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# INNOVATION AND PRODUCTIVITY: AN UPDATE[τ]

**Pierre Mohnen* and Bronwyn H. Hall****

*Abstract:* This paper reviews the existing evidence regarding the effects of technological and non-technological innovations on the productivity of firms and the existence of possible complementarities between these different forms of innovation.

*Keywords:* Innovation, Productivity
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## 1. Introduction

In the minds of many people, and certainly in the view of most policy makers, innovation is a key factor of economic growth. Innovation can be divided into technological innovations in the form of new products and services and non-technological innovations in the form of organizational or marketing changes. Growth itself can be achieved by putting more factors of production to work (increased investment, use of more land, decrease in unemployment and increase in labor force participation) and by achieving higher levels of output with the same amount of resources (total factor productivity -TFP- growth). Innovation per se does not increase the amount of productive resources, hence it affects growth mainly through TFP. By which channels does innovation affect TFP? What evidence do we have to state that innovation increases TFP? What kind of innovation has the greatest impact on TFP? Is there a complementarity between different forms of innovation? Those questions will be the main object of this paper.

This survey of the literature updates the survey by Hall (2011) on innovation and productivity and complements the Mairesse and Mohnen (2010) survey on the use of innovation surveys to better understand innovation.

The paper is organized as follows. In sections 2 and 3 we define respectively the notions of innovation and productivity, and we discuss the way they are measured. In section 4 we explain how, why and when innovation is likely to affect productivity. In section 5, we describe how the link between innovation and productivity has been modeled in empirical studies. In sections 6 and 7 we discuss the evidence gathered so far regarding the link between innovation and productivity and possible complementarities between different forms of innovation. Section 8 concludes.

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* Maastricht University and UNU-MERIT, Maastricht, The Netherlands. Email: mohnen@merit.unu.edu
** Maastricht University, UNU-MERIT, University of California at Berkeley, and NBER. Email: bhhall@econ.berkeley.edu

## 2. What is Innovation and How is it Measured?

Innovation can be measured by its inputs (the efforts made by firms to come up with new products, new ways to produce their output or to run their business more efficiently and to conquer new markets) or by its output (new products or processes successfully introduced, increases in profits or efficiency). On the input side, the first measure that comes to mind is **R&D**. But performing R&D is not enough to be successful in bringing a new product on the market. **Innovation expenditures** also encompass the acquisition of machinery, equipment and software to produce new products or processes, the purchase or licensing of patents, training related to the introduction of new products or processes, market research, and feasibility studies.

OECD's Oslo Manual (2005) sets the guidelines for the innovation surveys that collect data on innovation outputs, inputs and modalities. On the output side it distinguishes four types of innovation: product, process, organizational and marketing innovation. More formally they are defined as follows: "A **product innovation** is the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses. This includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics. A **process innovation** is the implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software. An **organizational innovation** is the implementation of a new organizational method in the firm's business practices, workplace organization or external relations. A **marketing innovation** is the implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing."[1] As indicated in the Oslo Manual, the borderlines of these definitions can be debatable. Products are to be understood as goods or services. Design changes which do not affect the functionalities or intended uses of the product do not qualify as new products but do qualify as marketing innovations. A new product may require new production technology. A new product can at the same time be a marketing innovation, when the functionalities or uses of the product change but also its external appearance. A new method of producing a good, i.e. a process innovation, may automatically involve a reorganization of work within the enterprise.

Innovation in its different forms can most easily be measured by a dummy variable. But this measure does not adequately measure the extent or intensity of innovation. For product innovation, the extent of innovation within the firm can be measured by the share of total sales that is due to new products. For process innovation, a few countries have chosen to measure the extent of cost reduction brought about by process innovation. For product, and in some countries also for process, innovations a

[1] See OECD (2005), annex B, pp.149-154.

distinction can be made between “new to the firm” or “new to the market”, depending on whether it is new only to the firm but already existing in the market or whether it corresponds to a product or process that did not exist before on the market. “New” can also be articulated as entirely new, substantially improved or marginally improved. It goes without saying that these notions do make economic sense but are difficult to measure in practice. Innovation surveys deliver data that are to a large extent subjective.

There are other forms of innovation that we shall not consider in this brief survey. First, we shall not look into the much used alternative output of innovation, or rather inventive activity, patents, which are used as formal means of protecting intellectual property rights associated with invention. Second, as mentioned in the beginning, innovative effort can also be measured on the input side, by R&D or other innovation expenditures. We shall only look at the relationship of the innovation output measures to productivity.[2] Third, innovations can be classified according to the initiator of the innovation: the public sector (public innovations), the user (user innovations), and innovations introduced by communities, which are often user innovations based on traditional knowledge, called “grassroot innovations”. Other ways to categorize innovations are as innovations in the way society is organized (social innovations), innovations for the poor, also denominated as “inclusive innovations” or “pro-poor innovations”, and finally innovations with an environmental objective (environmental innovations). We shall only include those innovations if they appear in the form of one of the four innovations we have mentioned in the previous paragraph.

## 3. What is Productivity and How is it Measured?

Suppose you had only one input, labor (L), to produce a certain amount of production (Q). Production would increase if more labor was hired and put to work. But it could also increase if labor was used more efficiently or if a new technology was adopted that raised the amount of output per labor, so-called labor productivity. Likewise with multiple factors of production, more could be produced by putting more units of each factor to work or by increasing the amount produced with the same amount of inputs. Again it could be due to a change in efficiency, which could partly be due to a substitution between inputs, e.g. a higher capital/labor ratio, or the adoption of a new technology. In a multi-input, multi-output context, productivity is defined as the ratio of an index of output over an index of input.

A first difficulty in measuring productivity is how to construct these indexes. The basic idea is that each factor gets a weight corresponding to its individual contribution, so that a more productive factor gets a higher weight than a less productive factor. If we knew the exact functional form of

[2] For a recent survey of the relationship between R&D spending and productivity, see Hall *et al.* (2010).

the production function, we could construct exact indexes (Diewert, 1976). These individual contributions can either be estimated econometrically or, if we can assume that markets are competitive, factors are always adjusted to their optimal levels and returns to scale are constant, the individual factor returns can be approximated by their factor prices normalized by the price of output.

### *3.1. How Can Productivity Increase?*

A first explanation lies in the exploitation of scale economies, the output expanding more than the inputs. A second explanation is the presence of unused capacity utilization. If some machines stay idle or there is temporarily excess labor, then production can partially be increased without hiring additional inputs. This situation refers to the cyclical nature of productivity and the presence of rigidities in input markets (labor hoarding, indivisibilities in capital stock, adjustment costs, time to build). A third explanation is technological change, i.e. new ways of producing old things requiring overall less input per unit of output. This outward shift of the production frontier corresponds to a new best practice. But firms can also get closer to the best practice by investing in new machines or by adopting new management techniques, something that in the literature is termed change in efficiency (Farrell, 1957).

### *3.2. The Measurement or the Estimation of Productivity*

The measurement or the estimation of productivity is full of challenges. Besides the issues of assigning a different marginal return to every input, depending on its quality (e.g. distinguishing workers by their skill levels), or the issue of separability between primary and intermediate inputs (i.e. bringing the non-separability between value added and intermediate inputs into the picture), there are two main measurement challenges that are particularly related to innovation. One is the incorporation of quality changes. If the output quality improves without fully showing up in the price statistics, then nominal output gets deflated too much when using an industry-wide output deflator. In this case, the quality improvement shows up as increases in revenue (price times quantity) but not as increases in real output. The same can be said on the input side. If for instance ICT equipment, which underwent huge quality improvements in the last twenty years, still gets deflated at the old prices that do not include quality adjustments, then input is undervalued and hence TFP in the using sector overestimated. So the choice to quality adjust the price of ICT affects the allocation of productivity gains between the producing and using sectors. The other challenge has also to do with prices but not as they relate to quality but as they relate to non-competitive pricing. Typically, innovators have for some time a market-power position that allows them to sell their products or services at above competitive prices, as in monopolistic competition, and hire some of their inputs, e.g. high-skilled labor, at below competitive prices, as in monopsonistic competition. Again, if output deflators are undervalued and input deflators overvalued, then part of productivity reflects price effects (see for instance Dobbelaere and Mairesse, 2010).

## 4. How does Innovation Affect Productivity?

Putting a **new product** on the market creates a new source of demand, which can give rise to scale economies in its production or to improved productivity because its production requires less of the inputs than the old products, although now we are already implicitly assuming a new production process or technology for the production of the new product. The new products may of course cannibalize the business and the profits made from producing the old products when the new products replace and drive out the old products from the market. The contrary may happen when the new products are complementary to the existing products. It is possible that selling the new products in parallel to the old products may lead to economies of scale in the distribution of the goods on the market. It may also be that at the beginning productivity declines, and afterwards it improves as the firm moves down the learning curve. Among the new products launched, some may be more successful than others, because they satisfy an immediate or latent need for the customers, or they benefit from a me-too snowball effect, or they nicely complement some other newly introduced product or service on the market.

**Process innovation** is a priori expected to have a clearer positive effect on productivity as new processes are often introduced in order to reduce production costs by saving some of the more costly inputs (often labor). Besides the direct effects on productivity, innovations can also have indirect effects, as when an initial productivity improvement leads to a price reduction, which, if demand is sufficiently price responsive, leads to a more than proportional increase in sales, which can create additional productivity improvements in the presence of returns to scale. The extent to which the unit cost reductions get translated into a price decrease depends on the extent of competition in the market, which can itself be a function of how important the innovation is.

The importance of a given product innovation can also be measured by the **degree of novelty**. A product new to the firm but not to the market can be regarded as a minor innovation, some would even qualify it as an imitation, whereas a product new to the market represents a more drastic innovation. In some surveys, like the Canadian survey, separate geographic markets are considered, like the provincial, national, North-American and world markets. A new to the market product has a larger potential for success. If it can be sold rapidly on a large market and if it corresponds to customer needs in all parts of that large market, by its sheer size it can benefit from scale effects and improve productivity. Competition, however, is likely to be stronger on the world market than on a local market and so is the danger of imitation. It is thus not immediately clear whether the scale effect or market power and appropriability effects dominate.

The success of a product on the market may depend on the quality of the associated marketing or on the (re)training of workers that produce the product. The productivity effects of innovation may therefore depend on the simultaneous presence of various types of innovation and it is interesting to investigate the presence of **complementarity** between different innovation modes.

## 5. Modeling the Link between Innovation and Productivity

Most of the models that have estimated the impact of innovation on productivity have done so within the so-called Crépon *et al.* (1998) – **CDM** – model. This model is generally presented as a recursive system of three blocks of equations. A first block explains the determinants of the probability to do R&D and of the intensity of R&D:

$$r_1 = 1[r_1^* > 0] \text{ where } r_1^* = \boldsymbol{X}_1\boldsymbol{\beta}_1 + \varepsilon_1$$
$$r_2 = r_2^* = \boldsymbol{X}_2\boldsymbol{\beta}_2 + \varepsilon_2 \text{ if } r_1^* > 0 \text{ and zero otherwise}$$

where $r_1$ is the indicator variable indicating whether there is R&D or not, $r_2$ is the intensity of R&D, $\boldsymbol{X}_1$ and $\boldsymbol{X}_2$ are vectors of explanatory variables and the ε's are the error terms.[3]

A second block explains the determinants of the probability to be innovative, in one way or the other, and the extent of product innovation (and/or process innovation if the data permit), R&D being one of those determinants:

$$i_1 = 1[i_1^* > 0] \text{ where } i_1^* = \boldsymbol{W}_1\boldsymbol{\gamma}_1 + \eta_1$$
$$i_2 = i_2^* = \boldsymbol{W}_2\boldsymbol{\eta}_2 + \eta_2 \text{ if } i_1^* > 0 \text{ and zero otherwise,}$$

where $i_1$ is the indicator variable indicating whether there is innovation output or not (e.g. product innovation), $i_2$ is the intensity of innovation output, $\boldsymbol{W}_1$ and $\boldsymbol{W}_2$ are vectors of explanatory variables, one component of which is $r_1^*$ or $r_2^*$, or their observed equivalent, and the η's are the error terms.

Finally the productivity equation depends on innovation output ($i = i_1^*$ , $i_2^*$ , $i_1$ or $i_2$), besides other explanatory variables **Z** (like physical capital intensity):

$$\frac{Q}{L} = \boldsymbol{Z}\mu + i\phi + u.$$

Generally, there is no feedback from productivity to R&D or to innovation, the model is static, it is estimated on cross-sectional data, the productivity is estimated in levels, and R&D does not enter productivity

[3] For simplicity we ignore the individual or time subscript.

directly.[4] When R&D and innovation are only measured as dichotomous variables, it is the incidence and not the intensity of innovation then enters the productivity equation.

The interesting feature of the **CDM model** is that it handles some of the endogeneity of R&D and innovation, in the innovation and productivity equations respectively, and that it explicitly models the selectivity of R&D performers and/or innovators. As far as the estimation is concerned, there is the usual tradeoff between efficiency and robustness to misspecification. The original model was estimated by asymptotic least squares, or minimum distance estimator, where all equations are estimated jointly. Even more information is exploited when the model is estimated by maximum likelihood with given distributions for the random part of the model. Most studies have opted for a sequential approach, where the predicted value of one endogenous variable enters the estimation of the next equation, with due account for the calculation of the standard errors and the inclusion of a correction factor for potential selection bias. Hall *et al.* (2009) and Musolesi and Huiban (2010) do not report a great difference in the estimation results when comparing a sequential IV estimation with a maximum likelihood estimation approach. As long as the endogeneity and selection are somehow treated, the results are rather robust to the estimation method. But, as illustrated in Mairesse *et al.* (2005), when endogeneity or selectivity are not corrected for, the significance of the estimated parameters drops tremendously, pointing to an error in variables problem, probably related to the subjectivity of the answers to some of the questions that generated the data, rather than a simultaneity problem.

## 6. Technological versus Non-Technological Innovation

Our first interest is to investigate the size of the elasticity of productivity (labor or total factor) with respect to the intensity of innovation. Most innovation surveys measure the intensity or the success of product innovation by means of the share of new products in total sales, i.e. the proportion of total sales that is due to products launched in the last three years (according to the Oslo Manual).[5] Some innovation surveys, such as the Swiss innovation survey, also try to capture the intensity of process innovation by asking the percentage of cost reductions due to process innovations made in the last three years. The other types of innovation are only captured by dummy variables, given the difficulties of measuring their specific contribution to output.

Table 1 summarizes a number of empirical studies that have estimated the **elasticity of productivity with respect to the intensity of product innovation**. The elasticities are, but for one case, positive and in

[4] These limitations reflect the limitations of the usual innovation surveys, which draw a new sample for each edition, precluding any panel data analysis.
[5] In the annual industrial survey organized by the China National Bureau of Statistics new product sales cover the products introduced in the year covered by the survey.

most cases significant. The magnitude of the elasticity varies, but it is not uncommon to find elasticities of the order of 0.25, implying that if innovative sales per employee go up by 10%, labor productivity rises by 2.5%. The magnitudes are lower and more volatile when the elasticity concerns the share of total sales due to new products instead of sales of new products per employee. They also tend to be lower when the growth rather than the level of productivity is estimated and when skilled labor or human capital is controlled for (Crépon *et al.* 1998; Criscuolo, 2009). In the only case where the elasticity had a negative sign (in Roper *et al.* 2008) knowledge capital utilization in the form of skilled labor was controlled for. Therrien and Hanel (2009) in their report of a few extensions of the core OECD model also remark that the introduction of human capital, physical capital and the use of value added per employee rather than sales per employee tend to reduce the productivity elasticity of output. This result suggests an identification problem between innovation and other measures of knowledge capital and physical capital. In the countries where services sector data were available, the OECD study led by Criscuolo (2009) reports that the effect was generally higher for manufacturing than for services firms with the notable exceptions of Germany and New Zealand. Lööf and Heshmati (2006) and Mairesse *et al.* (2005) do not find a significant difference in the elasticity of productivity with respect to the intensity of product innovation when they distinguish between products new only to the firm and products new to the market.[6]

Unfortunately, for all other types of innovation – process, organizational and marketing – the only innovation measures available are dichotomous measures. These measures are less satisfactory because first they refer to a three-year period (whereas the intensity refers to the last year of this three-year period) - so it is not clear what the exact timing is -, second they refer to various projects without weighting them by their level of success – blockbusters are mixed with flops - , and third they do not correct for size – it is normal than larger firms with more projects will have a higher chance to be innovative with at least one of them. But nonetheless they should give us some indication of the differential effect of various types of innovation on productivity. We shall in particular distinguish technological (product and process) from non-technological (organization and marketing) innovations.

[6] For Lööf and Heshmati (2006), see their table X. These results are not reported in our Table 1.

## Table 1. Studies on innovation and productivity using a continuous measure of product innovation

| *Authors (year)* | *Country* | *Observations* | *Estimation method* | *Output measure* | *Innovation measure* | *Impact of innovation+* | *Additional comments* |
|---|---|---|---|---|---|---|---|
| Crépon *et al.* (1998) | France | 4164 manufacturing firms, 1986-1990 | ALS | Log value added per employee | Log share of innovative sales | 0.104*** (0.016)<br><br>0.065*** (0.015) | Control for capital stock/employee;<br>+ control for labor skill |
| Lööf *et al.* (2003) | Finland<br><br>Norway<br><br>Sweden | 353 mfg firms, 1994-1996<br>485 mfg firms, 1995-1997<br>407 mfg firms, 1994-1996 | 3SLS | Log sales per employee | Log innovative sales per employee | 0.090 (0.058)<br><br>0.257*** (0.062)<br><br>0.148*** (0.044) | Control for process innovation dummy |
| Janz *et al.* (2003) | Germany<br><br>Sweden | 352 firms, 1998-2000<br>206 firms, 1998-2000<br>(in knowledge-intensive manufacturing) | Sequential IV + IMR | Log sales per employee | Log sales income from product innovation per employee | 0.268*** (0.100)<br><br>0.290*** (0.084) | Control for process innovation dummy |
| Mairesse *et al.* (2005) | France | 889 firms in HT sectors, 1998-2000<br>1354 firms in LT sectors, 1998-2000 | ALS | Log sales per employee | Logit transformation of share of innovative sales | 2.03<br><br>0.52** | Control for capital stock and materials per employee |
| Benavente (2006) | Chile | 438 manufacturing plants,1995-1998 | ALS | Log Value added per employee | Log share of innovative sales per employee | 0.179* (0.113) | Control for capital stock/employee |
| Lööf and Heshmati (2006) | Sweden | 1974 manufacturing firms, 1996-1998<br><br>1081 service firms, 1996-1998 | 3SLS + IMR | Log value added per employee | Log innovation sales per employee<br><br>Growth rate innov. sales per employee | 0.121*** (0.043) manuf.<br>0.093** (0.047) Services<br><br>0.070 *** manuf.<br>0.080** services | Control for process and organizational innovation |
| van Leeuwen and Klomp (2006) | Netherlands | 1926 firms, 1994-1996 | 3SLS | Growth of sales per employee | Log innovative sales per employee | 0.133*** (0.026) | Innovation not significant in growth of VA per employee |
| Jefferson *et al.* (2006) | China | 5451 large and medium sized mfg firms, 1995-1999 | Sequential IV | Log gross output | Log share of innovative sales | 0.035*** (0.002) | Control for capital stock and materials |
| Roper *et al.* (2008) | Ireland and Northern Ireland | Panel of 1620 observations over 4 innovation survey waves, 1991-2002 | Sequential IV | Value added per employee | Share of innovative sales | -0.302*** (0.067) | Control for process innovation dummy, labor skill |
| Criscuolo (2009) | 17 OECD countries | Micro data, 2002-2004, except for Austria (1998-2000), Australia (2003-2005), New Zealand (2004-2005) | Sequential IV | Log sales per employee | Log innovative sales per employee | Between 0.3 and 0.7 (mostly ***) | Control for process innovation dummy |

**Table 1. Continued**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Siedschlag *et al.* (2010) | Ireland | Panel of 723 firms over two CIS waves, 2004-2008 | Sequential IV | Log sales per employee | Log innovative sales per employee | 0.093*** mfg<br>0.098*** services | |
| Mairesse *et al.* (2012) | China | 13245 firms in 4 industries in 2005 and 2006 | Sequential IV | Log sales per employee | Log innovative sales per employee | Between 0.246*** and 1.119*** | Estimated separately for each industry |
| Raymond *et al*. (2012) | France and<br>Netherlands | Panel data, three waves of innovation surveys: 1994-96, 1998-2000, 2002-04; 2505 observations in France and 1639 in Netherlands | Maximum likelihood | Log sales per employee | Logit transformation of share of innovative sales | From 0.043*** to 0.107*** in France<br>From 0.045*** to 0.197*** in the Netherlands | Similar results when using observed or latent occurrence or intensity |

When more than one figure was reported, we took the preferred estimates, as reported by the authors. ALS stands for asymptotic least squares, IV for instrumental variables, IMR for inverse Mill's ratio; + standard errors in parentheses; mfg stands for manufacturing; ***significant at 1%; **significant at 5%; *significant at 10%

Table 2 summarizes those pieces of work that have estimated **semi-elasticities of productivity with respect to innovation dummy variables**.[7] The first thing to note is that, when estimated separately (i.e. without the other innovation dummy and without the intensity of innovation), process or product innovations are significant (see Mairesse *et al.* 2005; Parisi *et al.* 2006; Raffo *et al.* 2008, and Siedschlag *et al.* 2010). When innovation intensity is controlled for, it often happens that the coefficient of process innovation is negative and significantly so (Janz *et al.* 2003; Lööf and Heshmati, 2006; van Leeuwen and Klomp, 2006; Criscuolo, 2009). When product and process innovation dummies appear together, their coefficients often turn out non-significant, and if one of the two is significant it is more often product innovation (Griffith *et al.* 2006; Mairesse and Robin, 2008; Musolesi and Huiban, 2010). There seems to be again an identification problem there. The stronger measure of innovation (the intensity of product innovation) dominates the more noisy process innovation dummy. It could also be argued, see Hall (2011) that product innovations create a market power effect that increases the revenue measure of output, whereas efficiency improvements from process innovations may not show up in the revenue figures if they result in lower prices without corresponding increases in output (at least in the short run). Another identification problem could be due to the fact product and process innovations often appear together and that only their joint effect is the most visible (see Hall *et al.* 2009 and to some extent Chudnovsky *et al.* 2006).

Masso and Vahter (2008) have compared the productivity effect of various kinds of innovation occurring during a three-year period on the productivity observed at the end of that period and one or two periods ahead. Results are not significantly different. But, Huergo and Jamandreu (2004), in their preferred specification of TFP growth on age and process innovation on a panel of Spanish firms between 1990 and 1998, find that the process innovation dummy increases TFP growth by 1.5% the year of implementation followed by a three year long lower TFP increase, and then a strong TFP decline if no new process innovation takes place. Raymond *et al.* (2012) allow for persistence in innovation and productivity and for a feedback from productivity on product innovation (occurrence or success). They find signs of a Granger causality from past innovation on current productivity but not from past productivity on current innovation.

[7] Some early studies on innovation and productivity have used the number of innovations from the SPRU database. Sterlacchini (1989) obtained on a panel of 15 Italian manufacturing industry data a coefficient of 0.08 (0.04) for the number of innovations produced in a long-run TFP growth regression but no significant coefficient for the number of innovations used. Geroski (1989) reports a coefficient of 0.025 (0.010) for the number of innovations introduced in the last three years on a panel of 79 UK industries.

**Table 2. Studies on innovation and productivity using dummy variables for various kinds of innovation**

| Authors (year) | Country | Observations | Estimation method | Output measure | Innovation dummies | Impact of innovation | Additional comments |
|---|---|---|---|---|---|---|---|
| Janz *et al*. (2003) | Germany<br>Sweden | 352 firms, 1998-2000<br>206 firms, 1998-2000 (from knowledge-intensive manufacturing) | Sequential IV + IMR | Log sales per employee | Process | -0.136 ** (0.069)<br>-0.030 (0.119) | Innovation intensity is controlled for |
| Huergo and Jaumandreu (2004) | Spain | Panel 2300 firms 1990-98 | Non-parametric | Solow residual TFP growth | Process | 0.015 *** | Positive immediate effect that declines afterwards and become <0 after 3 years without new innovation |
| Mairesse *et al.* (2005) | France | 889 firms in HT sectors, 1998-2000<br>1354 firms in LT sectors, 1998-2000 | ALS | Log sales per employee | Product new to firm<br>Product new to market<br>Process | 0.031*** HT<br>0.051 *** LT<br>0.047 *** HT<br>0.050 *** LT<br>0.063 *** HT<br>0.097 ** LT | Introduced separately |
| Lööf and Heshmati (2006) | Sweden | 1974 manufacturing firms, 1996-98<br>1081 services firms, 1996-98 | 3SLS + IMR | Log value added per employee | Process<br>Organizational | -0.071 *** mfg<br>-0.071 services<br>-0.027 mfg<br>-0.069 services | Innovation intensity is controlled for |
| Parisi *et al.* (2006) | Italy | 465 manufacturing firms, 1992-1997<br>459 manufacturing firms, 1992-1997 | Sequential IV<br>Sequential IV | labor productivity growth<br>TFP growth | Product<br>Process<br>Product<br>Process | 0.08 (0.054)<br>0.14 (0.054)***<br>0.13 (0.069)*<br>0.15 (0.047)*** | 3 period growth rates; when both are introduced, they often turn non-significant |
| Duguet (2006) | France | 4085 mfg firms, 1986-1990 | ALS and GMM | TFP growth | Radical and incremental product innovation | 0.022 (0.004)** for radical<br>-0.01 (0.01) for incremental | |
| van Leeuwen and Klomp (2006) | Netherlands | 1926 firms, 1994-1996 | 3SLS | Growth of sales per employee | Process | -1.256 (0.471)*** | Control for capital/employee and for share of innovative sales |
| Griffith *et al.* (2006) | France<br>Germany<br>Spain<br>UK | 3625 firms, 1998-2000<br>1123 firms, 1998-2000<br>3588 firms, 1998-2000<br>1904 firms, 1998-2000 | Sequential IV | Log sales per employee | Product and process | 0.060*** prod<br>0.069** proc<br>-0.053 prod<br>0.022 proc<br>0.176*** prod<br>-0.038 proc<br>0.055*** prod<br>0.029 proc | |

**Table 2. Continued**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Chudnovsky *et al.* (2006) | Argentina | Panel of 718 mfg firms over 2 innovation survey waves, 1992-1996 , 1998-2000 | Sequential estimation with fixed effects | Log sales per employee | Product only<br>Process only<br>Prod + proc | 0.088 (0.076)<br>0.178 (0.081)**<br>0.136 (0.055)** | |
| Masso and Vahter (2008) | Estonia | 1142 firms, 1998-2000<br>916 firms, 2002-2004 | Sequential IV | Log of value added per employee | Product, process, organization | 0.002 prod<br>0.151*** proc<br>0.097* org | Control for capital intensity; bivariate probit |
| Raffo *et al.* (2008) | France (FR)<br>Spain (ES)<br>Switzerland (CH)<br>Argentina (AR)<br>Brazil (BR)<br><br>Mexico (MX) | Cross-sectional data, 1998-2001, except for Spain (2002-2004) | Sequential IV | Log sales per employee | Product and organization | 0.075***(FR) prod<br>0.156*** (ES) prod<br>0.101* (CH) prod<br>-0.219 (AR)prod<br>0.220*** (BR)prod<br>0.054***(BR)org<br>0.313***(MX)prod | Organizational dummy significant only for Brazil |
| Roper *et al.* (2008) | Ireland and Northern Ireland | Panel of 1620 observations over 4 innovation survey waves, 1991-2002 | Sequential IV | Value added per employee | Product<br>Process | 0.011 (0.031)<br>0.008 (0.030) | Control for innovation success, labor skill, capital intensity |
| Mairesse and Robin (2008) | France | 3524 manuf firms, 1998-2000<br>4955 manuf firms, 2002-2004<br>3599 services firms, 2002-2004 | Maximum likelihood | Log value added per employee | Product and process | 0.14 *** product<br>0.02 process<br>0.13 *** product<br>-0.02** process<br>0.17*** product<br>-0.01 process | Bivariate probit |
| Hall *et al*. (2009) | Italy | 9674 firm-year observations, panel of 10 years, mostly SMEs, 1992-2003 | Sequential IV | Log sales per employee | Product and process | 0.193 (0.267) process only<br><br>0.597*** (0.093) product | Bivariate probit; process innovation becomes non-significant if investment/employee is included (reported figures); without investment included, process innovation dominates |
| Musolesi and Huiban (2010) | France | 416 knowledge intensive business service firms, 1998-2000 | Maximum likelihood | Log value added per employee | Product<br>Process<br>Technolog.<br>Non-technolog. | 0.324***(0.124)<br>0.131 (0.198)<br>0.210* (0.117)<br>0.271 (0.194) | Has also been estimated by 2SLS, and IV |
| Criscuolo (2009) | 17 OECD countries | Micro data, 2002-2004, except for Austria (1998-2000), Australia (2003-2005), New Zealand (2004-2005) | Sequential IV | Log sales per employee | process | <0 or non-significant | Control for continuous product innovation |
| Siedschlag *et al.* (2010) | Ireland | Panel of 723 firms over two CIS waves, 2004-2008 | Sequential IV | Log sales per employee | . Product<br>. Process<br>.Organization | Mfg services<br>0.257** 0.609***<br>0.213** 0.450***<br>0.373***1.058*** | Not estimated jointly |

***significant at 1%; **significant at 5%; *significant at 10%; not all estimation results are always reported.

Masso and Vahter (2008) report that they do not find a significant difference in the innovation semi-elasticities when measuring productivity in terms of sales per employee or value added per employee, and that the effect of the various forms of innovation tend to be non-significant if the dependent variable is productivity growth. Duguet (2006) reports that only new-to-the-market product innovations have a significant effect on TFP growth.

Greenan and Guellec (1998) have shown that what we would now call organizational and marketing innovations had a positive effect on total factor productivity in a cross-section of French firms in 1987. Black and Lynch (2004) show that workplace innovations like reengineering, incentivizing, profit-sharing, have raised total factor productivity in US manufacturing establishments between 1993 and 1996. A few recent studies (Masso and Vahter, 2008; Polder *et al.* 2009; Musolesi and Huiban, 2010) have introduced the organizational or non-technological innovation dummies in productivity regressions. The results are similar to those obtained for product and process innovations, and the same critical remarks apply.

## 7. Complementarity between Different Types of Innovation

A new product may require a new way of producing it with lighter materials but a need for more precision instruments in the fabrication of the new product. Product innovations may thus often be combined with process innovations. New production processes in turn may raise productivity only if they are combined with a reorganization of work. On the one hand, ICT allows more decentralized decision making but also requires a higher degree of integration of the different activities, for instance through the use of an enterprise resource planning software (see Bresnahan *et al.* 2002; and Crespi *et al.* 2006). The introduction of a new way of producing a given product or service may thus need to be accompanied by an organizational innovation. The success of a new product or process on the market may depend on the quality of advertising, the speed in bringing it to the market, efficiency in its distribution, and after-sales service. In other words, product innovations may be more successful if complemented by marketing innovations.

Complementarity between two or more variables (often called strategies) can be tested by checking whether the demand for one increases in the presence of the other one (at least in the case of two variables)[8] or whether the joint use of two or more variables leads to a higher performance. In the latter case, a performance measure needs to be chosen. In the former case, the source of the complementarity remains unexplained. It is important, whenever possible, to correct for time-invariant

[8] In the case of more than two variables, the interdependence between all the variables needs to be taken into account.

individual effects so as not to attribute the complementarity to individual time invariant characteristics.

Martinez-Ros and Labeaga (2009) find evidence of complementarity between **product and process innovations** in Spanish manufacturing correcting for unobserved individual time-invariant heterogeneity. Product (process) innovation in one year increases if process (product) innovation occurred in the previous year. Miravete and Pernías (2006) found evidence of complementarity between product and process innovation in the Spanish ceramic tile industry.

The study of complementarity has been extended to organizational innovations. Ballot *et al.* (2011) for the UK and France, and Polder *et al.* (2009) for the Netherlands test the existence of pairwise and full complementarities between **product, process and organizational innovations**. Full complementarity is never obtained and the complementarity between pairs of strategies depends on the country examined, and, as shown by Ballot *et al.* (2011), it is contingent on the size of the firms and their knowledge intensity. Product and process innovations are found complementary in all three countries, product and organizational innovations in France, and process and organizational innovations in the UK and the Netherlands. In the Netherlands, the synergies were not found to be different for manufacturing and for services firms. Both studies though do not correct for unobserved individual effects.

Schmidt and Rammer (2007) obtain evidence on German firm data that the success with the introduction of market novelties (not of products new to the firm) or with process innovations increases in the presence of organizational and marketing innovations. Polder *et al.* (2009) report that in both manufacturing and services the combinations of innovations that contribute significantly to a higher productivity all involve organizational innovation: organizational innovation only, process combined with organizational innovation, and the combination of all types of innovation.

## 8. Conclusion

We can conclude from this brief survey of the empirical literature on innovation and productivity that innovation leads to a better productivity performance, or to be more precise to a better revenue per employee performance. Some of the effect of innovation goes to real output, and some of it to the price at which the output is sold. In the absence of good individual price measures it is hard to dissociate these two effects.

All four types of innovations considered - product, process, organizational and marketing innovations - contribute to a better productivity performance. Given the imperfect measurement of innovation and the simultaneity of different types of innovation, it is difficult to isolate the individual effect of each. Some complementarity between them seems to exist, even though it is hard to get a good grasp of the exact nexus of complementarities.

To progress in our understanding of the link between innovation and productivity, a few avenues are worth exploring. First, quantitative data are more likely to produce meaningful and robust results than qualitative yes/no data. An effort could be made to construct quantitative data for other than product innovations. Second, as more data become available it would certainly be worth constructing a panel dataset that would allow to correct for unobserved heterogeneity and to examine the dynamic aspects of the relationship. Third, as much as the CDM model was an improvement over the extended Cobb-Douglas production function approach for evaluating the returns to R&D, it would enrich our analysis if we could set up a richer structural model that would include the indirect aspects of innovation on firm performance via price effects and competition. Fourth, it would be interesting to analyze the entry and exit decisions of firms related to innovation as well as the effect of uncertainty. Because of risk, innovation may not just fail to show up in productivity figures but even lead firms to go bankrupt. Finally, in a more macro-economic perspective the market exit, competition and externality effects may yield quite a different picture of the outcome of innovation than the micro-economic partial equilibrium analysis pursued so far.

## References

Ballot, G., Fakhfakh, F., Galia, F., and Salter, A., 2011. The fateful triangle complementarities between product, process and organizational innovation in the UK and France. *TEPP Working Paper*, 2011-5.

Benavente, J.M., 2006. The role of research and innovation in promoting productivity in Chile. *Economics of Innovation and New Technology*, 15(4-5), pp.301-315.

Black, S.E. and Lynch, L.M., 2004. What's driving the new economy?: The benefits of workplace innovation. *The Economic Journal*, 114(493), pp.F97-F116.

Bresnahan, T.F., Brynjolfsson, E., and Hitt, L.M., 2002. Information technology, workplace organization, and the demand for skilled labor: Firm level evidence. *Quarterly Journal of Economics*, 117(1), pp.339-376.

Chudnovsky, D., Lopez, A., and Pupato, G., 2006. Innovation and productivity in developing countries: A study of Argentine manufacturing firms behavior (1992-2001). *Research Policy*, 35(2), pp.266-288.

Crépon, B., Duguet, E., and Mairesse, J., 1998. Research, innovation and productivity: An econometric analysis at the firm level. *Economics of Innovation and New Technology*, 7(2), pp.115-158.

Crespi, G., Criscuolo, C., and Haskel, J., 2006. Information technology, organizational change and productivity growth: Evidence from UK firms. *CEPR Discussion Paper,* 783.

Criscuolo, C., 2009. Innovation and productivity: Estimating the core model across 18 countries. In: OECD, *innovation in firms: A microeconomic perspective*. Paris: OECD Publishing. Ch.3.

Diewert, W.E., 1976. Exact and superlative index numbers. *Journal of Econometrics*, 4(2), pp.115-145.

Dobbelaere, S. and Mairesse, J., 2010. Micro-evidence on rent sharing from different perspectives. *NBER Working Paper*, 16220.

Duguet, E., 2006. Innovation height, spillovers and TFP growth at the firm level: Evidence from French manufacturing. *Economics of Innovation and New Technology*, 15(4-5), pp.415-442.

Farrell, M.J., 1957. The measurement of productive efficiency. *Journal of the Royal Statistical Society. Series A (General)*, 120(3), pp.253-290.

Geroski, P.A., 1989. Entry, innovation and productivity growth. *Review of Economics and Statistics*, 71(4), pp.572-578.

Greenan, N. and Guellec, D., 1998. Firm organization, technology and performance: An empirical study. *Economics of Innovation and New Technology*, 6(4), pp.313-347.

Griffith, R., Huergo, E., Mairesse, J., and Peters, B., 2006. Innovation and productivity across four European countries. *Oxford Review of Economic Policy*, 22(4), pp.483-498.

Hall, B.H., 2011. Innovation and productivity. *Nordic Economic Policy Review*, 2, pp.167-204.

Hall, B.H., Lotti, F., and Mairesse, J., 2009. Innovation and productivity in SMEs: Empirical evidence for Italy. *Small Business Economics*, 33(1), pp.13-33.

Hall, B.H., Mairesse, J., and Mohnen, P., 2010. Measuring the returns to R&D. In: B.H. Hall and N. Rosenberg, eds. *Handbook of the economics of innovation.* Amsterdam: Elsevier, pp.1034-1076.

Huergo, E. and Jaumandreu, J., 2004. Firms' age, process innovation and productivity growth. *International Journal of Industrial Organization*, 22(4), pp.541-560.

Janz, N., Lööf, H., and Peters, B., 2004. Firm level innovation and productivity – Is there a common story across countries. *Problems and Perspectives in Management*, 2, pp.184-204.

Jefferson, G., Bai, H., Guan, X., and Yu, X., 2006. R&D performance in Chinese industry. *Economics of Innovation and New Technologies*, 15(4/5), pp.345-366.

Lööf, H., Heshmati, A., Apslund, R., and Naas, S-O., 2003. Innovation and performance in manufacturing industries: A comparison of the Nordic countries. *International Journal of Management Research*, 2, pp.5-36.

Lööf, H. and Heshmati, A., 2006. On the relationship between innovation and performance: A sensitivity analysis. *Economics of Innovation and New Technology*, 15(4/5), pp.317-344.

Mairesse, J. and Mohnen, P., 2010. Using innovation surveys for econometric analysis. In: B.H. Hall and N. Rosenberg, eds.

*Handbook of the economics of innovation.* Amsterdam: Elsevier, pp.1130-1155.

Mairesse, J., Mohnen, P., and Kremp, E., 2005. The importance of R&D and innovation for productivity: A reexamination in light of the 2000 French innovation survey. *Annales d'Economie et de Statistique*, 79/80, pp.489-529.

Mairesse, J., Mohnen, P., Zhao, Y., and Zhen, F., 2012. Globalisation, innovation and productivity in manufacturing firms: A study of four sectors of China. *ERIA Discussion Paper*, 2012-10.

Mairesse, J. and Robin, S., 2008. Innovation and productivity in France: A firm-level analysis for manufacturing and services (1998-2000 and 2002-2004). In: *SYMPOSIUM on innovation at firm level.* Faculty of Economics and Management, University of Barcelona, Spain 1 July 2008.

Martinez-Ros, E. and Labeaga, J.M., 2009. Product and process innovation: Persistence and complementarities. *European Management Review*, 6(1), pp.64-75.

Masso, J. and Vahter, P., 2008. Technological innovation and productivity in late-transition Estonia: Econometric evidence from innovation surveys. *European Journal of Development Research*, 20(2), pp.240-261.

Miravete, E. and Pernías, J., 2006. Innovation complementarity and scale of production. *Journal of Industrial Economics*, 54(1), pp.1-29.

Musolesi, A. and Huiban, J.P., 2010. Innovation and productivity in knowledge intensive business services. *Journal of Productivity Analysis*, 34(1), pp.63-81.

Organization for Economic Co-operation and Development (OECD), 2005. *Oslo Manual,* 3rd ed. Paris: OECD.

Parisi, M.L., Schiantarelli, F., and Sembenelli, A., 2006. Productivity, innovation creation and absorption, and R&D: Micro evidence for Italy. *European Economic Review*, 50(8), pp.2037-2061.

Polder, M., van Leeuwen, G., Mohnen, P., and Raymond, W., 2009. Productivity effects of innovation modes. *Statistics Netherlands Discussion Paper,* 09033.

Raffo, J.D., L'huillery, S., and Miotti, L., 2008. Northern and Southern innovativity: A comparison across European and Latin American countries. *European Journal of Development Research*, 20(2), pp.219-239.

Raymond, W., Mairesse, J., Mohnen, P., and Palm, F., 2012. Dynamic models of R&D, innovation and productivity: Panel data evidence for Dutch and French manufacturing. In: EEA & ESEM, *27th Annual Congress of the European Economic Association & 66th European Meeting of the Econometric Society*. Malaga, Spain 27-31 August 2012.

Roper, S., Du, J., and Love, J.H., 2008. Modelling the innovation value chain. *Research Policy*, 37(6-7), pp.961-977.

Schmidt, T. and Rammer, C., 2007. Non-technological and technological innovation: Strange bedfellows? *ZEW Discussion Paper*, 07-052.

Siedschlag, I., Zhang, X., and Cahill, B., 2010. The effects of the internationalization of firms on innovation and productivity. *ESRI Working Paper*, 363.

Sterlacchini, A., 1989. R&D, innovations, and total factor productivity growth in British manufacturing. *Applied Economics*, 21(11), pp.1549-1562.

Therrien, P. and Hanel, P., 2009. Innovation and productivity: Extending the core model. In: OECD, *Innovation in firms: A Microeconomic perspective*. Paris: OECD Publishing. Ch.4.

van Leeuwen, G. and Klomp, L., 2006. On the contribution of innovation to multi-factor productivity growth. *Economics of Innovation and New Technologies*, 15(4-5), pp.367-390.