KLETTE, T. J. AND KORTUM, S. S. (2002), 'Innovating Firms and Aggregate Innovation', *CEPR Discussion Paper Series*, **3248**.

LUCAS, R. (1988), 'On the Mechanics of Economic Development', *Journal of Monetary Economics*, **22**, 3–42.

MAIRESSE, J. AND CUNEO, P. (1985), 'Recherche-developpment et performances des entreprises: une etude econometrique sur donnees individuelles', *Revue Economique*, **36**, 1001–42.

MAIRESSE, J. AND HALL, B. (1996), 'Estimating the Productivity of research adn Development in French and United States Manufacturing Firms: An Exploration of Simultaneity Issues with GMM Methods', in K. Wagner and B. van Ark, eds, *International Productivity Differences: Measurement and Explanations*, North Holland, Amsterdam.

MAIRESSE, J. AND SASSENOU, M. (1991), 'R&D and Productivity: a survey of econometric studies at the firm level', *STI Review*, **8**, 9–43.

MANKIW, N., ROMER, D. AND WEIL, D. (1992), 'A contribution to the empirics of economic growth', *Quarterly Journal of Economics*, **107** (May), 407–437.

MICHELACCI, C. (2003), 'Low Returns in R& D Due to the Lack of Entrepreneurial Skills', *Economic Journal*, **113** (484), 207–225.

NADIRI, M. (1980), 'Sectoral productivity slowdown', *American Economic Review*, **70**, 349–355.

NADIRI, M. AND PRUCHA, I. (1990), 'Comparison and Analysis of Productivity Growth and R&D Investment in the Electrical Machinery Industries of the United States and Japan', in C. Hulten and R. Norsworthy, eds, *Productivity Growth in Japan and the United States*, Chicago University Press, Chicago.

NICKELL, S. J. (1996), 'Competition and Corporate Performance', *Journal of Political Economy*, **104** (4), 724–746.

NICKELL, S. J., NICOLITSAS, D. AND DRYDEN, N. (1997), 'What Makes Firms Perform Well?', *European Economic Review*, **41**, 783–796.

OECD (2005), *Economic Survey of the United Kingdom*, Paris, OECD.

O'MAHONY, M. (1999), *Britain's Productivity Performance, 1950-1996*, London, NIESR.

O'MAHONY, M. (1992), 'Productivity and Human Capital Formation in UK and German Manufacturing', *NIESR Discussion Paper*, **28**.

O'MAHONY, M. AND DE BOER, W. (2002), 'Britain's relative productivity performance: Updates to 1999', mimeo, National Institute for Economic and Social Research.

PATEL, P. AND SOETE, L. (1988), 'L'évaluation des effets économiques de la technologie', *STI Review*, **4**, 133–183.

ROMER, D. (2001), *Advanced Macroeconomics*, 2nd edn, McGraw-Hill.

ROMER, P. M. (1990), 'Endogenous Technological Change', *Journal of Political Economy*, **98**, S71–S102.

SASSENOU, M. (1988), Recherche-Developpment et Productivite dans les Entreprises Japonaises: une Etude Econometrique sur Donnees de Panel, PhD thesis, EHESS, Paris.

SIANESI, B. AND VAN REENEN, J. (2003), 'The Returns to Education: Macroeconomics', *Journal of Economic Surveys*, **17** (2), 157–200.

SOLOW, R. M. (1956), 'A contribution to the theory of economic growth', *Quarterly Journal of Economics*, **70** (1), 65–94.

SUTTON, J. (1991), *Sunk Costs and Market Structure*, Cambridge, Mass., MIT Press.

TEMPLE, J. (1998), 'Equipment investment in the Solow model', *Oxford Economic Papers*, **50** (1), 39–62.

TEMPLE, J. (1999), 'The New Growth Evidence', *Journal of Economic Literature*, **37** (1), 112–156.

VAN REENEN, J., GRIFFITH, R. AND REDDING, S. (2004), 'Mapping the Two Faces of R&D: Productivity Growth in a panel of OECD industries', *Review of Economics and Statistics*, **86** (4), 883–895.