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"Innovation Adoption and Productivity Growth: Evidence for Europe"

Rosina Moreno and Jordi Suriñach

UB IREA
Research Institute of Applied Economics

AQR
Regional Quantitative Analysis Research Group

I|R|E|A|
Institut de Recerca en Economia Aplicada Regional i Públic
Research Institute of Applied Economics
WEBSITE: www.ub-irea.com • CONTACT: irea@ub.edu

AQR
Grup de Recerca Anàlisi Quantitativa Regional
Regional Quantitative Analysis Research Group
WEBSITE: www.ub.edu/aqr/ • CONTACT: aqr@ub.edu

Universitat de Barcelona
Av. Diagonal, 690 • 08034 Barcelona

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Abstract

The idea in this paper is to provide an empirical verification of the relationship between innovation adoption and productivity growth. After a brief revision of the literature about the concept and main determinants of innovation adoption/diffusion, the paper provides empirical evidence of the above-mentioned relationship through means of descriptive statistics and subsequently, we study the impact that innovation adoption may have on productivity growth through a regression analysis. The analysis is made with the statistical information provided by the Community Innovation Survey in its third and fourth waves, which concern innovative activities carried out between 1998 and 2000 and between 2002 and 2004 respectively. The countries covered are the 25 EU Member States plus Iceland and Norway as well as Turkey.

JEL classification: C8, J61, O31, O33, R0
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Rosina Moreno. AQR Research Group-IREA. Department of Econometrics. University of Barcelona, Av. Diagonal 690, 08034 Barcelona, Spain. E-mail: rmoreno@ub.edu

Jordi Suriñach. AQR Research Group-IREA. Department of Econometrics. University of Barcelona, Av. Diagonal 690, 08034 Barcelona, Spain. E-mail: jsurinach@ub.edu

1. Introduction

Technological progress is a priority for all those countries which aspire to support economic development. Innovation, when fostering competitiveness, productivity and job creation, is considered as an essential force for starting and fuelling the engine of growth (Romer, 1986). Such force crucially depends on the process of creation, accumulation and diffusion/adoption of knowledge which is often strongly localized into clusters of innovative firms, sometimes in close cooperation with public institutions such as research centres and universities.

Nowadays, thanks to the globalization and the rapid diffusion of technological knowledge, firms are forced to accelerate their rhythm of innovation and to expand their technological capabilities. This can be made through different mechanisms, either internal efforts in R&D or accessing external sources of technological knowledge and skills. In particular, collaborative agreements have become a strategy of knowledge sharing and transfer across firms which are increasingly recognised as an important (quasi-market) mechanism to access such external knowledge (Schilling, 2008). On the other hand, firms realize that all the components of an innovation do not need to come from within and that they can accelerate their own efforts or perhaps even broaden the scope of their own efforts by sourcing a part of the required technology externally, that is, by purchasing part of the innovation to a third party (outsourcing).

This implies that local growth depends on the amount of technological activity which is carried out locally and on the ability to exploit external technological achievements through the diffusion/adoption of such technologies (Martin and Ottaviano, 2001, Grossman and Helpman, 1994, Coe and Helpman, 1995).

There is a vast amount of papers analysing the relationship between innovation and growth. A large strand of the economic literature (Lundvall, 1992; Nelson, 1992; Nelson and Rosenberg, 1993; Verspagen, 1995) have supported empirically the positive role of innovation in fostering economic progress. As a consequence, many regional and national governments, as well as international organisations, have sharply increased their investments in innovation-based policies (see for example, Mikel-Navarro et al, 2009). However, less has been investigated on the relationship between the adoption of innovation from or together with external sources and productivity growth. The idea in this paper is therefore to provide an empirical verification of the relationship between one way of innovating, innovation adoption, and productivity growth. Initially, we are going to provide evidence of the above-mentioned relationship through means of descriptive statistics. Subsequently, we will study the real impact that innovation adoption may have on productivity growth through a regression analysis that takes into account the endogenous nature of the innovation adoption process. The analysis is made with the statistical information provided by the Community Innovation Survey in its third and fourth waves, which concern the innovative activities carried out between 1998 and 2000 and between 2002 and 2004 respectively. The countries covered are all 25 EU Member States plus Iceland and Norway as well as Turkey.

The outline of the paper is as follows. After this introduction, in the second section we review the literature providing theories on the role of innovation diffusion as well as on its determinants. Section 3 provides the empirical verification of the relatioship between innovation adoption and productivity growth through descriptive anallysis, whereas section 4 do it in a regression framework. Section 5 gives some concluding remarks.

2. The relevance of innovation diffusion and their determinants

2.1 Innovation, innovation adoption and economic growth

Innovation diffusion involves the initial adoption of a new technology by a firm (inter-firm diffusion) and the subsequent diffusion of the innovation within the firm (intra-firm diffusion), being the later the process by which the firm's old technologies and facilities are replaced by new ones. The diffusion stage, although apparently the less important phase of the process of technological change (at least, it has received less attention within research agenda and policy-makers),[1] is where the impact of this technological change on the economy takes place and where it

[1] When studying the innovation process, part of the literature has understand the technological change process into three distinct phases, that is to say, the invention process (whereby new ideas are conceived), the innovation process (whereby those new ideas are developed into marketable products or processes), and the diffusion process (whereby the new products spread across the potential market).

has to be evaluated. Indeed, the contributions made by technology to economic growth and development are determined by the rate and manner by which innovations spread through relevant population. Without diffusion, innovation would have little social or economic impact, albeit diffusion is also an intrinsic part of the innovation process.

In fact, for a long time in economic literature the major focus was on the process prior to the first attempt of commercialisation of a new idea (Fagerberg, 2006). This invention phase continues being an important issue but the relevance given to access to external (to the firm, to the country) sources of knowledge and the view of knowledge as the outcome of learning processes implies the existence of knowledge flows. Knowledge flows include technology transfer and the flow of know-how, knowledge and information, including both accidental spillovers and intentional transfers. There are many alternative routes for knowledge flows to materialize. They require a channel, such as for example an established collaborative link between two scientists from different firms, and a mechanism, that is a way in which communication can be achieved through the specific channel, such as co-operative research efforts, informal discussions, or the expressed ideas of a scientist. Such flows are not limited to the exchange of information between firms or institutions. As stated in David and Foray (1995) what characterizes and determines the performance of 'different systems of learning in science and technology' is not so much their ability to produce new knowledge as their ability to disseminate it effectively and allow it to become economically valuable to third parties. This is why in the last years there has been a transfer of interest from steady structures and absolute measures of innovative activities (such as R&D expenditure and patents) to the different types of interactions among actors within and beyond the boundaries of a national system.

Following the theoretical paper by Romer (1986) many studies have analysed the relationship between innovation and economic growth (Lundvall, 1992; Nelson, 1992; Nelson and Rosenberg, 1993; Verspagen, 1995), supporting empirically the positive role of innovation in fostering economic progress. With the rise of globalization, firms have been urged to focus on differentiating their products and services by innovating. In the case of Europe, innovation is increasingly considered as the only tool capable of allowing European firms to remain competitive in an increasingly changing economic context (Navarro et al, 2009). Therefore, given the relevance of innovation and of innovation diffusion, as part of it, for the generation of growth and for the increase in productivity, it is highly important to get to know its main determinants, since in a final step, they will also be indirectly relevant for growth.

2.2 Determinants of innovation adoption

According to previous literature (e.g. Hall and Khan, 2003), innovation diffusion results from a series of individual decisions to begin using the new technology, decisions which are the result of a comparison of benefits and costs of adopting the new invention (demand and supply-side perspectives).

From the *demand-side* there are two main conditions for innovation diffusion: being aware of the new technology and being able to use and adapt the new technology (what is referred to in the literature as absorptive capacity of the firm, region or country), and the profitability of adopting the new technology (depending on the price, on the expected returns, and on the level of risk). Therefore, from the demand side perspective, several factors such as the user's investments in human capital and R&D, user's organizational innovation, size and market features are among the main ones for explaining innovation diffusion.

Based on the literature focusing on the *supply-side* factors we can identify two main drivers of innovation diffusion: Supplier's R&D and innovation (the capability of firms to improve their technology, provide users with complementary products as well as to reduce the technology costs) and supplier's financial means (to be able to adapt the new technology and to inform potential users).

Technology transfers do not happen spontaneously. Some information is tacit, and requires interpersonal contact to be transmitted. Therefore, being aware of the technology and being able to adapt it requires effective contacts between suppliers and users. Interactions between users and suppliers are required for innovation diffusion to occur. These relationships support two distinct kinds of exchange between suppliers and users:

- Exchanges of tangible assets: Innovation diffusion may rely on flows of products and services. Imitation, reverse engineering, technology transfers increase with the openness of the economy. For this reason, trade is an important driver of innovation diffusion. Additionally, Foreign Direct Investment (FDI) is generally considered as the main mechanism which act as channel of the international diffusion of technology.

- Exchanges of intangible assets: Ideas are not freely accessible to everyone. They are instead, at least partly, embodied into people (Lucas, 1988). Therefore, the diffusion of tacit knowledge and their absorption would rely on effective interpersonal interactions. The main ones are: the face to face relationship (Berliant et al, 2001; Charlot et Duranton, 2006; Zucker et al, 1994), the human capital mobility, from one institution to another or over space (Almeida and Kogut, 1997; Breschi and Lissoni, 2003, 2006; Rallet and Torre, 1999, for instance), and the integration within networks (Singh, 2005; Sorenson et al, 2006; Gomes-Casseres et al, 2006; Autant-Bernard et al. 2007; Miguélez and Moreno, 2013a, 2013b).

Three factors are likely to improve these interactions between supply and demand. Firstly, Information and Communication Technologies ease interpersonal relationship and they give a better access to information, thus facilitating awareness about the new technology. Secondly, information and technology flows are favoured by vertical and horizontal integration of the market. This latter increases effective contacts and the flows of both tangible and intangible assets. Third, geographical concentration facilitates for suppliers to adapt the technology to potential users (see Lundvall, 1992). Spatial concentration also facilitates for users to be aware of the new technology, and reduce the risk (local trust).

Additionally, the *institutional dimension* is considered to be a highly important determinant of the adoption of innovation. Traditional economic and other regulations, such as competition and intellectual property rights protection, taxation, financing, education, national policies, EU-level policies and so forth can ease or block agents' interaction. This is particularly important when exploring the question of the emergence of the European Research Area and a European system of innovation since there are important differences in the ways public sector institutions and research facilities supporting industrial innovation have been set up and operate in each country.[2] Within the institutional dimension, the regulatory environment plays a predominant role (Baker, 2001; Cutler and McClellan, 1996 for instance). The regulatory environment displays several factors likely to influence innovation diffusion. Firstly, the role played by normalisation and standardisation procedures can be stressed. Secondly, the insurance system may also reduce the risk, at least for some sectors like medicines. Finally, considered as the main driver of innovation diffusion stemming from the regulatory environment we find certainly the IPR regime.

From a general point of view, intellectual property rights (IPRs) are legal mechanisms designed to represent a barrier to the possibility of free riding and imitation of new ideas, blueprints or technologies by agents which did not incurred in the costs of producing these innovations. Hence, as pointed out by Maskus (2000) IPRs may encourage new business development by stimulating technology innovation and compensating innovators for incurring in the fixed costs of R&D. The artificial creation of a temporary monopoly power for the successful innovator compensate for the fixed costs incurred during the risky process of technology and knowledge creation. Additionally, IPR may facilitate the creation of a market for ideas and mitigate disincentives to disclose and exchange knowledge which might otherwise remain secret (Merges and Nelson, 1994). However, strong IPRs will create market distortions through the creation of monopoly power for the innovator (see for example Deardorff, 1992).

All in all, ceteris paribus within the same economy, the enforcement of IPRs implies a trade-off between the positive incentive given to the R&D sector and the negative effect coming from an increase in the cost of imitation. If, on the one hand, increasing the protection of IPRs theoretically ensures the innovator to be rewarded for its investment in R&D it is argued, on the other hand, how strengthening IPRs protection significantly rises the costs of imitation (see Levin et al., 1988; Gallini, 1992; Helpman, 1993; Lai, 1998; from one side, and Barro, 2000; Acemoglu, 2004; Barro, 1998; Hall and Jones, 1999; Knack and Keefer, 1995; Aghion and Howitt, 2005, from the other).

[2] Adoption and diffusion of innovation can also be impacted by other types of regulations, such as environmental regulations that may even prohibit or require the use of certain technology or production methods (for instance, Gray and Shadbegian, 1998).

Another driver of innovation that is of utmost importance in cases such as the European one is the role played by *economic integration across countries*. Specifically, product market integration such as the Internal Market may have an impact on the incentives to innovate and to adapt innovation through different channels, four of which we consider in depth.

Firstly, the creation of an Internal Market implies a greater market size which in turn increases profits and allows writing off the fixed R&D costs over a larger volume of production and sales (Schmookler, 1966). In Arrow (1962)'s words "competition leads to more innovation, because competition means more production, and therefore more units to spread the fixed costs of innovation".

Secondly, the creation of a single market should lead to increased knowledge spillovers because of more intensified trade and investments. Indeed, the reduced barriers to cross-border flows of products and factors favours trade and investments across countries belonging to the same economic area so that innovation can be more easily transmitted and adapted.

Thirdly, the integration of economies makes them a more attractive location to do business. By attracting inward FDI, integration would encourage the diffusion of new technologies developed elsewhere. Therefore, the Internal Market stimulates technology transfer and diffusion via the increased FDI flows.

Fourthly, a higher integration of the market implies a higher productive specialisation, so that the presence of MAR externalities[3] would lead to higher innovation diffusion. Following Arrow (1962) and Romer (1986, 1990) it is claimed that geographical agglomeration of industries produces knowledge externalities which can have positive effects on the rate of innovation (MAR-externalities) since agglomeration describes efficiency gains from the existence of technological spillovers due to the existence of a pool of specialized labour, the location of customers and suppliers, and physical and institutional infrastructures, that arise from the collocation of firms of the same industry. In the EU case, following Midelfart-Knarvik et al (2004), the single market has

[3] Marshall-Arrow-Romer externalities.

led to specialised regions and an uneven distribution of manufacturing industries in Europe. Thus, allegedly, integration leads to specialization and, therefore, to more innovation.

An Internal Market can imply an increase in the standardisation of products and processes. The question which is not so clearly answered is whether setting internal EU standards promotes the diffusion and development of technologies or, on the contrary, pre-empting competition among standards slows down the improvement of existing standards and the development of more efficient alternatives. Also, in integrated economies, the mobility of labour is higher. Mobility of high skilled workers is a source of knowledge spillovers, which are a diffusion mechanism of innovation (Crespi, 2004; Miguélez et al, 2010; 2013c). Finally, firms operating in a more integrated market are therefore exposed to higher competition, having stronger incentives to innovate in order to retain their market positions and stay ahead of the competitors (Aghion et al, 2005; Griffith et al, 2006). Since integration and competition go hand by hand, we go deeper in this last determinant in the rest of this section.

Within an integrated area, competition is expected to increase due to the removal of non-tariff barriers which is targeted to creating a large integrated market for goods and services, allowing the realisation of economies of scale. Indeed, integration generally changes the conditions of competition by facilitating market entry by new firms and by reducing the ability of firms to segment national markets geographically. In the case of the European Internal Market, empirical evidence shows that on average, price-cost margins of the sectors most affected by the Single Market Programme declined (Ilzkovitz et al, 2007). European companies reacted to this decline in profit margins by reducing their costs and obtaining efficiency gains through an increased presence on the markets of other Member States (increased multinationality) and a concentration of activities on the core businesses of companies (reduced sectoral diversification). Additionally, the on-going process of liberalisation in the network industries, while taking account of the need to provide services of general economic interest, implies a stepwise opening up of the telecommunications, postal services, energy and transport sectors to competition. This consequent fiercer competition in integrated markets is expected to result in (allocative and productive) efficiency gains. This would stimulate innovation because the risks of being eliminated from the market are higher, providing increased incentives for producers in such an area to invest in product and process innovations, improving the dynamic efficiency of the economy.

According to economic literature, Porter (1990) argues that local competition encourages innovation by forcing firms to innovate or fail. In this view, for any given set of industrial clusters, competitive pressure enhances innovation and productivity. In Gilbert (2007)'s view, competition can promote innovation by reducing the value failing in R&D, but with no-exclusive IPRs, competition can decrease innovation incentives by lowering post-innovation profits. Also, Aghion et al (2001, 2005) defends the existence of the "escape-the-competition" effect, where the market is indeed competitive. According to their arguments, competition discourages laggard firms from innovating, whilst encourages neck-and-neck firms to innovate.

With the emphasis on the impact of competition on innovation adoption, Reinganum (1981) stresses the double edge, that is, on the one hand, one might expect that competitive pressure accelerate the adoption of innovations in order to be more productive and achieve its own monopoly. But on the other hand, each firm will capture less of the post adoption of the innovation, and so may have less incentive to adopt. Redmond (2004) also stresses that competition among firms frequently involves product innovation, and sometimes telecommunication technologies. This in turn would increase the telecommunication infrastructures of the society, which facilitates information flows, and therefore, the diffusion of innovations. Additionally, as Gruber (2000) stresses in a study analysing the diffusion of mobile telecommunications in Eastern Europe, the speed of diffusion increases with the number of firms. The argument behind this stresses that telecommunication technologies increases the potential subscribers that can be served, and the market potential therefore increases. The argument in such technological fields is the same as in Redmond (2004), that is, more technological progress support the existence of firms in the market and their entry, then increase the market competition and therefore the speed of the diffusion of a certain technology. According to his results, competition has a positive impact on diffusion. As the World Bank (1994) points out for the case of the telecommunication market, the entry of new firms is the single most powerful tool for encouraging telecommunications development because monopolies rarely meet all the demand. More competition, moreover, attracts capital, especially foreign capital, which carries a high degree of technological knowledge. Therefore, the results of his investigation provide support to the view that competition accelerates the diffusion of innovations.

All the determinants of innovation diffusion surveyed in this section should be taken into account when considering the impact of innovation adoption on economic growth. In section 4, we offer a model that includes such endogeneity through a two-stage model.

3. Empirical verification of the relationship between innovation adoption and productivity growth through descriptive analysis

The expected relationship between innovation diffusion/adoption and productivity growth is positive as highlighted in previous empirical and theoretical literature. For instance, the Nelson-Phelps (1996) model of technology diffusion/adoption is based on the idea that changes in productivity and in total factor productivity depend, among other variables, on the rate of technology diffusion from the leader country to each of the countries under consideration. We follow the same idea, whereas instead of considering the diffusion from the leader country to the rest of countries we will consider a measure gathering the extent of the change in the adoption of innovation in each country, change computed between the data in CIS3 and that of CIS4. For each firm, the CIS gives information on the way both (i) product and (ii) process innovations have been developed. When answering the CIS questionnaire, firms have to choose between three answers related to the nature of their declared innovation: (i) innovation developed mainly by the firm, (ii) innovation developed mainly together with other firms or institutions, (iii) innovation developed mainly by other enterprises or institutions. The nature of the proposed CIS question, therefore, allows us to disentangle all the product or process innovations which have been developed (totally or at least in part) outside the interviewed firm. Hence, we are able to distinguish between the creation of innovation (those products and processes developed directly by the interviewed firm) and those innovations which have been, instead, adopted from other firms or made in collaboration with them.

We therefore consider that innovation adoption occurs as soon as the firm declares that its process or product innovations have been developed “Mainly together with other enterprises or institutions” or "Mainly by other enterprises or institutions". On the basis of this definition, the magnitude of adoption at the national level is then measured as the share of adopting firms, using the following ratio:

Adopting enterprises / Number of innovative enterprises [4]

Our definition of innovation adoption is a broad one in the sense that we do not only consider explicit innovation adoption but also the adoption coming as a result of innovation developed together with other enterprises, that is, adoption that relies on knowledge sharing. Most studies stress the importance of effective collaboration to adapt the technology and make it suitable for the adopter (Rosenberg, 1972). We believe, therefore, that the broad definition employed in this contribution is apt to consistently capture the phenomena of innovation adoption from an interesting and wide perspective.[5]

In the next figures we will try to get evidence on this relationship in the case of the European countries using data for productivity growth in the period between 2000 and 2005 from EUROSTAT. We start by providing some scatterplots plotting the average productivity growth in the Y-axis versus different indicators of the growth of adoption of innovation.

Figure 1 plots the average productivity growth versus the change in the global indicator of the adoption of innovation with information at the national level. Therefore, with the information for the average of the different sectors in each country, Figure 1 offers a non-significant coefficient of correlation with a value of 0.246 (p-value: 0.28). In case the correlation is weighted by the size of GDP in each country, a non-significant but negative value would be obtained, in contrast with the theoretical assumptions. However, if the extreme cases of Greece (with very high productivity growth rates) and Norway (with high growth rates and the lowest rates of innovation adoption) are

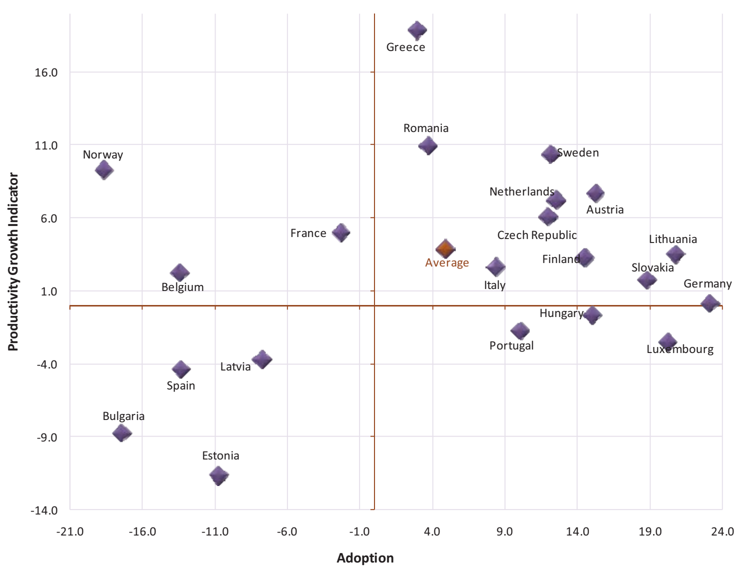
[4] The denominator is measured following the standard definition used by the EU to measure the share of innovation within countries or NACE. Innovative firms are those which innovate in product and/or process, including "ongoing or abandoned innovation activities" (process or product).

[5] For a further description of the construction of the innovation adoption variables, see Autand-Bernard et al (2010).

not included, the weighted correlation becomes positive (coefficient of correlation of value 0.0975; p-value: 0.69) and even significant if it is not weighted by the size of the GDP in each country (coefficient of correlation of value 0.488; p-value: 0.03).

If looking at the countries, it can be observed how this positive relationship is mostly due to the positive relationship among both variables for the countries with productivity decreases, that seem to benefit more from the adoption of innovation (lower decreases of productivity as innovation adoption grows). This would be the case of Estonia, Bulgaria, Latvia, Spain, Portugal, Luxembourg and Hungary (coefficient of correlation of value 0.815; p-value: 0.02). On the contrary we do not observe such a clear relationship for the countries with high levels of productivity, since there are very different patterns of behaviour: some countries present very low increases of adoption of innovation (such as France, Norway and Belgium) and some others important increases in innovation adoption (Italy, Finland, Sweden, Netherlands, Austria, Czech Republic, Lithuania and Slovakia). It seems therefore that the adoption of innovation is positively related with productivity in those countries that experience lower increases of productivity, which can take more advantage of knowledge flows.

Figure 1. Changes in innovation adoption and productivity growth



In the next figures we analyse the relationship between productivity growth and innovation adoption in the case of product and process innovations separately. As depicted in Figure 2, we obtain a significantly positive relationship at a 10% level, with a value of 41.4% when considering product adoption if Greece and Norway are not considered (with them, the coefficient of correlation presents a value of 0.075; p-value of 0.75). So, for product innovation adoption, the relationship seems more clearly positive than in the general case. Again, we observe that the relationship is clearer for the countries with decreases in productivity.[6]

The picture does not change much when one studies the relationship between productivity growth and changes in the adoption of process innovations (Figure 3). Although it is not significant with a correlation coefficient of 33.7% (p-value: 0.13), once we delete Greece and Norway, the correlation becomes clearly significant (coefficient of correlation of 0.426; p-value: 0.06). In general terms it can be concluded that there is a positive relationship between changes in adoption rates and in productivity growth no matter the type of innovation, although it is more straightforward in the case of the adoption of process innovations. This could be due to the fact that introducing a new production process makes the firms to be more efficient, reducing costs and which would imply higher productivity rates.

[6] The values of productivity changes may vary along the different plots. This is due to the fact that each national value is obtained as an average of the growth rates of productivity in the different sectors for which we have data on the variable of adoption considered in the plot. Since the observations presenting missing values for innovation adoption are different in the diverse categories of adoption, the national averages of productivity growth rates do not lead to the same value in all the plots.

Figure 2. Changes in product innovation adoption and productivity growth

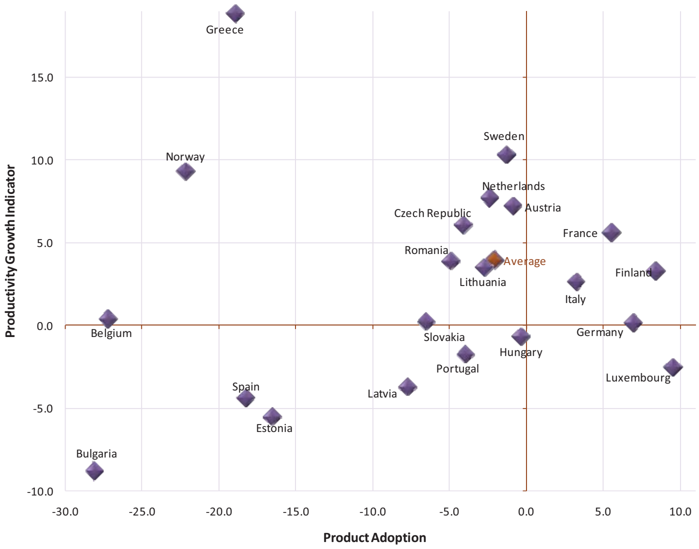
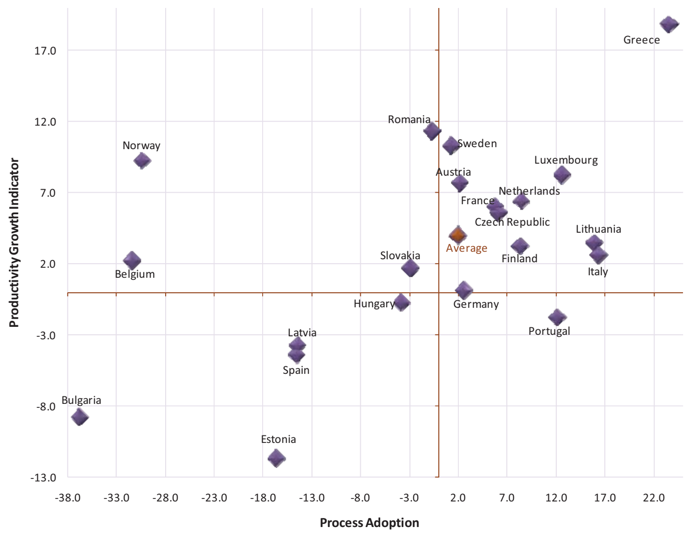


Figure 3. Changes in process innovation adoption and productivity growth



Similar conclusions are obtained when plotting the relationship between productivity and adoption of product/process innovations in case of cooperating with other firms or institutions (Figures 4 and 5). Again the relationship is positive for product adoption (18.6% that becomes significant once Norway is dropped, with a higher value of correlation, 37%), but even more significantly positive for the case of process adoption (45.7%, significant at a 5% level, with all the countries considered). Therefore, as in the general case, the correlation is higher for process than for product innovation also when focusing on the cooperation link. Using cooperation-based adoption, however, tends to slightly increase the effect of product adoption on productivity. It seems therefore that R&D cooperation with other firms or institutions has a positive and significant effect on firms' performance, a relationship that has largely been studied at the micro level (Miotti and Sachwald, 2003; Belderbos et al., 2004a; Lööf and Broström, 2008; Aschoff and Schmidt, 2008).

Figure 4. Changes in product coopearation-based innovation adoption and productivity growth

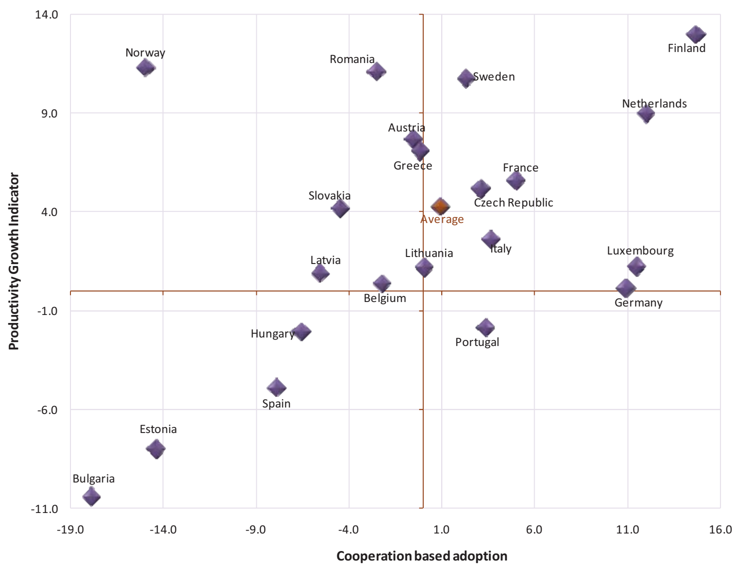
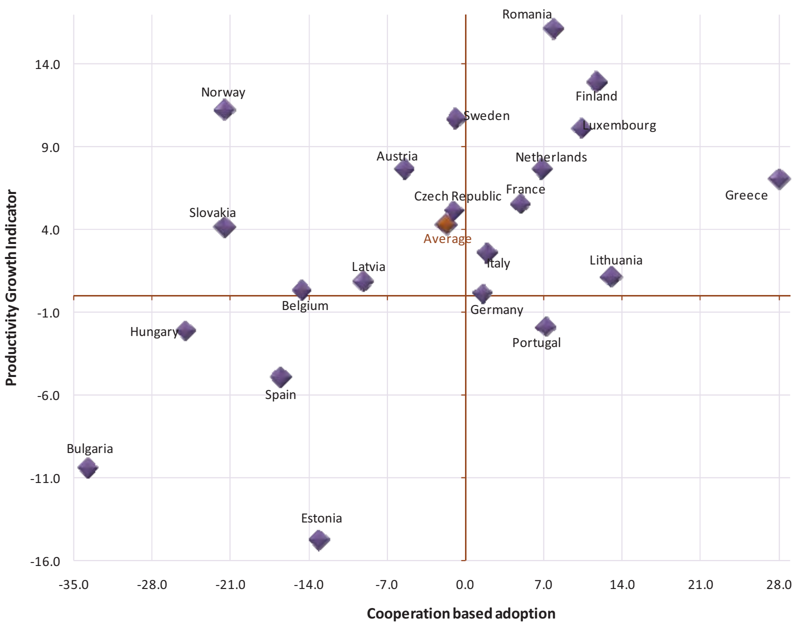


Figure 5. Changes in process cooperation-based innovation adoption and productivity growth



The conclusions are not maintained when plotting the relationship between the evolution of productivity and adoption of product/process innovations in the case of purchasing the innovation from other firms or institutions (Figures 6 and 7). Again the relationship is positive for product adoption (46%, being significant at a 3% level), but it is no longer significant for the case of process adoption and even presenting a negative although small value (-11%, although positive without Hungary). Therefore, contrary to the general case and to the case of innovation adoption made in cooperation, the correlation is not significant for process innovations when they are acquired from an external enterprise or organisation.

Figure 6. Changes in product other organisation-based innov adoption and productivity growth

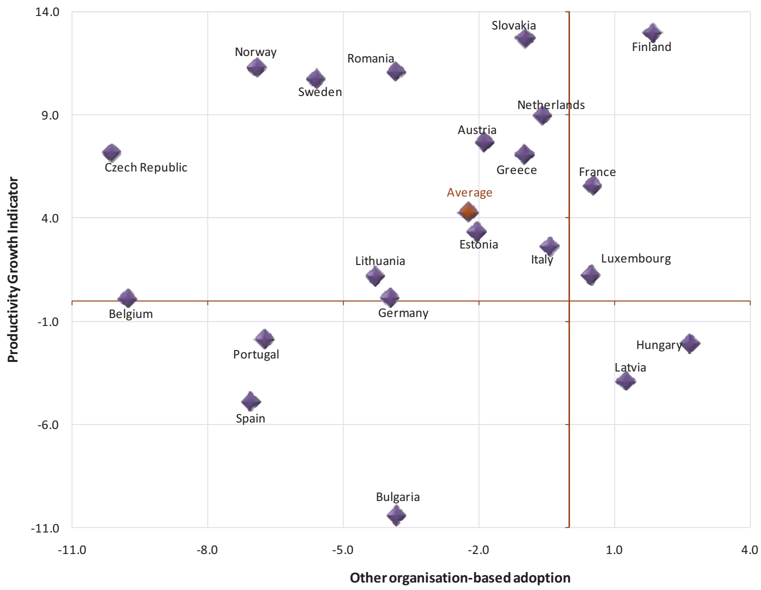
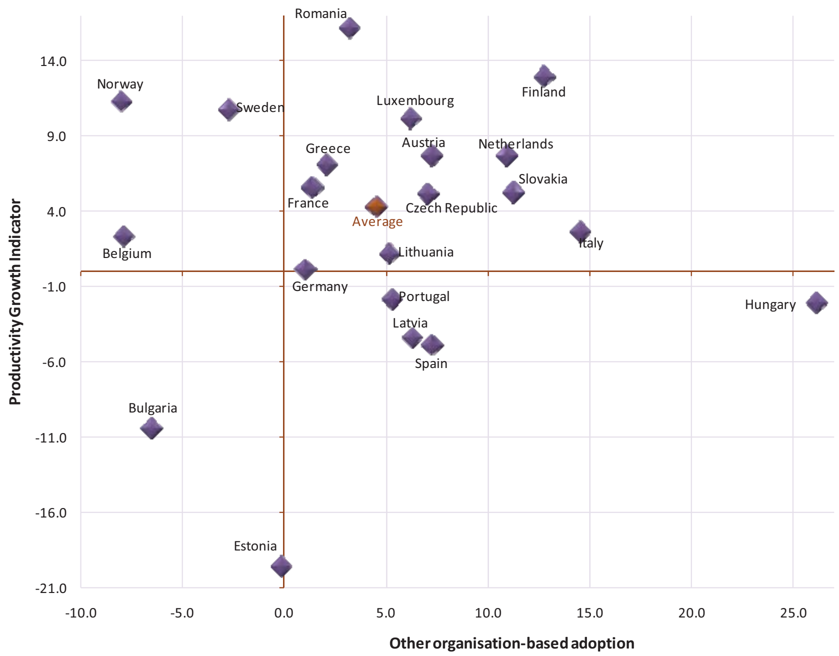


Figure 7. Changes in process other organisation-based innov adoption and productivity growth



Although not conclusive for all types of innovation adoption, in general terms we have obtained that there exists a positive correlation between innovation adoption and productivity growth which is significant in some cases. However, we cannot conclude a real impact of innovation adoption on productivity unless it is analysed through regressions. Therefore, the descriptive analysis offered in this section on the time evolution of the relevant indicators of both items need to be complemented by regression results shedding some lights on the possible role played by innovation and specially innovation diffusion as emerged by CIS data. This is done in the next section through the estimation of a growth equation.

4. Empirical verification of the relationship between innovation adoption and productivity growth. Regression analysis

Growth theories have been classified either in a neoclassical or endogenous growth group. In what is related to predictions for convergence, the neoclassical model (Solow, 1956; Swan, 1956) supports a convergence process based on the existence of decreasing returns in capital accumulation. Increases in capital lead to increases less than proportional in product. This circumstance explains the existence of a steady state level for the main magnitudes, such as product per unit of employment, to which the economy will tend after any transitory shock. These being the case, poor economies will grow at higher rates than rich ones, guaranteeing convergence across all of them.

On the other hand, endogenous growth models are characterized by giving mechanisms that determine the absence of convergence. In a first step, the fact of not imposing decreasing returns to capital (Romer, 1986; Lucas, 1988) and some ulterior mechanisms in which technological growth is a non-decreasing function of some factors (among others, the resources devoted to innovation), lead to models in which there is not a steady state or long run equilibrium. In other words, these models would not impose any limits to growth. These mechanisms, although through different ways, allow economies which are initially rich to keep this condition the same as poor economies. In fact, an important part of the efforts in endogenous models have been motivated on the notable persistence observed in the differences in the levels of income and welfare across economies.

However, the implications in terms of convergence derived from both types of models are not straightforward. As can be easily deduced from the assumptions of neoclassical models, the convergence predicted can not be directly translated to the disappearance (of a great part) of the differences across economies. This will also be true when all the economies share the same steady state. Also, in the scope of the endogenous growth models it is possible to design mechanisms that will allow approaching the development levels across economies through, for instance, technological diffusion processes.

A simple growth equation can be expressed as (Barro and Sala-i-Martin, 1995):

(1) $$\log(\mathrm{GDPpw}_{c,i,t} / \mathrm{GDPpw}_{c,i,t-1}) = a - (1 - e^{-\beta T}) \log(\mathrm{GDPpw}_{c,i,t-1}) + u_{c,i,t}$$

that includes a random error term which proxies transitory shocks. The subscripts c and i denote the country and sector respectively, t is the year under consideration and -l refers to a one-year time lag. This way, the intercept would reflect all the factors influencing the steady state.

With respect to the steady state, if we can just consider it to be proxied by the intercept, we would be imposing the existence of the same steady state in all the economies under consideration, which is known as absolute convergence. However, we can think of some specific factors that have a real influence in it and consider them explicitly. These factors can be introduced ad-hoc through the consideration of additional explanatory variables, in a way that has been called growth equations à la Barro. Specifically, we are interested in considering the impact of innovation creation as well as innovation adoption. These factors are introduced ad-hoc in the way à la Barro as follows:

(2) $$\log(GDPpw_{c,i,t} / GDPpw_{c,i,t-l}) = \delta_0 + \delta_1 \log(GDPpw_{c,i,t-l}) + \delta_2 \hat{I}nnoAdopt_{c,i,t-1} + \delta_3 \; InnoCrea_{c,i,t-1} + DUM_c \delta_4 + DUM_i \delta_5 + DUM_t \delta_6 + u_{c,i,t}$$

where the variable InnovAdopt is the fitted value of the innovation adoption rate obtained in the two-stage procedure carried out in Manca et al (2011), but this time with a panel structure thanks to the availability of data from CIS3 and CIS4. InnoCrea is a variable for innovation creation proxied by R&D expenditure in different categories as obtained from CIS. In our case, we estimate a growth equation for the sample of 26 countries of the EU for which we have information on labour productivity obtained from EUROSTAT (value added per worker) for two time periods: 2000-2002 and 2003-2005. This way, the explanatory variables coming from CIS are referred to the time periods 1998-2000 and 2002-2004, so that there is a time lag in the impact of these explanatory variables on the endogenous. We estimate by fixed effects with the use of weighted regressions, according to the economic size of the countries measured with GDP.

Therefore, the econometric specification we will exploit is detailed in eq. (2) where the fitted value of innovation adoption as given in eq. (12) in Manca et al (2011) is inserted as a regressor in the actual eq. (2).[7] This amounts to run a two-stage least square estimation (2SLS). In fact, by using this kind of estimation we are solving at once also the likely problem of endogeneity that may affect productivity growth and innovation adoption. In fact, either innovation adoption may have a direct effect explaining productivity growth but, at the same time, productivity growth may cause innovation adoption rates to increase or decrease. By estimating in two stages we solve the endogeneity problem and get consistent estimates of the partial effects of innovation adoption. This way, through the consideration of these 2SLS estimation we are also inferring the effect of the IM on productivity growth.

The results for the estimation are depicted in Table 1. As it can be observed in column (i) there is not an absolute convergence in the period considered, given the positive value of the coefficient of the level of value added in the initial year. This would point to the fact that departing from low values of value added does not imply growing at a higher rate than those starting with higher values of value added.

In column (ii) we condition this regression model including a proxy for innovation adoption (the fitted value of the innovation adoption rate obtained in the previous estimation) and a proxy for innovation creation (Total R&D expenditures). Additionally, we consider the variable that considers the percentage of EU regulations in Internal Market implemented by each member state in the two years of our panel, proxied by the Transposition Deficit Indicator for Internal Market (TDI Internal Market). Although some IM measures have already been taken into account in the first and second

[7] In Manca et al (2011) innovation adoption is estimated in two-stages. In a first stage we define the impact of some major Internal Market regulations on cooperation, competition and trade across EU countries. The results of this first stage show how different IM regulations are important determinants of these three macroeconomic variables that we consider afterwards having an impact on innovation adoption. Hence, in a second stage we address whether innovation adoption rates significantly depend on the degree of cooperation, trade and competition as well as some control variables such as national legal structures and IPR regulations.

stage of the estimation procedure (see Manca et al, 2011), we are also interested in controlling for the most general measure which is the extent to which the regulations in the Internal Market have been undertaken by the countries. As observed, in this second column the lack of convergence is maintained with a significant and positive sign of the level of value added in the initial year. Additionally, the TDI of the Internal Market presents a positive although not significant coefficient, meaning that the adoption of more EU regulations by each member state does not lead to higher increases, once the impact on trade, competition and cooperation, the main channels through which the Internal Market affects innovation diffusion, is taken into account. Indeed, although the theoretical reasons behind the argument that internal market implies higher innovation and innovation diffusion are several, the evidence suggests that the Internal Market in the EU does not seem to have been a sufficient catalyst for innovation and resource reallocation towards technology intensive activities despite the observed reduction in mark-ups and evidence pointing to a reorganisation of production activities (Ilzkovitz et al, 2007). While the effect of the Internal Market on R&D and innovation has been positive, it has not been strong enough to significantly improve the innovation and productivity growth performance of the EU. The innovative performance of the EU as a whole and of most EU countries lags significantly behind that of top performers such as the US and Japan. European companies are not sufficiently encouraged to innovate and, in this respect, the Internal Market has been an insufficient driver of innovation. See Ilzkovitz et al (2007) for some explanation behind this result.

More interesting for our purpose are the signs and significance of the parameters on innovation. The innovation adoption rate is positive and significant at a 10% level in all the specifications estimated, indicating that those countries that increase their rates of innovation adoption tend to present higher productivity growth rates. This result would be in line with the conclusions drawn on the descriptive analysis. On the contrary, although positive, we do not obtain a significant coefficient for the total R&D expenses as a proxy for innovation creation. This would be in contrast to what has been obtained in previous literature and in light of the surveyed empirical and theoretical literature on innovation. It is somehow surprising the little role played by innovative investments as a determinant of productivity. Two reasons could be behind this result. First, R&D expenditures is an indicator for innovation on the input side, and it has been criticised in some papers since it does not really encompasses the results of the innovation efforts made by the enterprises. Second, this measure for R&D expenditure is very general and encompasses very different types of innovation. Given that the CIS data contains detailed information on different innovative items, we are going to split total R&D expenditure into its different categories and see whether there exists a differentiated impact according to these several categories.

The results on the impact of the different categories of R&D expenditures are shown in columns (iii) to (viii). First of all, it is worth pointing out that all the conclusions obtained from the rest of parameters are maintained: lack of convergence, positive and significant impact of innovation adoption and positive although not significant impact of the TDI Internal Market. With respect to the different categories of innovation, we can observe that only those of Extramural R&D as well as the one on Training have a significant and positive impact on productivity growth.[8] This is the case both introducing the R&D expenditures one by one and also if all the types of R&D are included together in the same regression, as in the last column.

5. Concluding remarks

Innovation ranks high among the factors behind the lack of convergence across the EU regions. Part of the economic growth literature highlights the growth-enhancing role of innovation and considers that most of the regional divergence in growth patterns in Europe can be ascribed to the localized and intrinsically path-dependent nature of the innovation process (Abreu et al., 2008). Arguably, a pivotal element to ensure economic growth lies in accessing external sources of knowledge and facilitating interactive learning and interaction in innovation. This knowledge diffusion can take place through diffusive patterns based on knowledge externalities, that rely on informal transmission channels, relatively bounded in space, but also through intentional relations such as research collaborations across firms and institutions. The present paper is a step in this direction and estimates a convergence equation where cooperation activities in innovation are introduced.

[8] Whereas the variable on Total R&D expenditures refers to the expenditure itself, the variables for the different categories refer to the number of firms engaged in the corresponding category of R&D activities. This is due to the the non-availability of the variables on innovation expenditure for some of the categories in the CIS. On the contrary, the number of firms engaged is provided. Therefore, one cannot compare directly the coefficient for Total R&D expenditures and those of the different categories or innovation, since in the latter it is referring not to expenditures but to the number of firms. The fitted values of this innovation adoption are used in the present paper for estimating equation (2).

Among the main results, it seems that an effort in line of making enterprises increasing innovation adoption, either in the form of cooperating with other enterprises or incorporating innovations made by other enterprises has a positive and clear impact on productivity growth. However, the impact of increasing R&D expenditures is not as clear, and depends on the type of innovation carried out. In this sense, we have obtained that the countries making efforts to increase the number of their firms engaged in extramural R&D or the number of firms engaged in training tend to have higher increases in productivity. On the contrary, the result is not as clear if the type of innovation that is encouraged is R&D intramural or acquisition of machinery.

From a policy perspective, these results illustrate that, not only R&D efforts are important to generate innovations, but also the *embeddedness* of agents in their local networks of alliances as well as their degree of *connectedness* with the outside world. Further, it is precisely the concepts of *embeddedness* and *connectedness* which are in the core of the *smart specialisation* strategy recently launched by the European Commission (McCann and Ortega-Argilés 2011).

Table 1. Growth Equation (endogenous variable: labour productivity growth)

Productivity	3.272	14.515	8.436	8.904	8.716	8.954	9.038	10.462
	(3.04)***	(4.65)***	(2.90)***	(3.19)***	(3.03)***	(3.17)***	(3.12)***	(3.69)***
Adoption		23.702	29.562	37.737	31.609	36.571	23.126	35.396
		(1.67)*	(2.38)**	(3.04)***	(2.37)**	(2.83)***	(1.81)*	(2.23)*
R&D Expend.		0.017						
		-0.06						
Intra R&D			1.199					1.489
			-1.05					(-0.71)
Extra R&D				3.037				4.477
				(2.64)***				(2.44)**
Acq Machin					1.215			-4.425
					-0.97			(-1.71)
Training						2.702		6.758
						(1.97)**		(2.18)**
Market innov							-0.524	-5.267
							(-0.49)	(-3.01)**
TDI IM		0.329	0.384	0.313	0.376	0.291	0.402	0.402
		-1.22	-1.36	-1.13	-1.33	-1.03	-1.41	-1.41
Constant	-15.703	-107.382	-97.501	-106.418	-98.806	-105.438	-85.697	-85.697
	(-3.22)***	(-3.53)***	(-2.99)***	(-3.37)***	(-2.98)***	(-3.26)***	(-2.67)***	(-2.67)***
# Obs	364	134	141	141	141	141	139	139
# Countries	26	16	16	16	16	16	16	16
R-squared	0.2	0.38	0.33	0.36	0.33	0.35	0.33	0.33

Absolute value of t statistics in parentheses. *, **, *** significant at 10%, 5% and 1%, respectively. Time and Sectoral dummies have been inserted in all regressions. The time dimension refers to 2000 and 2004 (CIS3 and CIS4), except in the case of the endogenous variable in which the growth rate is computed between 2000 and 2002 for the first time span and between 2003 and 2005 in the second one.

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Institut de Recerca en Economia Aplicada Regional i Públic
Research Institute of Applied Economics

WEBSITE: www.ub-irea.com • **CONTACT:** irea@ub.edu

AQR

Grup de Recerca Anàlisi Quantitativa Regional
Regional Quantitative Analysis Research Group

WEBSITE: www.ub.edu/aqr/ • **CONTACT:** aqr@ub.edu

Universitat de Barcelona
Av. Diagonal, 690 • 08034 Barcelona