Using productivity growth as an innovation indicator

October 2011

Bronwyn H. Hall[1]

University of Maastricht and UC Berkeley

Report for the High Level Panel on Measuring Innovation, DG Research, European Commission

1. Executive Summary

This paper explores the latest work on methodologies for establishing a quantitative link between innovation and productivity – highlighting various schools of thought, experiences in Europe and elsewhere, and key issues that remain. The goal is to assess productivity as a potential indicator of innovative activity. Before delving into the methodologies for measuring the innovation-productivity relationship, it is important to understand some issues with measuring both innovation and productivity.

Although the OECD has established a commonly accepted definition of innovation, experience with the Community Innovation Surveys and surveys like them has shown that it is difficult to measure innovation in a consistent and statistically comparable way. This is due primarily to two issues:

- The definition of innovation (including the term "new") can be interpreted in different ways by the respondents of these surveys and this can lead to questionable results (particularly when aggregating and comparing across countries).
- Although it produces a somewhat more reliable measure, the survey question on the share of sales derived from newly introduced products does not capture process or organizational innovation, which leads to a bias towards product innovators and "R&D doers".

The measurement of productivity is also challenging, due to the difficulty of defining and measuring real inputs and outputs (especially in the service sector) and their associated

[1] I am grateful to Emily Wise for her help in preparing this paper and to Martin Curley, Amnon Salter, and other members of the Expert Group on Measuring Innovation for comments on earlier drafts.

price deflators. Much of the benefit of innovation investment may show up in increased (or sometimes decreased) prices at the firm level due to shifts in market power and this will not be well captured by conventional price indices. In addition, the choice of real input and output measures affects the allocation of the benefits of innovation at the sector level. Nevertheless, among innovation output measures, multi-factor productivity is one of the best understood and measured, because of the attention that has been paid to this measure by economists and statisticians inside and outside governments for the past 50 years.

Given the above-mentioned issues with measuring innovation and productivity, one can understand the level of complexity in measuring the relationship between them. A complementary paper (Hall 2011) reviews 25 studies that have attempted to estimate a quantitative relationship between firm-level productivity and innovation measures, many of them using the so-called CDM model, introduced by Crepon, Duguet, and Mairesse (1998). This paper discusses and summarizes those results, with the overall conclusion that there is a positive relationship between innovation in firms and their growth in revenue or value-added, and that this positive relationship appears to be due primarily to product innovation.

Recently, various research projects (including INNODRIVE and COINVEST) and organisations (including NESTA) have used a growth accounting approach (as presented in Corrado, Hulten and Sichel 2006) to measure the contribution of innovation activity to productivity at the national level. This approach augments the production function with estimates of investments in innovation-related intangibles. Challenges related to this approach include defining what should be included in intangibles, how intangibles should be depreciated, etc. The OECD is currently coordinating work on measuring intangible capital in order enable consistent, cross-country analysis of the contribution of intangibles to economic growth. Unlike the productivity indicator, the growth accounting approach is based on innovation input expenditure rather than output.

In conclusion, the CDM model and CHS growth accounting approach provide complementary methods for examining the contribution of innovation to productivity. Yet a number of questions related to measuring innovation using CIS-type data, measuring intangibles, etc. remain areas for future work. In particular, neither approach is capable of delivering a proven causal relationship between the two, although there are good reasons to think that one exists.

2. Introduction

The question to be addressed by this paper is whether aggregate productivity growth can be considered a good indicator of innovative activity at the country level. And, if so, which measure of productivity is appropriate and measurable? Should we use labor productivity (private firm output per person-hour)? GDP per capita? Or total factor productivity, adjusting for changes in capital and vertical integration?[2] Should we focus only on private firm productivity or use economy-wide measures? Alternatively, should we try to account for the contribution of innovative activity to productivity growth specifically?

The first question one might ask is about the scope of such a measure: do we want to measure innovative activity (and therefore productivity) for the entire economy, including the government and non-profit sectors, or are we mainly concerned with innovation in the private sector? There are arguments for both approaches. Given the variation across countries in the size of the public sector and its role in the economy, and the presence of state-owned firms, it might be appropriate for international comparison to use an economy-wide productivity measure like GDP per working-age population. However, such a measure runs the risk of being so aggregate that it is difficult to use for diagnostic purposes and fails to measure the most dynamic and innovative part of the economy very well. In addition, the problems of real output measurement are particularly acute in the case of government output, which is seldom traded on the market.

Another question is whether innovation by individual firms has an impact on their productivity, and if so, by how much. As I show below, the answer to this question is by no means obvious, at least in the case of traditional process innovation. A monopolistic profit-maximizing firm that becomes more efficient via innovation may see a much larger decline in price than increase in quantity, leading to falling revenue along with increasing profit. "True" productivity may have increased, but measured productivity will not. Fortunately, in practice product innovation generally has a more positive impact on both price and quantity, so the net impact of innovation is usually postive, and the empirical work described below supports this conclusion. Thus it is possible to use multi-factor or total factor productivity as an indicator of successful innovative activity on the part of the firm, with the understanding that this measure is only a proxy and may capture other changes in the firm's environment.

[2] A few definitions may be helpful here. "Productivity" is a catch-all term that refers to output per unit of input but has to be defined in context. It may refer to "labor productivity," which is output per employee or per person-hour, but it may also refer to "multi-factor productivity" or "total factor productivity," which are terms describing a measure that adjusts labor productivity for differences in capital and other inputs (energy, purchased inputs, materials). The OECD has settled on the term "multi-factor productivity" rather than "total factor productivity" to allow for the possibility that not all inputs have been accounted for. This paper uses the two terms interchangably, and sometimes refers to total factor productivity as TFP.

Given the results for individual firms' productivity, a second question is how these results aggregate to the economy as a whole, once we take account of the exit of inefficient firms and the entry of new (and innovating firms). About this question, much less is known, although work by Halitwanger and co-authors has tried to do some accounting for aggregate productivity using census data for the United States (Foster, Halitwanger, and Syverson 2008). Bartelsman, Haltiwanger, and Scarpetta (2009) extends the inquiry into the allocative efficiency of entry and exit by firms to data on firms in the US and seven European countries. They develop a relative diagnostic measure of inefficient allocation of resources across firms based on the covariance of firm size and productivity wihin industry. The idea of this measure is that economies that are subject to inefficient regulation which prevents firms from growing or shrinking to their optimal size will display a lower correlation between firm size and productivity, since more productive firms will not be able to grow and displace less productive firms. They show that this measure changed in the way one would expect in three East European countries between the early 1990s and the 2000s. However, in spite of its promise for analyzing the sources of aggregate productivity growth, this kind of work has formidable data requirements. More importantly, it does not yet incorporate any measure of innovation as a causal measure.

An alternative approach to measuring the contribution of innovation to productivity growth at the aggregate level uses newly available national account data on investment innovation and intangibles. This approach has been pioneered by Corrado *et al*. (2008) and is now the subject of considerable effort in the UK (UK NESTA 2009) and the EU (INNODRIVE). In essence, using growth accounting requires a measure of investment expenditures on innovation which are then capitalized and their contribution to productivity measured in the same way as the contribution of ordinary tangible capital. In addition, the production of this innovation capital is often added to output. Note that undertaking this exercise requires estimates of the rate of return to innovation and the depreciation rate of innovation capital and therefore depends on some of the evidence based on microeconomic research. Considerable experimentation with the exact methodology is now taking place at the various national statistical agencies that seek to develop systems of national income accounts incorporating intangibles. In addition, assuming a normal rate of return to innovation investments and then computing their contribution to growth means that the resulting estimate is based on an input measure of innovation, rather than an output measure.

The paper is structured in the following way: I begin with a definition of innovation and a brief look at the numbers that have been generated by various innovation surveys. This is followed by a discussion of the basic model that links innovation to productivity and what it tells us about how to interpret coefficient estimates based on this model. I then review the accumulated micro-economic evidence on the relationship and draw some conclusions about the quality of productivity as an indicator.

3. Innovation – concept and measurement

Thanks to work by the OECD and others, we now have a definition of innovation done by firms that is fairly standard across a wide range of countries and surveys:

"An innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations."[3]

Most research on the relationship between innovation and productivity has been based on surveys that use a version of this definition. Thus there has been consistency in the definition of the innovation variables across studies, although perhaps not consistency in the interviewees' understanding of the definition. However, note that there is at least one slightly ambiguous feature of the definition, in that it does not define "new" very precisely. Some of the surveys have made a distinction between "new to the firm" innovations and "new to the market" innovations, which can be a way of distinguishing more radical innovation from imitation. But often the interpretation of "new" is left to the survey respondent, although this is changing over time as experience is acquired with the survey instruments.

In spite of the apparent clarity of the definition of innovation in the Oslo Manual, measuring innovation in a form that is useful for statistical analysis has proved challenging. The central problem is that no two innovations are alike. Some innovations (e. g., the invention of the telephone or perhaps the telegraph) create a whole new market sector whereas others are useful but trivial, and there is a wide range in between. In general we can say that smaller innovations are more numerous than game-changing ones. Table 1 in Acs and Audretsch (1990) shows this clearly. During the year 1982, over 85 per cent of the innovations they identified from a comprehensive review of over 100 trade journals were modest improvements to existing products, and none created entire new markets. Fewer than 2 per cent were considered even the first of its type on the market in existing market categories.[4]

Contemporary innovation surveys have typically measured innovation in two ways: first, by asking whether the firm introduced an innovation of a certain type (product, process, organisational, marketing, etc.) during a preceding period (usually the past three years) and second, by asking what share of the firm's sales are due to products introduced during

[3] *Oslo Manual* (OECD 2005), third edition, p. 46.

[4] Note that by using the 1982 date, Acs and Audretsch did miss two major innovations: the IBM personal computer and Microsoft DOS, both of which were introduced in 1981 and which arguably meet the definition of "created entire new market".

the same preceding period. The first measure has a number of drawbacks, which have become quite evident as it has been used in many empirical studies. When examined across a range of firm sizes, it produces the misleading results that larger firms are more likely to be innovative, whereas in truth larger firms are involved in a wider range of activities and therefore more likely to have an innovation in at least one of them. So this variable cannot be used to make the kind of statements that one sometimes hears, such as "large firms are more innovative than small firms."

Another problem is the previously mentioned unequal size of innovations and the failure in some surveys to distinguish between "new to the market" and "new to the firm." Based on the Acs and Audretsch results we know that many more of the innovative firms will have introduced improvements to existing products rather than entirely new goods and services, but the latter may be more important than the former. This view of the "skewness" of innovation values is supported by a large amount of research on the valuation of patented inventions (Harhoff *et al.* 1999; Scherer and Harhoff 2000; Hall *et al.* 2005). Although patented inventions are not precisely the same as innovations, they are similar and their distribution shares some of the properties of innovation distributions, with the majority worth very little, and a few that are quite valuable to their owners.

Because of the imprecision and noisiness of the innovation dummies, many researchers prefer to use the second measure, the share of sales of innovative products, which does give a good indication of how important the innovation(s) were overall for the firm in question. Unfortunately, this measure is useful only for goods and services and cannot be used to capture process or organisational innovation. Nevertheless, it is the one relied on by more than half of the papers discussed in the following sections, often accompanied by a dummy for process innovation. Only one example exists where firms were asked to quantify the impact of process innovation on cost reduction (Peters 2006, for Germany).

Figure 1, which is based on data from these kinds of surveys, shows the distribution of the share of firms that report any kind of innovation during the three year period 2006-2008 by country and size of firm.[5] The figure is instructive: it shows that in most countries, between 30 and 60 per cent of firms introduce a product or process innovation during a three year period, and that the rate of introduction is much higher and also more even across countries among large firms, as might have been expected. In fact, the coefficient of variation for the innovation share across countries is 0.3 for the SMEs and 0.12 for the large firms, confirming the higher dispersion rate for SMEs.

---

[5] The data for this and the subsequent figure comes for the most part from the European Community Innovation Survey 6 for 2006-2008. The individual statisical offices have tried to make the numbers as comparable across countries as possible. Data for the United States comes from the new 2008 Business R&D and Innovation Survey (BRDIS), conducted by the National Science Foundation and may not be exactly comparable to the European data.

Figure 2 shows a breakdown by product and process innovation, where innovation is defined as the development of a new to the firm process or product by the enterprise or its group.[6] In this case we are able to compare the European countries to the United States, by restricting the population of firms to a common set of innovative sectors across the two regions.[7] The two types of innovation are roughly equal, with a slight preference for process innovation and some differences across countries. It is however, worth noting that the United States is by no means the most innovative among these countries by this measure, although this conclusion should be viewed with caution given the slight noncomparability of the U.S. data.

4. Productivity – concept and measurement

What we mean by the term "productivity" is fairly easy to understand although difficult to measure: it is the quantity of output that can be produced using a given level of inputs. If productivity is to be used as a measure of innovation, there is an implicit assumption that increases in output not accompanied by increases in inputs are due to innovative activity.

Economists generally describe the relationship between output and the level of inputs using a production function, of which the most convenient for analysis is the following:

$$Q = AC^{\alpha}L^{\beta} \quad (1)$$

Where Q is output, C is the level of capital stock, and L is labor (and potentially other non-capital inputs).[8] A is the overall level of productivity which may vary across entities. That is, because of organizational differences, frictions, or other constraints, entities with identical levels of C and L may not be able to achieve the same level of output Q.

[6] In the US case, the definition does not include the group to which the enterprise belongs. Because group structures are rare in the US, this distinction makes little difference. However, it does mean that the European numbers could be slightly higher given the broader definition of the firm doing the innovating.

[7] These sectors are manufacturing, telecommunications, computer services and software publishing, finance, and some technical professional services. The restriction is necessary because the U.S. data do not contain enough detail outside manufacturing to match the innovative sector definition used by Eurostat, which is quite broad. The narrow definition used here is NACE activities C, J58, J61, J62, J63, K, M71. The broader definition used by Eurostat and elsewhere in this paper includes NACE activities B, D, E, G46, and H (mining, utilities, wholesale trade excluding motor vehicles, and transportation and storage).

[8] The treatment here has been greatly simplified by omitting purchased inputs (such as materials, energy, etc.). In practice these inputs are more important on a share basis than either capital or labor and would need to be included in estimation (typically accounting for about 0.7 of the inputs). Alternatively, one can measure output as value added, which is usually defined as output less purchased inputs. The precise choice of what to include or exclude depends to some extent on data availability, and several variations have been pursued in the literature discussed here. In particular, many of the available datasets do not include measures of the firm's capital stock and researchers are forced to resort to proxies such as current investment spending.

For measurement purposes, the logarithm of equation (1) is taken:

$$q_{it} = a_{it} + \alpha c_{it} + \beta l_{it} \qquad i = entity, t = time \tag{2}$$

where the added subscripts denote the fact that productivity levels are usually measured for a number of entities over several time periods. Equation (2) yields an expression for total factor productivity (usually denoted TFP):

$$TFP \equiv a_{it} = q_{it} - \alpha c_{it} - \beta l_{it} \tag{3}$$

All well and good, but measuring TFP therefore requires measures of real output Q, real capital stock C, and labor input L (as well as possible other inputs, such as energy and materials), to say nothing of the coefficients α and β. I discuss the latter problem first.

There are two widely used approaches to estimating the weights α and β to be applied to the inputs in the productivity measure: 1) assume that input markets are competitive and that there are no sources of rents to the firm in question (e.g., assume constant returns to scale and perfect competition), which implies that the coefficients are the shares of revenue received by each of the factors; [9] and 2) assume the coefficients are (roughly) constant across entities and estimate them via regression. Solution (1) is favored by statistical agencies and others who simply need a measure of TFP for an individual entity and may not have a sample available for estimation. This is also the solution used for growth accounting, and will therefore be the approach favored if we wish to obtain a TFP measure for a whole sector or economy. Solution (2) is the one typically used by econometricians and the main one employed in the literature discussed in Section 4 of this paper.

The second problem, how to measure the inputs and outputs themselves, is subject to a multitude of solutions. Unfortunately, the choices can have considerable impact not only on the measurement of TFP but also on the relation of that measure to innovation. The difficulty lies in the measurement of real inputs and outputs, holding constant the unit of measure over time. To take a concrete and well-known example, computers, which are a component of capital, have changed considerably over time. If we measure their contribution to the inputs simply as expenditure on computers, it is likely to be roughly constant over time, and TFP will grow as the computers become more productive. However, if instead we deflate the computer expenditure by an index of the effective price of computing power, which has fallen dramatically over the past 30 years, the real quantity of computers will grow substantially during the same period, and TFP growth will be

[9] This approach can be modified to account for scale economies and market power as in R. Hall (1988), or indeed almost anything that implies homogeneity of some degree in the production function. See below for a modification that allows the firms to have some degree of market power.

correspondingly less. In essence, some technical change or innovation has been transferred from TFP to its inputs.[10]

The same argument applies to the labor input, where quality has probably generally increased over time so that a person-hour 30 years ago is not the same as one today. All this means that TFP measures need to be used carefully, with an understanding of the approach used to deflation and quality adjustment. That is, at the level of the individual firm, many of the effects of innovation may show up as higher quality inputs if they are quality adjusted, and will not appear in output. The production of these higher quality inputs will be reflected in the aggregate data, with the possible exception of labor quality, most of which comes from the education sector, which may or may not be accurately reflected in aggregate productivity measures.

For the output measure, the problem is even more striking when we look at the level of the firm or enterprise, because of the potential for variations in market power across firms, and for the role that innovation plays in creating and/or increasing that market power. The easiest way to see this is to rewrite the TFP equation in terms of revenue rather than real output, under the assumption of an iso-elastic demand equation. The idea behind this approach is that each firm produces differentiated products and therefore faces its own downward sloping demand curve. Firms have idiosyncratic output prices, so that deflation of revenue by an overall deflator simply yields real revenue rather than an actual output measure. I denote the log of real revenue by r_{it} and the log of the firm's output price by p_{it}, with $r_{it} = p_{it} + q_{it}$. Write the iso-elastic demand equation facing the firm in logarithmic form as follows:

$$q_{it} = \eta p_{it} \tag{4}$$

where η is the (negative) demand elasticity. Combining equations (2) and (4) yields the following expression for the (observable) revenue as a function of the inputs and TFP:

$$r_{it} = \frac{\eta+1}{\eta}(a_{it} + \alpha c_{it} + \beta l_{it}) \tag{5}$$

The above equation implies that the estimated coefficients of capital and labor in the productivity equation will be negative if demand is inelastic ($0>\eta>-1$) and biased downward if demand is elastic ($\eta<-1$). As η approaches -∞ (perfectly elastic, or price-taking), the bias disappears and the equation is identical to equation (2), but with revenue in place of output.

[10] A large literature has developed on the methodologies for estimating the production function in the presence of simulateneity between input and output choice and errors of measurement. Some key papers are Blundell and Bond (2000), Griliches and Mairesse (1984), and Olley and Pakes (1996).

The conclusion is that if a regression based on equation (5) is used to estimate TFP (a_{it}), the estimate will typically be biased downward over a reasonable range of demand elasticitie s. Note also that for a profit-maximizing firm, the bias is equal to *1-m*, where *m* is the markup. The further we are from perfect competition (*m=1*) and the higher the markup, the greater is the downward bias. After I present the basic model that relates innovation and productivity in the next section, I will derive the implications of equation (5) for the measurement of that relationship.

5. The innovation-productivity relationship

Modeling the relationship

When looking at the contribution of innovative activity to productivity, the usual starting point is to add a measure of the knowledge or intangible capital created by innovative activity to the production function:

$$Q = AC^{\alpha} L^{\beta} K^{\gamma} \tag{6}$$

Here *K* is some kind of proxy for the knowledge stock of the firm. *K* can stand for a number of aspects of the entity's innovative capability: its technological knowledge obtained via R&D, its competency at transforming research results into useful products and processes, and so forth. It can even be based on innovative success rather than capability. Traditionally *K* has been measured as a stock of past R&D spending but as other kinds of data have become available, other measures involving patents or innovation indicators have been used.

As before, the logarithm of equation (6) is taken:

$$q_{it} = a_{it} + \alpha c_{it} + \beta l_{it} + \gamma k_{it} \qquad i = entity, t = time \tag{7}$$

Because much of innovative activity is directed towards new products and product improvement, it is useful to rewrite the demand equation to allow the knowledge stock to shift the demand curve facing the firm:

$$q_{it} = \eta p_{it} + \varphi k_{it} \qquad \varphi > 0 \tag{8}$$

Assuming that the knowledge stock has a positive coefficient implies that the effect of increased knowledge or innovative activity is to shift the demand curve out by making the firm's products more attractive to its customers, at a given price.

Combining equations (7) and (8) as before, we obtain the following equation for revenue:

$$r_{it} = \left(\frac{\eta+1}{\eta}\right)(a_{it} + \alpha c_{it} + \beta l_{it}) + \left(\frac{\gamma(\eta+1)-\varphi}{\eta}\right)k_{it} \qquad (9)$$

This equation shows that knowledge stock K is likely to contribute to revenue and therefore to measured productivity growth via two channels: directly by increasing the efficiency of production and indirectly by shifting the demand curve for the firm's products outward (note that η is negative so that $-\varphi/\eta$ is positive).[11] It is usual to think of these two channels as process and product innovation.

For full identification of the system implied by equation (9), it would be desirable either to have data on individual firm output prices to allow separate estimation of η and φ or to have some information on the components of K that might be directed toward processes and/or products. At the simplest level, one can gain some idea of the relative importance of the two types of innovation for productivity using the innovation dummy variables available from the various innovation surveys. An implication of the foregoing model is that process innovation will have ambiguous effects on revenue productivity, whereas the effect of product innovation is likely to be positive.

In the studies reviewed here, the estimation of equation (9) is generally performed by regressing a measure of log revenue per employee (r_{it}-l_{it}) on the logs of capital or investment, firm size measures in terms of employment, and various proxies for innovative activity. Industry dummies at the two-digit level are almost always included, to control for things such as omitted inputs (in cases where value added is not available), differences in vertical integration, the omission of capital stocks (in cases where only current investment is available), and the overall level of technological knowledge. Although the model is in terms of the stock of knowledge or innovative capability, the usual proxies for this variable are the current level of innovative activity, measured as a dummy for some innovation during the past three years, or as the share of products sold that were introduced during the past three years. Because the estimation is almost always cross sectional, the fact that a flow of innovation rather than a stock is used will make little difference to the interpretation of the estimates, provided that innovation is persistent within firms. See Peters 2009 for evidence that this is the case.

Empirical evidence

Hall (2011) provides a detailed review of the studies that have attempted to estimate a quantitative relationship between firm-level productivity and innovation measures explicitly. That paper lists 25 papers of which all but two use data from the Community Innovation Survey (CIS) or its imitators in other countries. Of those using CIS-type data, 18

[11] This treatment ignores another possible effect of innovative activity: the possiblity that the demand elasticity is changed by the introduction of new products.

use some variant of the well-known CDM (Crepon, Duguet, and Mairesse) model for the analysis. One of these papers used both levels and growth rates to measure productivity (Loof and Heshmati 2006), but most have chosen either levels (14 papers) or growth rates (10 papers) exclusively.

Use of the CDM model implies that most of the estimates are essentially cross-sectional ones that ignore issues of the timing of innovation and its contribution to productivity (exceptions are Masso and Vahter 2008, Belderbos et al 2004, Peters 2006). This is a reflection of the nature of the innovation surveys, which ask about innovative behavior during the past three years and contain or are matched to other firm information that is contemporary with the innovation data. The data available are usually not sufficient to construct a time series (panel) for the firms involved since the samples are redrawn for each survey and there is little overlap. Thus the analysis relates productivity in one period to innovation in the same period or slightly before that period but does not trace out any dynamic response. It is noteworthy that the results for the papers that do use lagged measures of innovation are not notably different from those using contemporary measures, reinforcing the cross-sectional and long run interpretation of these results.

The CDM model has been described by many others in detail (see the discussion and references in Hall 2011) and I will not present it here. Suffice it to say that the model relates R&D, innovation, and productivity in a sequential multi-equation model that allows for self-selectivity in performing R&D and undertaking innovation, and simultaneity between these activities and productivity. The hope is that the model is able to deliver at least a quasi-causal measure of the impact of various kinds of innovation on productivity.

Tables 1a (levels, using innovative sales share), 1b (levels, using the product innovation dummy), and 2 (growth rates) summarize the results for the productivity-innovation relationship that have been obtained from estimation of the CDM model. I discuss each of these tables in turn. It should be noted that although I am treating the estimates as comparable, the precise regressions used in any particular paper will differ from those in other papers, as will the data construction itself. In spite of these variations, the results for the elasticity of output with respect to the innovative sales share (shown in Table 1a) are reasonably consistent across countries and time periods. The highest elasticities (0.23-0.29) are for knowledge-intensive or high technology sectors. Most of the elasticities for Western Europe lie between 0.09 and 0.13, and less-developed countries, the service sector, and the low technology sectors have elasticities less than 0.09, with the exception of the insignificant estimate for Chilean data. Thus we can conclude that innovative sales are associated with revenue productivity, and that the association is stronger for higher technology sectors. For a typical Western European manufacturing firm, doubling the share of innovative sales will increase revenue productivity by about 11 per cent.

Table 1b presents the results of the productivity regression that uses a 0/1 measure of product innovation instead of the innovative sales share. For reasons mentioned earlier, this measure will vary by size of firm purely for measurement reasons and should be considered a much weaker proxy for innovative output. We do see that the results are more variable, although still positive for the most part. For manufacturing sectors in Western Europe, typical values are around 0.05-0.10, implying that product innovating firms have an average productivity that is about 8 per cent higher than non-innovators, but there is a wide dispersion.

The results for process innovation in both Tables 1a and 1b are even more variable, with some negative, some zero, and some positive. Note that the few positive estimates in Table 1a are for the two cases where the authors included this variable alone in the productivity regression, without the innovative sales variable (Mairesse et al. 2005 for France and Siedschlag et al. 2010 for Ireland). Because of the high correlation between product and process innovation, including any one of the innovation variables is likely to produce a positive coefficient, as the included variable will proxy for all kinds of innovation. The other positive estimates occur when product innovation is measured by a dummy rather than by the share of innovative sales, which suggests that they are partly due to the measurement error implicit in using a dummy to proxy for innovation. That is, we know from many of the surveys that process and product innovation go together. Therefore if we have a weak measure of product innovation, we might expect that the process innovation dummy would pick up more of the overall innovative activity. Recalling the discussion of equation (9), one could argue that the estimates in Table 1a, which are mostly negative for process innovation and positive for product innovation, suggest that firms are operating in the inelastic portion of their demand curves and that revenue productivity is enhanced mainly by the introduction of new and improved products, and not by efficiency improvements.

Table 2 presents results for a productivity regression where the left hand side is productivity growth, rather than its level. This relationship is not precisely the growth rate version of the regressions that lie behind Table 1, since it relates growth to the level of innovative activity, not to its growth rate. In general, the results are similar to but slightly lower than the level version of the equation, with an innovative sales elasticity focused on the range 0.04-0.08, and a product innovation dummy of about 0.02. As before, process innovation is negative for productivity growth when included with product innovation in the equation, although positive on its own. It is noteworthy that the only study with a true estimate of the cost savings due to process innovation rather than a dummy (Peters 2006) yields a large and marginally significant elasticity of 0.14, implying that if we had better measures of process innovation, we might be able to improve the measure of its impact considerably.

From this summary of the empirical relationship between the various innovation measures and firm-level revenue productivity we can conclude the following: first, there is a positive relationship, albeit somewhat noisy, between innovation in firms and their growth in revenue or value added. Second, the positive relationship is primarily due to product innovation. The impact of process innovation is more variable, and often negative. This can be interpreted in one of two ways: the typical firm enjoys some market power and operates in the inelastic portion of its demand curve so that revenue productivity falls when it becomes more efficient. Alternatively, it is possible that there is so much measurement error in the innovation variables that only one of the two is positive and significant when entered in the productivity equation. Without instruments that are better targeted to predicting the two different kinds of innovation, this possibility cannot be ruled out.

As a final reality check, I compare the enterprise innovation rates at the country level with overall labor productivity (GDP per hours worked, also from OECD data). The results are shown in Figure 3. With the exception of an outlier (Norway), the share of both SMEs and large firms that innovate appears to be positively related to labor productivity at the country level. Simple univariate regressions for the relationship were moderately significant, and even more so when robust methods such as Least Absolute Deviations or Least Median of Squares were used. So the correlation between innovative activity and productivity is visible at the aggregate level as well, although the measures used for both innovation and productivity are somewhat different. The next section of the paper discusses an approach to innovation measurement that uses aggregate data.

6. Growth accounting

This section of the paper describes the growth accounting approach to measuring the contribution of innovative activity to productivity, as practiced by Corrado *et al.* (2006), UK NESTA (2009), and new systems of national accounts that include intangibles.

The basic setup of the growth accounting approach derives from the same model as that used in measuring productivity, but there are two major differences: First, growth accounting is largely about the ways in which the growth of inputs, including innovation inputs, affect the growth of output, whereas the productivity-innovation relationship is about levels. Second, instead of estimating the contribution of each input to output, it is assumed that the share of value added going to each input factor corresponds to its contribution to output growth, which corresponds to the first method for estimating the input coefficients discussed earlier.

We start with an aggregate production function as in the original growth papers by Solow (1956) and Abramovitz (1956):

$$Q(t) = A(t) \cdot f(C(t), L(t)) \tag{10}$$

This equation states that output Q (value added) is a function of capital C, labor L, and other factors A (the 'residual', often attributed to technical change)

Take the time derivative of equation (10) to obtain a relationship in terms of growth rates:

$$G_Q = G_A + \varepsilon_K G_K + \varepsilon_L G_L \tag{11}$$

ε's are elasticities of output with respect to inputs. For growth accounting purposes, they are measured as the share of the value added s that goes to each input factor.

In order to incorporate intangible or innovation investment, we augment output with the creation of intangible (innovation) assets and augment the inputs with measures of intangible capital due to innovative activity:

$$G_{\tilde{Q}} = s_C G_C + s_L G_L + s_K G_K + G_{TFP} \tag{12}$$

where K denotes intangible capital and $\tilde{Q}$ denotes output including the production of intangible capital. This formulation is attractive because it fits into the newly revised SNAs.

Aggregate G_{TFP} is the share-weighted productivity growth of different sectors (final goods, investment, intangibles). It is similar to the growth of A in the original model and is an unmeasured residual. NESTA (2009) proposed that an innovation index be measured as the share of labor productivity growth due to innovation investments, which is $s_K G_K$ in the above equation. Thus this measure is essentially an input measure, rather than an output measure, because it does not depend directly on output and the other input factors, although the level of output is used in computing the share weight. In the absence of omitted inputs other than innovation inputs, G_{TFP} can be thought of as a kind of excess return to the innovation input. In contrast, the CDM approach on the other hand, essentially allocates all of $s_K G_K + G_{TFP}$ to innovation, capturing both the normal returns to the innovation input and any deviation of output from those normal returns.

There are some methodogical issues in doing this kind of growth accounting. First, how should we depreciate intangibles? Second, how much of marketing and advertising expense do we want to include? How much of firm-level training? How should we value organisational change? Should we measure labor quality more carefully? If not, improvements in labor quality will end up in the TFP growth residual.

7. A summary of "state of the art" – the practical level[12]

This section of the paper presents a short summary of a number of projects conducted by organisations and governments working in this area – including what models/frameworks and measures that are used, and what lessons have been learned from these experiences.

OECD

The OECD collaborates with several European framework programs such as the INNODRIVE and COINVEST projects on methods for measuring intangible capital consistently across countries in order to enable analysis of the contribution of intangibles to economic growth.

The OECD's most recent work has focused on the exploitation of **micro-data** to conduct comparative empirical analysis. In this context, the OECD has studied innovation and productivity issues since 2007, and is now engaged in the 3rd wave of empirical studies (based on a "decentralized" approach to exploit confidential micro-data). The OECD provides a common framework (experts meet and identify common research and policy questions; the indicators and the econometric modeling is decided; and software routines are developed), and researchers with access to their own country's micro-data compile results that are then compared and written up either by OECD or lead countries.

Phase 1 led to the publication in 2009 of *Innovation in firms: A microeconomic perspective,* which was based on 4 projects, of which two deal with the link between innovation and productivity (OECD 2009; OECD 2010b). Phase 2 launched 9 "micro-data" projects, of which two followed up on the innovation-productivity link, using the CDM modeling framework described earlier but extending it to take into account firms' distance from the technology frontier and their industry market structure (OECD 2010a).

Results from the various projects differ, depending on the stage of development and level of competition. Table 3.3 of OECD (2009) is reproduced as Table 3 of this report. It shows the results of estimating the final stage of the CDM model (the productivity equation) for the year 2004, using the same methodology across 17 OECD countries. Unfortunately, because this exercise was based only on data available in the surveys, they were unable to include a measure of the capital stock in the productivity equation, which makes the results slightly noncomparable to most of those in Table 2a. Nevertheless, it is noteworthy that the innovative sales elasticities are similar to those in the earlier work, if a bit higher, and that the coefficient of process innovation in the presence of product innovation is uniformly small and negative, although not always significant.

---

[12] This section of the report was written jointly with Emily Wise.

Additional results reported by the OECD from Phases 1 and 2 of the project are the following: First, firms that introduce *both* product and process innovations derive on average 30% more innovation sales per employee than those introducing only product innovations. Similarly, firms with higher innovation expenditure per employee have more innovation sales per employee than other firms. The elasticity range is between 0.1 and 0.3 for most participating countries.

Second, a firm's distance from the global technology frontier matters. Distance from the frontier is proxied by how far a firm's productivity level (measured either by turnover per employee or value added per employee) is from the top productive firms worldwide. Firms further away from the technology frontier invest less in innovation per employee and have lower returns from innovation (lower innovation sales per employee) than those closer to the frontier. However, firms with a low productivity level at the beginning of the period are as likely to innovate as those with a higher productivity level. These findings hold for firms in almost all participating countries.

Finally , public support makes a difference, especially for firms that are further away from the technology frontier. While both firms close to and far away from the technology frontier benefit from public funding for innovation, those that are further away from technology frontier that receive public funding spend 60% to 100% more on innovation than those that do not receive public funding, whereas for firms closer to the technology frontier, those that receive public funding spend 30% to 50% more on innovation than those that do not receive public funding.

The OECD is currently defining the projects for phase 3, and has highlighted three proposals for work in 2011-12 that may be relevant to the measurement of innovation using productivity:

- Follow up work based on patents/trademarks link to business registers (to look at the link between innovation and firm dynamics).
- Work on enterprise dynamics looking at the role of entry and exit, focusing on young high growth firms.
- Sources of growth: the role of intangible assets (micro and sectoral level analysis addressing the relationship between investment in intangibles, innovation, and productivity.)

Also ongoing – is a coordination action that the OECD are leading for research on ICT, Innovation and productivity (a 2-year project called ICTNET supported by DG INFSO via Framework 7). With respect to innovation, the main focus will be on the relationship between ICT investment (in particular, broadband) and productivity, and intangible assets and productivity (a growth accounting project led by Jonathan Haskel at Imperial College).

USA

In January 2008, the U.S. Department of Commerce released a report (produced by an Advisory Committee on Measuring Innovation in the 21st Century, chaired by Carl Schramm of the Kauffman Foundation), *Innovation Measurement – Tracking the State of Innovation in the American Economy.* The report recommended "a stronger framework for identifying and measuring innovation in the national economy." As part of that work, the U.S. Bureau of Economic Analysis (BEA) requested that the Science and Technology Policy Institute (STPI) explore the business perspectives of innovation. The resulting report, *Measuring Innovation and Intangibles: A Business Perspective* (Stone et al. 2008) created a compendium of the logic and methods businesses use to measure and monetize innovation.[13] It also identified sources for, and gaps in, innovation data and outlined critical areas for future research. A 2009 report from the Athena Alliance extended that work and presented two alternative frameworks for measuring innovation.[14] The first framework focuses on measuring innovation activities at the firm/organization level. The second takes a broader macro-level look at the fundamental investments that allow firms and other organizations to carry out innovation activities.

At the same time, The National Science Foundation (together with the Bureau of the Census, which conducts the survey) has heavily revised the former RD-1 survey to include a set of pilot questions on innovation that are similar to those on the Community Innovation Survey. The first such survey, renamed the Business R&D and Innovation Survey (BRDIS) was launched in 2008 and some of its results were shown in Figure 2.[15] Experience with that survey has lead to another revision in order to improve the response rate for the innovation questions *inter alia* but none of the data for 2009 or 2010 have yet been released.

All of the above reports address the measurement of innovation – but do not focus on the innovation-productivity links.

UK/NESTA

In 2008, the UK Department for Business, Innovation and Skills (BIS) published a White Paper on Innovation entitled *Innovation Nation* and commissioned NESTA to develop an Innovation Index. The resulting Innovation Index formed part of the BIS Annual Innovation Report 2010 published on January 25, 2011. The Index measures the investment in

---

[13] See http://www.athenaalliance.org/pdf/MeasuringInnovationandIntangibles-STPI-BEA.pdf

[14] See http://www.athenaalliance.org/pdf/InnovationFrameworks-STPI.pdf

[15] See http://www.nsf.gov/statistics/srvyindustry/about/brdis/

intangible assets and demonstrates the importance of these investments in driving economic growth. The Innovation Index includes factors such as product design, training in new skills, organisational innovation, developing new customer offerings and brands, and copyright. NESTA has referred to this as 'hidden innovation', finding that it is as important to productivity as R&D in the UK.

Supporting the Annual Innovation Report, NESTA published two Index reports:

- *Driving economic growth: innovation, knowledge spending and productivity growth in the UK* (January 2011), which presents latest data on investments in intangible assets and the contribution to productivity growth. The report is based on a modification of the pilot Index published in 2009, providing greater accuracy in the measurement of the investments in intangibles and the contribution to productivity growth. The report includes an industry breakdown highlighting the importance of manufacturing in overall productivity growth as well as the share of investments in intangibles within consumer and business services.

- *Measuring wider framework conditions for successful innovation: A system's review of UK and international innovation data* (January 2011), which is a comprehensive review of the data for measuring the wider conditions for successful innovation using the functional model of the innovation system as presented in the pilot Index in 2009. The report considers the relative strengths and weaknesses of current data, highlighting where gaps in the measurement of the conditions exist. Each section concludes with proposals for new data to address the gaps identified.

The measurement of innovation in the Index is based on the growth accounting framework presented in the interim report (UK NESTA 2009). The growth accounting approach provides the opportunity to develop innovation indicators in a logically consistent economic framework based on the national accounts, avoiding double counting, and directly linked to economic measures used for policy (such as productivity and investment). The methodology draws on a wide range of measures of innovation, which are covered in the innovation literature. They complement, but do not substitute, the task set at NESTA: to produce an index which is integrated with, and helps explain, macroeconomic measures of output growth, employment and productivity. The definition of innovation, on which the report bases the innovation index, is the contribution of all forms of knowledge to growth, as opposed to the contribution due to investment in physical inputs and labour.

EU KLEMS

The EU KLEMS project on Growth and Productivity in the European Union was a research project supported under the 6th Framework Programme, coordinated by Bert van Ark of the Groningen Growth and Development Centre, University of Groningen (running from 2003-2008).

The purpose of the project was to create a database on productivity by industry for EU member states with a breakdown into contributions from capital (K), labour (L), energy (E), materials (M) and service inputs (S). The variables are organized around the growth accounting methodology, and the data series is publicly available at http://www.euklems.net. The project also included a number of analytical research projects in the areas of: analysis of productivity, prices, industry structures, technology and innovation indicators; labour markets and skills; technological progress and innovation; link to productivity research using firm level databases.

The result of the project was a database containing industry-level measures of output, inputs and productivity for 25 European countries, Japan and the US for the period from 1970 onwards.[16] The database has been updated in November 2009 and March 2011(see http://www.euklems.net/index.html for more detailed information). Because the database covers most countries of interest using a consistent methodology and contains all the ingredients for computing multi-factor productivity in the private sector, it could be very useful for constructing a productivity indicator of innovation success.

Following on this project, the World KLEMS Consortium was established at Harvard University in Augsut 2010, whose goal is to extend the methodology to countries beyond the OECD. See and Jorgenson (2010) and http://www.worldklems.net for further information on this initiative.

INNODRIVE

The INNODRIVE project (on Intangible Capital and Innovations: Drivers of Growth and Location in EU) was an EU Framework 7 project, operating between March 2008-February 2011 and coordinated by the University of Vaasa in Finland.

The aim of the research project was to improve our understanding of intangible capital by providing new data on intangible capital and identifying its impact on economic growth. The study constructed measurements of the capital embodied in intellectual assets (e.g. human capital, R&D, patents, software and organisational structures) and computed the contributions to growth associated with intangible capital accumulation in manufacturing, service industries and the rest of the economy. The project's final conference was held in Brussels 22-23 February 2011.

[16] For a summary overview of the methodology and construction of the EU KLEMS database, see: O'Mahony et al. (2009). For more details and analysis, see Timmer et al. (2010).

The INNODRIVE project produced new estimates of intangibles for EU27 countries and Norway following the approach of Corrado, Hulten & Sichel (2006) – referred to as CHS. INNODRIVE advanced the CHS approach by developing new data on intangibles at the company level (using both expenditure- and performance-based estimates of intangible capital) – allowing analysis of different types of intangibles and their role in economic performance and growth.

The main findings of this project were the following:

- investment in intangibles (other than R&D) matters for creating value.
- the structure of intangibles differs across countries.
- accumulation of intangible capital promotes labour productivity and well-being.

All data produced at the national level (macroeconomic data and aggregated figures from the micro data) are publicly available on the project's website (www.innodrive.org). INNODRIVE is actively collaborating with other projects underway (in particular the COINVEST project) and with the Conference Board in the US, in order to build up a consistent picture of intangible capital in the EU27, Norway and the US.

8. Conclusions

This paper has surveyed the various measurement approaches for assessing the contribution of innovation to productivity. Conceptually there are two major methodologies: the first associates all residual multi-factor productivity (MFP) growth to innovative activity, and therefore constitutes an output measure. The second assumes a normal rate of return for innovation investment and computes the input contribution to multi-factor productivity growth made by such investments. The paper reviewed the evidence and concluded that MFP and it growth are indeed related to innovative activities as reported on the Community Innovation Surveys. This results suggests that MFP growth, as measured by a growth accounting approach such as that used by the KLEMS project, could serve as an indicator of innovation.

One problem with MFP growth as a measure is that it tends to fluctuate in the short term with the business cycle and other factors, so it is better examined over a medium term horizon. Figure 4 shows the annualized 5 year growth rates for three recent periods (1995-2000, 2000-2005, 2005-2010) for a number of OECD economies.[17] During the 1995-2000 period, the highest ranked countries were Ireland, Korea, Finland, and Portugal, whereas during the most recent period the leading countries were Korea, Austria, the Netherlands,

[17] The data source is the OECD multi-factor productivity series from their Statistics website, downloaded in October 2011.

Portugal, the US, and the UK. With the possible exception of Portugal, these results do not seem unreasonable, but they do exhibit a certain level of volatility.

The requirements for a good indicator were outlined in the first report by this group. No single indicator is capable of satisfying them all, but an MFP measure does a reasonable job of satisfying many of them. The requirements and the qualifications of an MFP measure with respect to those requirements are the following:

1. **Simple and understandable.** Although this can be debated, MFP is conceptually simple if not easy to measure – it expresses how much output is attained by a particular firm, region, or country given its input in terms of labor and capital. Its growth measure the improvement achieved.
2. **Sizable and direct.** MFP is broad, and with the exception of unpriced goods related to the quality of life (the environment, etc.), it includes the whole economy.
3. **Objective**. As a well-defined concept that has been used for many years and is produced by national statistical agencies, it is an objective measure.
4. **Presently computable**. It is being computed at present by most OECD economies, and the world KLEMS project is spreading this to other countries.
5. **Stable**. The measure itself is stable in definition. If one is to use MFP growth, achieving some stability requires averaging over the business cycle.
6. **Internationally comparable**. Yes.
7. **Decomposable.** This measure is highly decomposable to regions and sectors.
8. **Low susceptibility to manipulation**. See ”objective.”
9. **Easy to handle technically**. As the product of national statistical agencies for other purposes, it is well-understood by them.
10. **Sensitive to stakeholder's views**. It is an output measure par excellence, as it measures the bottom line of the measured economy.

Thus we can conclude that multi-factor or total factor productivity growth could serve as a reasonable measure of successful innovation of (almost) all kinds in the economy, and at multiple levels of aggregation (firms, sectors, regions, member states).

9. Sources

Abramovitz, M. (1956). Resource and Output Trends in the United States since 1870, *American Economic Review* 46 (2): 5-23.

Acs, Z. J., and D. B. Audretsch (1990). *Innovation and Small Firms*. Cambridge, MA: MIT Press.

Aghion, P., R. Blundell, R. Griffith, P. Howitt, and S. Prantl (2009). The effects of entry on incumbent innovation and productivity, *Review of Economics and Statistics* 91(1): 20-32.

Aidis, R., S. Estrin, and T. Mickiewicz (2009). Entrepreneurial Entry: Which Institutions Matter?, Discussion Paper No. 7278. (CEPR, London, UK).

Alesina, A., S. Ardagna, G. Nicoletti, and F. Schiantarelli (2003). Regulation and Investment, NBER Working Paper No. 9560. (NBER, Cambridge, MA).

Allman, K., J. Edler, L. Georghiou, B. Jones, I. Miles, O. Omidvar, R. Ramlogan and J. Rigby (2011). *Measuring wider framework conditions for successful innovation: A system's review of UK and international innovation data,* (London, UK: NESTA). Available at http://www.nesta.org.uk/publications/assets/features/measuring_wider_framework_conditions_for_successful_innovation

Andersson, R., J. M. Quigley, and M. Wilhelmsson (2009). Urbanization, productivity, and innovation: Evidence from investment in higher education, *Journal of Urban Economics* 66: 2-15.

Belderbos, R., M. Carree, and B. Lokshin (2004). Cooperative R&D and firm performance, *Research Policy* 33: 1477-1492.

Benavente H., J. M. (2006). The role of research and innovation in promoting productivity in chile, *Economics of Innovation and New Technology* 15: 301-315.

Blundell, R., and S. R. Bond (2000). GMM Estimation with persistent panel data: an application to production functions, *Econometric Reviews* 19: 321-340.

Brouwer, E., and A. Kleinknecht (1999). Innovative Output, and a Firm's Propensity to Patent. An Exploration of CIS micro data, *Research Policy* 28: 615-624.

Chudnovsky, D., A. Lopez, and G. Pupato (2006). Innovation and productivity in developing countries: A study of Argentine manufacturing firms' behavior (1992-2001), *Research Policy* 35: 266-288.

Ciccone, A., and E. Papaioannou (2006). Red Tape and Delayed Entry, CEPR Discussion Paper No. 5996. (CEPR, London, UK).

Corrado, C., C. R. Hulten, and D. E. SIchel (2006). Intangible Capital and Economic Growth, National Bureau of Economic Research Working Paper No. ____ (NBER Cambridge, MA).

Corsino, M., and R. Gabriele (2011). Product innovation and firm growth: evidence from the integrated circuit industry, *Industrial and Corporate Change* 20: 29-56.

Crepon, B., E. Duguet, and J. Mairesse (1998). Research, Innovation, and Productivity: An Econometric Analysis at the Firm Level, *Economics of Innovation and New Technology* 7: 115-156.

Crespi, G., and P. Zuniga (2010). Innovation and Productivity: Evidence from Six Latin American Countries, IDB Working Paper Series IDB-WP-218. (Inter-American Development Bank, Washington, DC).

Criscuolo, C.,Criscuolo, C., and J. E. Haskel (2003). Innovation and Productivity growth in the UK: evidence from CIS2 and CIS3, CeRiBA Working Paper. (LSE, London, UK).

Denison, E. F. (1966). Discussion of Jorgenson and Griliches, *American Economic Review* 56(1/2): 76-82.

Djankov, S. (2009). The Regulation of Entry: A Survey, *World Bank Research Observer* 24: 183-203.

Djankov, S., R. La Porta, F. Lopez-de-Silanes, and A. Shleifer (2002). The Regulation of Entry, *Quarterly Journal of Economics* 117: 1-37.

Duguet, E. (2006). Innovation Height, Spillovers and TFP Growth at the Firm Level: Evidence from French Manufacturing for Company Performance, *Economics of Innovation and New Technology* 15 (4/5): 415-442.

Fisman, R., and V. Sarria-Allende (2004). Regulation of Entry and the Distortion of Industrial Organization, NBER Working Paper No. 10929. (NBER, Cambridge, MA).

Foster, L., J. Haltiwanger, and C. Syverson (2008). Reallocation, Firm Turnover, and Efficiency: Selection on Productivity or Profitability?, *American Economic Review* 98(1): 394-425.

Freeman, C. and L. Soete (1997). *The Economics of Industrial Innovation*, third edition. (London: Pinter).

Galia, F., and D. Legros (2004). Complementarities between obstacles to innovation: evidence from France, *Research Policy* 33: 1183-1199

Geroski, P. A. (1998). An applied econometrician's view of large company performance. *Review of Industrial Organization* 13: 271-293.

Geroski, P. A. (1989). Entry, Innovation and Productivity Growth, *Review of Economics and Statistics* 71: 572-578.

Griffith, R., E. Huergo, J. Mairesse, and B. Peters (2006). Innovation and Productivity in Four European Countries, *Oxford Review of Economic Policy* 22: 483-498.

Griliches, Z. (1998). *R&D and Productivity: The Econometric Evidence*. Chicago, IL: Chicago University Press.

Griliches, Z. (1996). The discovery of the residual: A historical note*. Journal of Economic Literature* 34(3): 1324-1330.

Griliches, Z. (1994). Productivity, R&D and the Data Constraint, *American Economic Review* 84: 1-23.

Griliches, Z. and J. Mairesse (1984). Productivity and R&D at the Firm Level. In Z. Griliches (ed.), *R&D, Patents, and Productivity*. Chicago, IL: Chicago University Press, 339-374.

Hall, B. H. (2011). Innovation and Productivity, draft of paper for the *Nordic Economic Policy Review*.

Hall, B. H. (1993). Industrial Research during the 1980s: Did the Rate of Return Fall?, *Brookings Papers on Economic Activity* Micro (2): 289-344.

Hall, B. H., A. B. Jaffe, and M. Trajtenberg (2005). Market Value and Patent Citations, *Rand Journal of Economics* 36: 16-38.

Hall, B. H., F. Lotti, and J. Mairesse (2009). Innovation and Productivity in SMEs: Empirical Evidence for Italy, *Small Business Economics* 33: 13-33.

Hall, B. H., F. Lotti, and J. Mairesse (2008). R&D, innovation, and productivity: new evidence from Italian manufacturing microdata, *Industrial and Corporate Change*, 17 (July): 813-839.

Hall, B. H., J. Mairesse, and P. Mohnen (2010). Measuring the Returns to R&D. In Hall, B. H. and N. Rosenberg, *Handbook of the Economics of Innovation*, pp. 1034-1076. Amsterdam and New York: Elsevier.

Hall, R. E. (1988). The relationship between price and marginal cost in U. S. Industry. *Journal of Political Economy* 96 (5): 921-947.

Harhoff, D., F. Narin, F. M. Scherer, and K. Vopel (1999). Citation Frequency and the Value of Patented Inventions, *Review of Economics and Statistics* 81: 511-515.

Haskel, J., P. Goodridge, A. Pesole, G. Awano, M. Franklin, and Z. Kastrinaki (2011). *Driving Economic Growth*, (London, UK: NESTA). Available at http://www.nesta.org.uk/publications/assets/features/driving_economic_growth

Huergo, E., and J. Jaumandreu (2004). Firms' age, process innovation and productivity growth, *International Journal of Industrial Organization* 22: 541-559.

Jaffe, A. B., and K. Palmer (1997). Environmental Regulation and Innovation: A Panel Data Study, *Review of Economics and Statistics* 79: 610-619.

Janz, N., H. Loof, and B. Peters (2003). Firm Level Innovation and Productivity – Is there a Common Story Across Countries? Mannheim, Germany: ZEW Discussion Paper No. 03-26.

Jefferson, G. H., H. Bai, X. Guan, and X. Yu (2006). R&D Performance in Chinese industry, *Economics of Innovation and New Technology* 15: 345-366.

Jorgenson, D. W. (2010). World KLEMS Initiative, special lecture to RIETI, Tokyo, Japan. Available at http://www.rieti.go.jp/en/events/11072601/summary.html

Jorgenson, D. W., and Z. Griliches (1967). The Explanation of Productivity Change, *Review of Economic Studies* 34: 249-283.

Klapper, L., L. Laeven, and R. Rajan (2006). Entry regulation as a barrier to entrepreneurship, *Journal of Financial Economics* 82: 591-629.

Kremp, E., and J. Mairesse (2004). Knowledge Management, Innovation, and Productivity: A Firm Level Exploration Based on French Manufacturing CIS3 Data. Cambridge, MA: NBER Working Paper No. 20237.

Loof, H., and A. Heshmati (2003). The Link between Firm-Level Innovation and Aggregate Productivity Growth: A Cross-Country Examinaion, *Research Evaluation* 12: 131-147.

Loof, H., and A. Heshmati (2006). On the relationship between innovation and performance: A sensitivity analysis, *Economics of Innovation and New Technology* 15: 317-344.

Loof, H., A. Heshmati, R. Asplund, and S.-O. Nåås (2001). Innovation and Performance in Manufacturing Industries: A Comparison of Nordic Countries. Stockholm, Sweden: SSE/EFI Working Paper Series in Economics and Finance No.457.

Mairesse, J., and P. Mohnen (2001). To Be or Not To Be Innovative: An Exercise in Measurement, NBER Working Paper No. w8644. (NBER, Cambridge, MA).

Mairesse, J., and P. Mohnen (2005). The Importance of R&D for Innovation: A Reassessment Using French Survey Data, *Journal of Technology Transfer* 30: 183-197.

Mairesse, J. and P. Mohnen (2010). Using innovation surveys for econometric analysis, in B. H. Hall and N. Rosenberg (eds.), *Handbook of the Economics of Innovation*, Volume II. Amsterdam and New York: Elsevier, pp. 1129-1155.

Mairesse, J., P. Mohnen, and E. Kremp (2005). The Importance of R&D and Innovation for Productivity: A Reexamination in Light of the 2000 French Innovation Survey, in Jacques Mairesse and Manuel Trajtenberg (eds.), Special issue of *Annales d'Economie et de Statistique* 79-80 in Memory of Zvi Griliches: 487-528.

Masso, J., and P. Vahter (2008). Technological innovation and productivity in late-transition Estonia: econometric evidence from innovation surveys*, European Journal of Development Research* 20: 240-261.

Mohnen, P., J. Mairesse, and M. Dagenais (2006). Innovativity: A comparison across seven European countries*, Economics of Innovation and New Technology* 15: 391-414.

Motohashi, K. (2011). Innovation and Entrepreneurship: A first look at linkage data of Japanese patent and enterprise census. Tokyo, Japan: RIETI Discussion Paper Series 11-E-007.

OECD/OCDE (2010b). *Innovation and Firms' Performance: Exploiting the Potential of Microdata* (working title), Paris: OECD, forthcoming.

OECD/OCDE (2010a). *Measuring Innovation: A new perspective*, Paris: OECD

OECD/OCDE (2009). *Innovation in Firms: A Microeconomic Perspective*, Paris: OECD.

OECD/OCDE (2005). *Oslo Manual: Guidelines for collecting and interpreting innovation data*, third edition, Paris: OECD.

OECD/OCDE (2003). *The Sources of Economic Growth in OECD Countries*, Paris: OECD.

Olley, G. S., and A. Pakes (1996). The dynamics of productivity in the telecommunications equipment industry, *Econometrica* 64: 1263-1297.

O'Mahony, M. and M. P. Timmer (2009). Output, Input and Productivity Measures at the Industry Level: the EU KLEMS Database, *Economic Journal* 119(538): F374-F403.

Parisi, M. L., F. Schiantarelli, and A. Sembenelli (2006). Productivity, innovation and R&D: Micro evidence for Italy, *European Economic Review* 50: 2037-2061.

Pavitt, K., M. Robson, and J. Townsend (1987). The Size Distribution of Innovating Firms in the UK: 1945-1983*, Journal of Industrial Economics* 35: 297-316.

Peters, B. (2009). Persistence of innovation: stylised facts and panel data evidence, *Journal of Technology Transfer* 34: 226-243.

Peters, B. (2006). Productivity effects of innovation activities, Chapter 4 of Peters, B., *Innovation and Firm Performance: An Empirical Investigation for German Firms*, University of Würzburg: PhD thesis.

Polder, M., G. Van Leeuwen, P. Mohnen, and W. Raymond (2009). Productivity effects of innovation modes. The Hague: Statistics Netherlands Discussion Paper No. 09033.

Raffo, J., S. l'Huillery, and L. Miotti (2008). Northern and southern innovativity: a comparison across European and Latin American countries, *European Journal of Development Research* 20: 219-239.

Roper, S., J. Du, and J. H. Love (2008). Modeling the innovation value chain, *Research Policy* 37: 961-977.

Roth, F., and A.-E. Thum (2010). Does intangible capital affect economic growth? OECD, Paris: INNODRIVE Working Paper No. 3, September.

Scherer, F. M., and D. Harhoff (2000). Technology Policy for a World of Skew-distributed Outcomes*, Research Policy* 29: 559-566.

Solow, Robert M. (1956). A Contribution to the Theory of Economic Growth, *Quarterly Journal of Economics* 70 (1): 65—94.

Siedschlag, I., Z. Zhang, and B. Cahill (2010). The effects of the internationalisation of firms on innovation and productivity, ESRI Working Paper No. 363 (Economic and Social Research Institute, Dublin, Ireland).

Sterlacchini, A. (1989). R&D, innovations, and total factor productivity growth in British manufacturing, *Applied Economics* 21: 1549.

Tanaka, N., M. Glaude, and F. Gault (2005). *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data*, Paris: OECD and Eurostat.

Timmer, M. P., Inklaar , M. O'Mahony, and B. van Ark (2010). *Economic Growth in Europe*, Cambridge University Press.

UK NESTA (2009). Innovation, Knowledge Spending, and Productivity Growth in the UK. Interim report for NESTA Innovation Index project, London, November.

US National Science Foundation (2010). NSF releases new statistics on business innovation, SRS Info Brief NSF 11-300, Washington, DC, October.

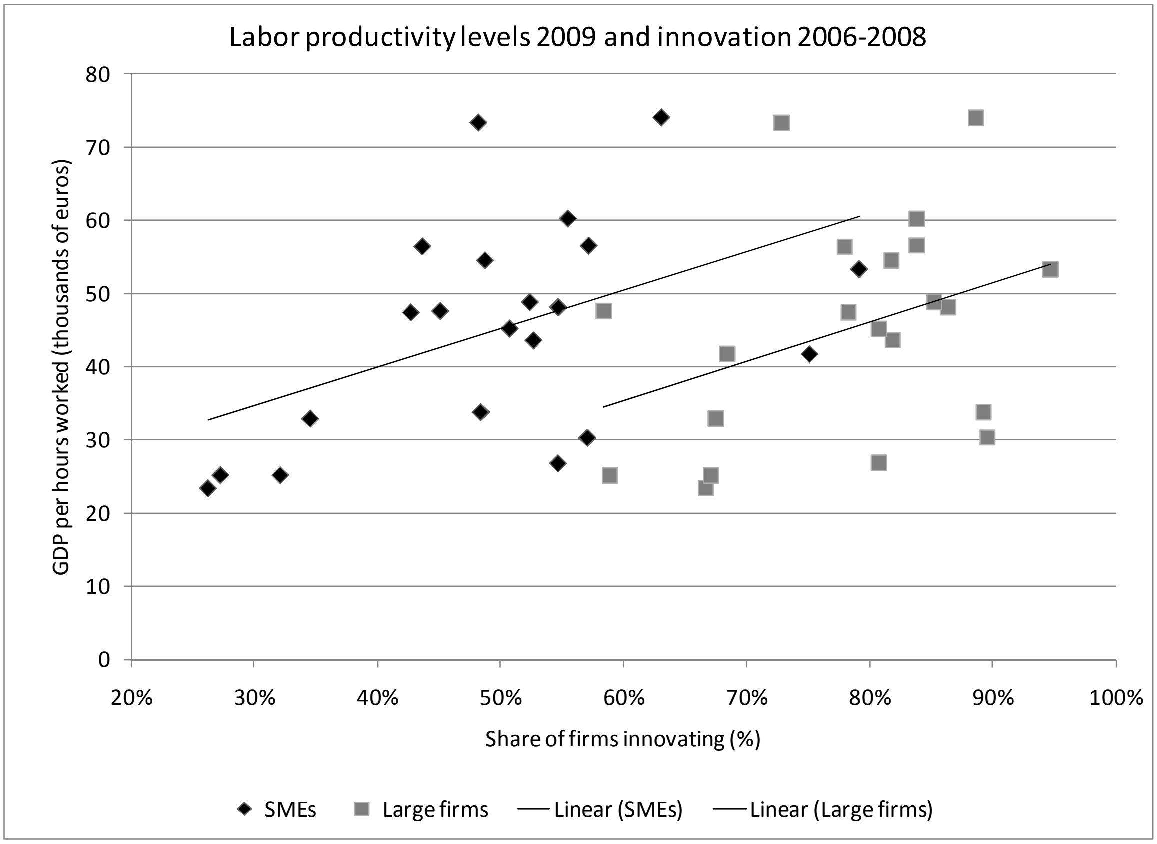
US Dept of Commerce (2009). *Innovation Measurement – Tracking the State of Innovation in the American Economy*. Available at http://www.kauffman.org/uploadedFiles/innovation_measurement_11808.pdf

van Leeuwen, G. (2002). Linking Innovation to Productivity Growth Using Two Waves of the Community Innovation Survey, OECD Science, Technology and Industry Working Papers 2002/8. (OECD/OCDE, Paris).

van Leeuwen, G., and L. Klomp (2006). On the contribution of innovation to multi-factor productivity growth, *Economics of Innovation and New Technology* 15: 367-390.

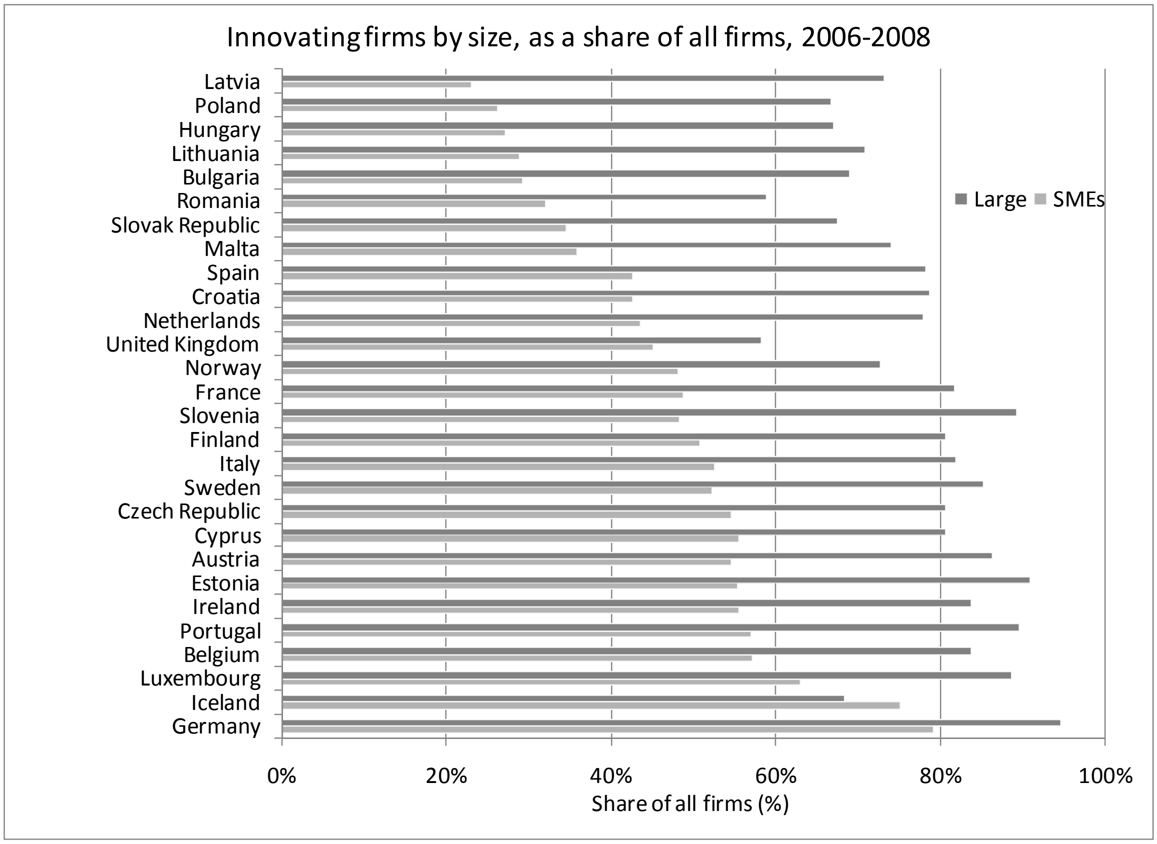
Allman, K., J. Edler, L. Georghiou, B. Jones, I. Miles, O. Omidvar, R. Ramlogan and J. Rigby (2011). *Measuring wider framework conditions for successful innovation: A system's review of UK and international innovation data,* (London, UK: NESTA).

Figure 1: Labor productivity levels and product innovation, by country



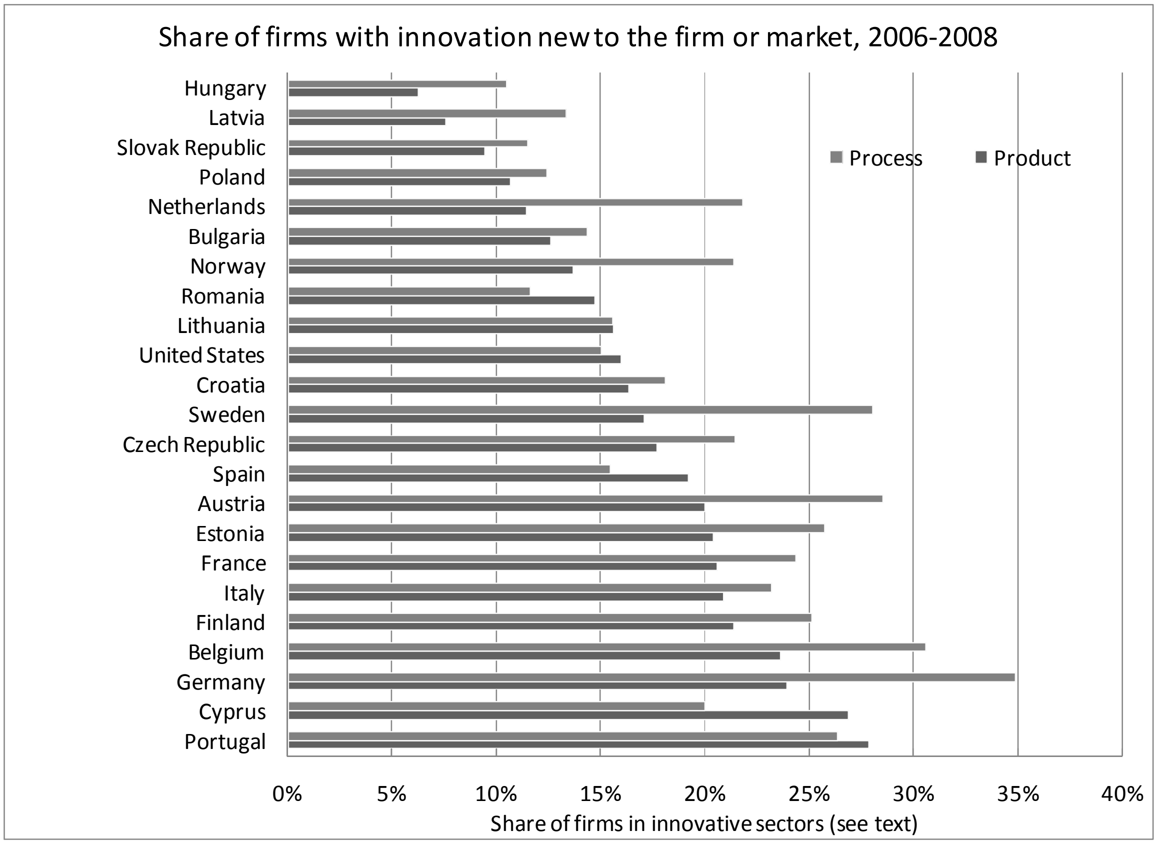
Source: OECD.stat and Eurostat website, CIS 2008, July 2011.

Figure 2: Innovating firms by size, as a share of all firms, 2006-2008



Source: Eurostat website, CIS-2008, July 2011.

Figure 3: Innovating firms by type of innovation, as a share of all firms, 2006-2008



Source: Eurostat website, CIS-2008, July 2011; NSF InfoBrief 11-300, October 2010.

Figure 4

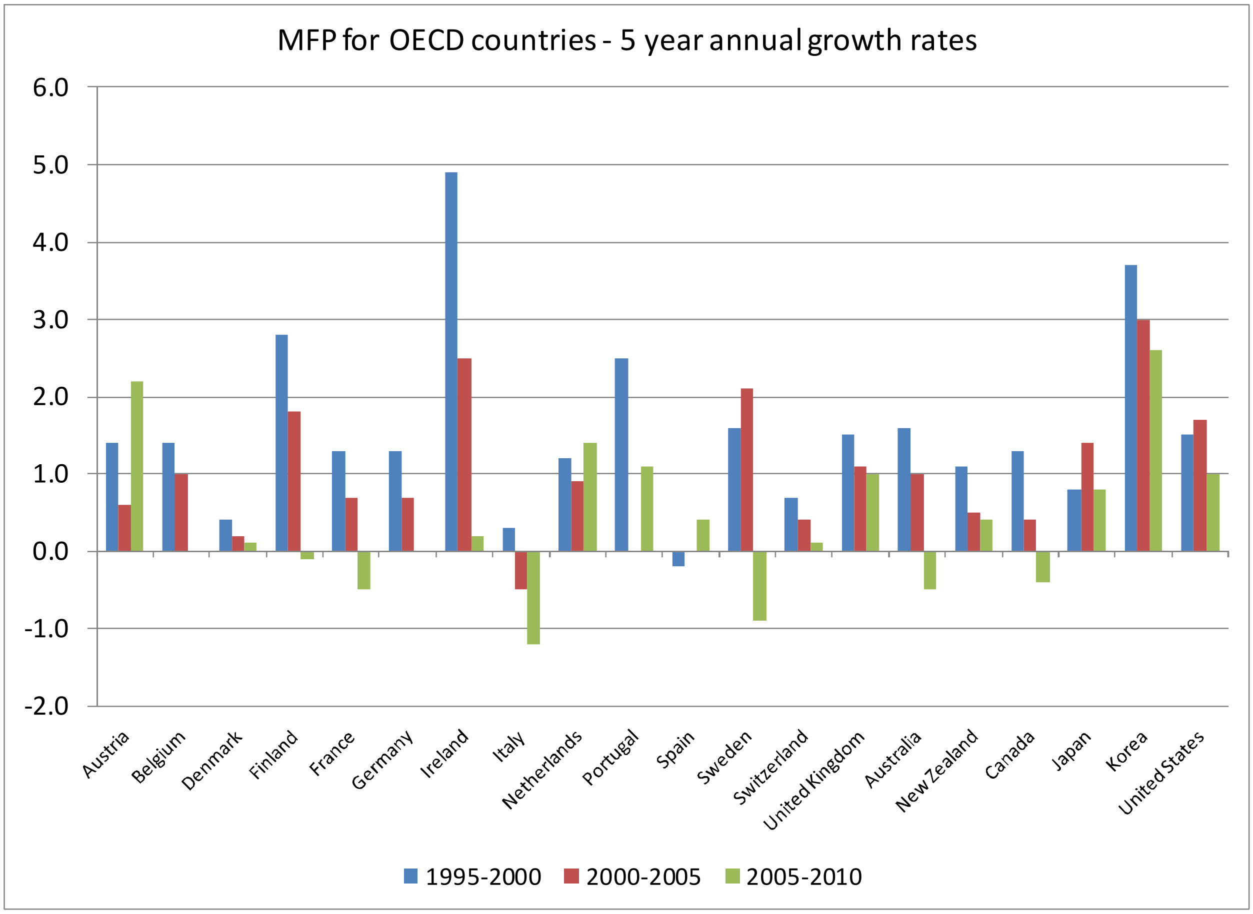

MFP for OECD countries - 5 year annual growth rates
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
Austria
Belgium
Denmark
Finland
France
Germany
Ireland
Italy
Netherlands
Portugal
Spain
Sweden
Switzerland
United Kingdom
Australia
New Zealand
Canada
Japan
Korea
United States
1995-2000
2000-2005
2005-2010

Table 1a: Results for the productivity-innovation relationship in TFP levels

Sample	*Time period*	*Elasticity with respect to innov sales share*	*Process innovation dummy*
Chilean mfg sector	1995-1998	0.18 (0.11)*	
Chinese R&D-doing mfg sector	1995-1999	0.035 (0.002)***	
Dutch mfg sector	1994-1996	0.13 (0.03)***	-1.3 (0.5)***
Finnish mfg sector	1994-1996	0.09 (0.06)	-0.03 (0.06)
French mfg sector	1986-1990	0.07 (0.02)***	
French Hi-tech mfg #	1998-2000	0.23 (0.15)*	0.06 (0.02)***
French Low-tech mfg #	1998-2000	0.05 (0.02)***	0.10 (0.04)***
German K-intensive mfg sector	1998-2000	0.27 (0.10)***	-0.14 (0.07)**
Irish firms #	2004-2008	0.11 (0.02)***	0.33 (0.08)***
Norwegian mfg sector	1995-1997	0.26 (0.06)***	0.01 (0.04)
Swedish K-intensive mfg sector	1998-2000	0.29 (0.08)***	-0.03 (0.12)
Swedish mfg sector	1994-1996	0.15 (0.04)***	-0.15 (0.04)***
Swedish mfg sector	1996-1998	0.12 (0.04)***	-0.07 (0.03)***
Swedish service sector	1996-1998	0.09 (0.05)*	-0.07 (0.05)

Table 1b: Results for the productivity-innovation relationship in TFP levels (product innovation measured as a dummy)

Sample	*Time period*	*Product innovation dummy*	*Process innovation dummy*
Argentinian mfg sector	1998-2000	-0.22 (0.15)	
Brazilian mfg sector	1998-2000	0.22 (0.04***	
Estonian mfg sector	1998-2000	0.17 (0.08)**	-0.03 (0.09)
Estonian mfg sector	2002-2004	0.03 (0.04)	0.18 (0.05)***
French mfg sector	1998-2000	0.08 (0.03)**	
French mfg sector	1998-2000	0.06 (0.02)***	0.07 (0.03)**
French mfg sector	1998-2000	0.05 (0.09)	0.41 (0.12)***
French mfg sector	2002-2004	-0.08 (0.13)	0.45 (0.16)***
French service sector	2002-2004	0.27 (0.52)	0.27 (0.45)
German mfg sector	1998-2000	-0.05 (0.03)	0.02 (0.05)
Irish firms #	2004-2008	0.45 (0.08)***	0.33 (0.08)***
Italian mfg sector	1995-2003	0.69 (0.15)***	-0.43 (0.13)***
Italian mfg sector SMEs	1995-2003	0.60 (0.09)***	0.19 (0.27)
Mexican mfg sector	1998-2000	0.31 (0.09)**	
Spanish mfg sector	2002-2004	0.16 (0.05)***	
Spanish mfg sector	1998-2000	0.18 (0.03)***	-0.04 (0.04)
Swiss mfg sector	1998-2000	0.06 (0.02)***	
UK mfg sector	1998-2000	0.06 (0.02)***	0.03 (0.04)

Source: author's summary from Hall (2011), Appendix Table 1.
Innovative sales share and process innovation included separately in the production function.

Table 2: Results for the productivity-innovation relationship in TFP growth rates

Sample	*Time period*	*Elasticity wrt Innov sales share*	*Product innovation dummy*	*Process innovation dummy*
Argentinian mfg sector	1992-2001		0.09 (0.08)	0.18 (0.08)**
Dutch mfg sector	1994-1998	0.009 (0.001)***		-1.2 (0.7)*
Dutch mfg sector	1996-1998	0.0002*** #		
French mfg sector	1986-1990		0.022 (0.004)***	
German mfg sector	2000-2003	0.04 (0.02)**		0.14 (0.08)* @
Italian mfg sector	1992-1997		0.12 (0.09)	0.04 (0.12)
Spanish mfg sector	1990-1998		0.015 (0.004)***	
Swedish mfg sector	1996-1998	0.07 (0.03)**		
Swedish service sector	1996-1998	0.08 (0.03)***		
UK mfg sector	1994-1996	-0.02 (0.02)		0.02 (0.01)*
UK mfg sector	1998-2000	0.07 (0.03)**		-0.04 (0.02)**

Source: author's summary from Hall (2011), Appendix Table 1.
elasticity with respect to innovation expenditure per sales.
@ elasticity with respect to cost reduction per employee.

Table 3: Labor productivity regressions for CIS 2004

	D (Belonging to a group)	*Log employment*	*D (process innovation)*	*Innovative sales elasticity*	*Number of observations*
Australia	0.120	0.144***	–0.089	0.557***	509
Austria	0.182**	0.011	0.044	0.312***	359
Belgium	0.328***	–0.003	–0.116**	0.447***	718
Brazil	0.183**	0.140***	–0.211***	0.647***	1954
Canada	0.250***	0.0772**	–0.122**	0.436***	2273
Denmark	0.186**	0.0732***	–0.041	0.345***	584
Finland	0.244***	0.0859**	–0.068	0.314***	698
France	0.232***	0.0536***	–0.129***	0.474***	2511
Germany	0.0838**	0.0625***	–0.116***	0.500***	1390
Italy	0.093	0.004	–0.192**	0.485***	747
Korea	0.171***	0.084	–0.083	0.689***	626
Luxembourg	0.434***	0.035	–0.142	0.226*	207
Netherlands	0.022	0.0902***	–0.044	0.409***	1374
New Zealand	0.128**	0.0662***	–0.135***	0.682***	993
Norway	0.256***	0.041	–0.072	0.344***	672
Switzerland		0.113***	–0.091	0.295	394
United Kingdom	0.150***	0.058***	–0.121***	0.550***	2989

Notes:

Source: OECD (2009), Table 3.3.

Results are based on 2004 innovation surveys (CIS 4 for European countries), except for Austria which used CIS 3 data; Australia where the innovation survey has 2005 as the reference year and New Zealand that has a two-year reference period, 2004-05.

Industry dummies and inverse Mills ratio are included but not reported.

For Canada and Brazil the regressions are weighted to the population.

For Australia, the group variable is imputed from responses to the question about whether the enterprise collaborated with other members of their group and is underreported as it omits enterprises that are part of an enterprise group but did not collaborate with other enterprises within the group on innovation projects.

For New Zealand, information on innovation sales is codified as a categorical variable; to transform it to a continuous variable midpoints of each range are used and multiplied by total reported expenditure.

For all countries, except Belgium and Korea, significance levels are reported based on bootstrapped standard errors.

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.