The effects of own R&D and external knowledge spillovers on firm innovation and productivity: The case of Slovenia*

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Abstract

Recent empirical work has examined the extent to which national and international spillovers affect the functioning of a firm. Foreign direct investment and trade have been shown to serve as channels for the mediation of knowledge spillovers. The aim of this paper is to analyse whether, and to what extent, firm ability to innovate is induced by firm's own R&D activity and what is the effect of factors external to firm. We first estimate the impact of firms' internal R&D capital and external R&D spillovers on innovation activity within an integrated dynamic model. In the second step, we proceed to estimate the impact of firms' innovations on productivity growth. Using firm-level innovation and accounting data for a large sample of Slovenian firms from 1996-2002, the paper produces some interesting findings. First, firm R&D expenditures as well as external knowledge spillovers, such as national and international public R&D subsidies, foreign ownership and intra-sector innovation spillovers foster the ability of firms to innovate. Second, innovations resulting from firm's R&D may contribute substantially to its total factor productivity growth. Here, foreign ownership is shown to have a dual impact on firm's TFP growth - while it enhances firm ability to innovate it also contributes to TFP growth via superior organization techniques and other channels of knowledge diffusion. These results, however, are not robust to different econometric techniques. By using matching techniques and firm propensity to innovate in order to match innovating firms with otherwise similar non-innovating firms we find no support for the importance of innovation on productivity growth.

Keywords: innovation, external knowledge spillovers, FDI, trade
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1. Introduction

According to endogenous growth theory, technological progress is endogenous, it is driven by an deliberate investment of resources by profit-seeking firms (Smolny 2000). To successfully undertake innovation activity, a firm normally needs to combine several different channels of knowledge, capabilities, skills and resources. The critical factors seem to be the abilities and incentives of those managers who exercise strategic control, the size of the funds that are generated by the firm itself and the organizational integration of the firm (Lazonick 2005). Still, as noted by Fagerberg (2005), the central finding in literature on innovation is that, in most cases, innovation activities depend heavily on external sources. The pattern of worldwide technical change is dictated in large part by international technology diffusion because only a handful of rich countries account for most of the world's creation of new technology (Keller 2004**)**. Eaton and Kortum (1999) and Keller (2002a) find that for most countries foreign sources of technology are of dominant importance (accounting for 90% or more of productivity growth).

Along these lines, economic analysis of innovation identifies international knowledge flows (through FDI, trade, licensing and international technological collaborations) as important determinants of the development and the diffusion of innovations. Here, the notion of technology and knowledge spillovers is central. It is based in theories of endogenous technical change of the early 1990s (see, for instance, Aghion and Howitt 1998, Grossman and Helpman 1991, Romer 1990), claiming that the return to technological investments is partly private and partly public (Keller 2004). Because of the non-exclusive character of technology an innovation, which is produced by one firm, may and can also be used by another firm, without incurring very much additional cost (Smolny 2000). These are technology or knowledge spillovers.

The central objective of this paper is to test whether, and to what extent, firm's ability to innovate is induced by firm's own R&D activity as well as factors external to firm and what are the most important channels of external knowledge spillovers. These can be in the form of direct technology transfer (through FDI, trade, licensing, importing etc.), learning effects (innovation spillovers and learning-by-exporting) as well as in the form of public R&D subsidies. So far, most of these channels have been studied separately[1]. Here, we analyse the impact and determine the relative importance of direct and indirect knowledge transfer through inward FDI and trade versus the impact of R&D subsidies and firms' own R&D activity for innovation activity of firms within an integrated dynamic model. We pay particular attention to firms' absorption capacity and other determinants of firms' innovation activity and external knowledge spillovers identified in the literature.

In building the conceptual approach for testing the relevance of external knowledge spillovers, the channels of external knowledge spillovers occupy the central place. However, since we test the relevance of external knowledge spillovers in an integrated framework, we are also interested in the endogenous factors of firms' innovation activity, firms' own R&D in the first place. Firms' endogenous factors co-determine their absorption capacity for external knowledge spillovers as well.

[1] A notable exception is Ornaghi (2004), who modelled knowledge capital as a function of own investment in R&D and spillovers. She explicitely claims that in examining the role of external knowledge spillovers for firms' innovation, one must do that in the framework of an integrated framework of explaining firms' innovatory activcity, i.e. one should take into account endogenous factors of firms' innovatory activity, as well as external knowledge spillovers.

Most of the existing empirical studies estimate either the rate of return to firms' own R&D expenditures or the impact of external knowledge spillovers on firms' productivity growth. Instead, we estimate the impact of firms' internal R&D capital and external R&D spillovers on firms' productivity growth in a two step procedure. In the first step we determine the impact of firm own R&D capital and external R&D spillovers on firm's innovation activity. In the second step, we then estimate the efficiency of firms' innovation activity, i.e. we estimate the impact of firm's innovations on firms' productivity growth. In doing so we use firm level data on innovation activity (based on CIS) combined with firm financial data for a large sample of Slovenian firms in the period 1996-2002 and apply both simple OLS regressions as well as more sophisticated econometric approaches, such as matching techniques.

The remainder of the paper is structured as follows. Section two provides the theoretical background on innovation, knowledge spillovers and productivity growth. Section three discusses firm's own R&D and other channels of external knowledge spillovers as a determinant of firm's innovation capacity. Section four presents descriptive analysis of the determinants of innovation activity, while Section 5 provides estimations of the effect of the innovation activity on firms' productivity growth. The last section concludes.

2. Theoretical background

Eaton-Kortum (1996) model. In a seminal study on innovation, technology diffusion and productivity growth Eaton and Kortum (1996) propose a quality ladders based model of aggregate growth in line with that of Grossman and Helpman (1991). It is assumed that homogenous and freely tradable output is produced with a constant-returns-to-scale Cobb-Douglas production function. The primary driver of output growth is the changing quality of inputs as the number of inputs used in production remains constant over time and is the same across countries. Adopted inventions improve the quality of inputs by a percentage amount, where the size step of the invention is a random variable drawn from the exponential distribution. The same invention may be adopted in more than one country, but some inventions will only be applicable to the technologies of one or two (ε is the marginal probability that an invention that occurred in one country is applicable in another). Crucially, Eaton and Kortum assume that a given invention is a larger inventive step in technologically less developed countries, henceforth inventions in technologically more advanced countries are, on average, bigger and better.

International knowledge spillovers are limited by the probability that an invention made in one country can be adopted in another (ε), which is, among other things, dependent on the distance between the two countries, the level of human capital in the adopting country and the level of adopting country's imports (as a share of GDP) from the innovation-generating country. The second factor clearly reflects the absorption capacity of the knowledge adopting country, while the third factor explores trade as an additional vehicle for technology diffusion.

Baldwin-Braconier-Forslid (2005) model. Filling a void in firm-level theoretical and empirical work on the role of foreign direct investment (FDI) on openness and growth Baldwin, Braconier and Forslid (2005) present a growth model where multinational companies (MNCs) affect the endogenous growth of incumbent firms via technological spillovers. The novelty of their approach lies in the fact that the pro-growth role of MNCs is not limited to the direct effects as knowledge-spillovers assume an important role in the growth rate of domestic firms.

The basic model of MNCs is based on Horstmann and Markusen (1987) where the motives for FDI can be characterized by the tradeoff between scale of production and proximity to markets (as described by Brainard (1997)). The world consists of two symmetric countries producing two traded goods (a Walrasian perfectly competitive good and a differentiated good) using two factors (labor and knowledge capital). Where the homogenous good is produced using labor as the only factor, manufacturing varieties of the differentiated product requires both labor and capital inputs. Production of the manufacturing variety requires a_x units of labor as well as a one-time investment in a unit of variety-specific knowledge based capital, K. However, knowledge capital is not a primary factor and has to be produced with a_I units of labor under perfect competition. This yields the familiar cost function for production in the differentiated-goods sector with the fixed cost of production (F) equaling a_I units of labor. Crucially, the authors assume that the know-how embodied in each variety-specific unit of knowledge capital cannot be patented since it involves tacit knowledge embodied in workers and can therefore be exploited (in slight variations) by other firms. This assumption ensures that K is not internationally traded at arm's length. Any firm hoping to exploit its own knowledge capital is therefore forced to either export finished goods or produce abroad by becoming an MNC. Demand choices are based on the Cobb-Douglas structure of preferences between homogenous goods and an index of differentiated goods. Furthermore, in line with other similar studies, the composite index of differentiated (i.e. manufacturing goods) is constructed as a CES function over all available varieties (domestically produced and imported).

The decision between the two forms of servicing the foreign market is, as is common in related literature, dependent on the importance of the cost of exporting (τ) and the cost of setting up local production in the foreign country (additional fixed cost in terms of knowledge capital, Γ). FDI occurs for levels of trade free-ness and FDI barriers satisfying:

(1) $$\Gamma \leq \frac{1-\tau^{1-\sigma}}{1+\tau^{1-\sigma}}$$

where σ is the elasticity of substitution between differentiated varieties. This, fairly standard result, reveals the aforementioned trade-off between proximity (as proxied by transport costs) and concentration (as measured by additional cost of establishing foreign-based production facilities, Γ). As trade costs increase reducing the ratio on the right-hand side of (1) FDI will be more likely to occur at a given level of Γ.

Modeling spillovers. Given the focus of this paper, we are particularly interested in the modeling of knowledge spillovers in the above setting. At the heart of the endogenous growth model, as presented by Baldwin et al., are learning externalities in the capital- producing (i.e. innovation) sector. The authors assume the existence of Marshall-Arrow-Romer (MAR) or Romerian externalities driven primarily by ongoing communication among firms within a sector with the level of communication driven primarily by proximity (location) rather than the level of economic interaction among firms. Knowledge therefore flows from one firm to another via a process the authors label "osmosis". The process of knowledge transfers is formalized by assuming the existence of a sector-wide learning curve in the knowledge-capital-producing sector (i.e. innovative sector) where learning is of the "osmosis" type. Productivity of innovation-sector labor improves as the cumulative output (and experience) of the innovation sector rises. Firms therefore become more efficient at developing varieties as more varieties are developed. Specifically, Baldwin et al. assume the following learning curve in the innovating sector:

(2) $$a_I = \frac{1}{(K+\lambda K^*)+\mu(n+m+m^*)}; \quad 0 \leq \lambda \leq 1,\ 0 \leq \mu$$

where λ measures the internationalization of spillovers and μ measures the importance of spillovers due to diversity and learning across sectors[2]. The above learning curve ensures that with the same amount of labor in the innovative sector more knowledge capital is produced as while the fixed cost of production is reduced.

Although Baldwin et al. do not explicitly consider the absorption capacity of individual firms for knowledge spillovers, it can be easily incorporated into the model by simply assuming that the learning curve (and with it the scope for possible knowledge spillovers) differs depending on a threshold level of firm size and/or its accumulated knowledge capital.

3. Knowledge spillovers, firms' absorption capacity, innovation activity and productivity growth

The main objective of our paper is to analyse whether and to what extent external knowledge spillovers impact on firms' innovation activity. Based on the generally accepted premise that technology plays a key role in determining productivity, and due to the non-availability of explicit data on firms' innovation activity, empirical studies of the impact of external knowledge spillovers on firms' innovation activity as a rule regress productivity growth on external knowledge spillovers, most often those via FDI. The result is then interpreted as the impact of external knowledge spillovers on firms' innovation activity. This, however, is only an indirect measure, only the second best solution, which bears certain problems. The problem of measuring technological externalities with productivity spillovers is recognised by several authors. Alvarez and Robertson (2004) point that by using indicators of technological innovation they avoid the use of productivity measures that have been controversial in previous studies. Chen (1997) suggests that one of the problems with studies that link trade to productivity is that productivity is often measured as a residual, where anything not included in the estimation equation could contribute to productivity. Smarzynska (2003) indirectly points to the same problem by recognizing that while the knowledge spillovers present a rationale for governments to susbsidize FDI inflows, this is not the case when improved productivity of local firms is due to increased competition, as inducing greater competition may be achived by other means (import liberalization, anti-trust policies etc.).

The problem of measuring the impact of external knowledge spillovers (or technological externalities) with productivity spillovers arises from the fact that there are other factors, apart from technological externalities, which have an impact on productivity spillovers and which are not controlled for in the models. In other words, technological externalities may be the most important factor of productivity spillovers, but not the only one. To the extent that productivity spillovers are also a result of other factors apart from technological externalities, the productivity spillovers are not really a good indicator of technological externalities[3]. There are also factors that may prevent the transformation of technological externalities into productivity spillovers, like the bankruptcy of domestic firms due to strong foreign competition, insufficient absorption capacity of domestic enterprises for technological externalities, system/institutional deficiencies etc.[4] To eliminate these problems our proposition is to measure the impact of

[2] These are also termed Jacobian spillovers and involve learning across sectors and activities. In this case, the production of manufacturing varieties (n + m + m*) serves as a source of cost-saving spillovers to the *I* sector.

[3] Ornaghi (2004) points exactly to this issue. His results in the Spanish case suggest that knowledge spillovers play an important role in improving the quality of products and, to a lesser extent, in increasing the productivity of the firm.

[4] The problem here is that much work remains to be done until the precise process of spilling-over will be described correctly; the exact channels of embodied and disembodied spillovers remain undetermined.

external knowledge spillovers directly by their impact on firms' innovation activity. Therefore, we estimate the probability of firms' innovation activity due to external knowledge spillovers and public R&D subsidies, own R&D in the firms, firms' absorption capacity and a number of control variables, which co-determine firms' innovation activity and the extent of external knowledge spillovers[5]. In the remainder of this Section we discuss briefly the importance of each of the determinants.

3.1. Own R&D as a determinant of firm's innovation activity

Own R&D is the crucial determinant of firm's innovation activity/capacity and of firm's capacity to absorb external knowledge. For this reason, R&D can be thought of as having two complementary effects on a firm's innovation activity and productivity growth (Cohen and Levinthal 1989). First, R&D directly expands a firm's technology level by new innovations, which is called the innovation effect. On the other hand, it increases a firm's absorptive capacity – the ability to identify, assimilate and exploit outside knowledge, which is usually called the learning or the absorption effect. These two important effects are both included in our model.

Theoretical foundations for the innovation effect are supplied by the literature on endogenous innovation and growth (see, for instance, Aghion and Howitt 1992, 1998, Grossman and Helpman 1991, Romer 1990). Cameron, Proudman and Redding (2003) quote a body of empirical work in favour of positive influence of R&D on productivity growth. Important references include Griliches (1980), Griliches and Lichtenberg (1984), Mansfield (1980), Hall and Mairesse (1995), Griffith, Redding and Simpson (2004). The R&D capital model has been the ruling research paradigm to investigate the relationship between firms' innovation and productivity growth. This approach adds some measure of knowledge capital, computed from the data on R&D, to the list of inputs entering the production function. According to (Ornaghi 2004), a distinguishing feature of this type of capital is that it does not depend only on firms' own research effort, but also on the pool of general knowledge a firm has access to, i.e. a firm may learn from innovations of other firms. This is how technological externalities or spillovers are brought in the model.

Firm's own R&D activity is not the only determinant of its external knowledge spillovers absorption capacity. Also one should distinguish between firm's and country's abrsorption capacity; the former importantly depends on the latter. The capacity to adopt external knowledge spillovers, often referred to as "technological capabilities" (Wang 1989, Lall 1992) or "national absorbtive capacity" (Movery and Oxley 1995), depends on a number of factors. Domestic technological capabilities, R&D investments and human capital are the most obvious (Cameron, Proudman and Redding 2003). Borenzstein, De Gregorio and Lee (1998) and Hoppe (2005) stress the importance of human capital that exists and is used in the economy. They claim that the contribution of FDI to the transfer of technology and economic growth is greater the higher the level of human capital stock in the host economy. Other determinants of absorption capacity identified in the literature includes company size (Ornaghi 2004), trade, investment and business climate in a host country[6], and the extent of agglomeration of foreign

[5] Regressing of both productivity growth and innovation activity on external knowledge spillovers would enable to differentiate between the technological and competition externalities of external knowledge spillovers, which is of relevance for economic policy.

[6] The better and the more liberal the investment and business climate the higher the spillover effects (Keller 2004, Balasubramanyam, Salisu and Sapsford 1996, Moran 1998).

subsidiaries in a host country (Sgard 2001)[7]. Yet another possible determinant of knowledge and FDI spillovers, which has not beeen mentioned or analysed in the literature, is the size of a host economy. It seems logical that a host economy should have a certain critical size to enable foreign subsidiaries to engage local suppliers and to influence local competitors. This seems especially relevant in the case of local suppliers, i.e. backward linkages. Small size of the Slovenian economy is certainly not an aspect in favour of knowledge and FDI spillovers.

3.2. Channels of external knowledge spillovers

The channels of international technology transfer and their importance for growth have been studied extensively in the 1990s. These studies identify three principal channels of international research and development (R&D) spillovers. The first is a direct transfer of technology via international licensing agreements (Eaton and Kortum 1996), though recently these provide a less important source, as the latest and most valuable technologies are not available on license (UNCTAD 2000). The second is FDI that provides probably the most important and the cheapest channel of direct technology transfer as well as of indirect knowledge spillovers to developing countries. The third channel of technology transfer is through international trade, in particular imports of intermediate products and capital equipment as well as through learning-by-exporting into industrial countries.

<u>Direct FDI effects (foreign vs domestic ownership).</u> In dealing with FDI as a source of foreign technology and productivity growth one should distinguish between direct effects of FDI and FDI spillovers. Direct effects of FDI relate to the impact of foreign ownership on the technology transfer to and productivity of foreign subsidiaries; they relate to the issue of why are foreign sisbsidiaries (or MNEs in general) more efficient than domestic companies (or non-MNEs in general). Thus, in measuring contribution of FDI to the technological upgrading of a host country one should first take into account the technological endowment of the local subsidiary of a foreign firm, which can be expected to be superior to that of local producers (Sgard 2001).

There is a lot of empirical evidence on positive direct technology transfer from a MNE to its local affiliates in terms of higher productivity levels and growth. These studies, using firm-level panel data, include developed as well as developing countries (e.g. Haddad and Harrison 1993, Blomström and Wolff 1994, Blomström and Sjöholm 1999, Aitken and Harrison 1999, Girma, Greenaway and Wakelin 2001, Barry, Görg and Strobl 2002, Alverez, Damijan and Knell 2002, Blalock 2001, Damijan, Knell, Majcen, Rojec 2003b etc.). FDI as a source of foreign technology and productivity growth has been particularly important for firms in transition economies because of the urgent need to restructure quickly. Foreign ownership often provides local firms with efficient corporate governance, as they - mainly privatized to insiders - do not have incentives and resources to restructure (Blanchard 1997). FDI may also be the cheapest means of technology transfer, as the recipient firm normally does not have to finance the acquisition of new technology. And it tends to transfer newer technology more quickly than licensing agreements and international trade (Mansfield and Romero 1980), and has the most direct effect on the efficiency of firms. Damijan, Knell, Majcen and Rojec (2003b), on a set of more than 8,000 firms for 10 advanced transition countries in the period 1995-1999, find that direct FDI provide by far the most important productivity effect for local firms.[8]

[7] In order to have positive spillover effects, foreign firms must represent a substantial share of the economy.

[8] Direct effects of FDI are found to provide on average an impact on a firm's productivity that is larger by factor 50 than the impact of backward spillovers and by factor 500 larger than the impact of horizontal spillovers.

FDI spillovers. The issue of FDI spillovers is the most extensively analysed channel of external knowledge spillovers in the literature. Knowledge spillovers from FDI take place when the entry or presence of foreign subsidiaries, which have typically better technologies and organizational skills than domestic firms, increases knowledge of domestic firms and MNEs do not fully internalize the value of these benefits (Smarzynska 2003). The presence of a foreign subsidiary can thus increase the rate of technical change and technological learning in the host economy indirectly through knowledge spillovers to domestic firms.

Kokko (1992) and Blomstrőm and Kokko (1998) identify at least four ways how technology might be diffused from foreign subsidiaries to other firms in the economy: (i) demonstration-imitation effect, (ii) competition effect, (iii) foreign linkage effect and (iv) training effect. Demonstration effect occurs if domestic firms learn superior production technologies from arm's length relationships with foreign subsidiaries. Competition effect is when competition from foreign subsidiaries forces domestic rivals to update production technologies and techniques to become more productive (see, for instance, Griffith, Redding and Simpson 2004, Lim 2001 etc.). Foreign linkage effect goes through engaging of domestic suppliers for foreign subsidiaries (see, for instance, Markusen and Venables 1999, Görg and Strobl 2004, Griffith, Redding and Simpson 2004 etc.) and by foreign subsidiaries giving access to new specialized intermediate inputs also for domestic firms (Rodriguez-Clare 1996), or because domestic firms use local intermediate goods suppliers whose productivity has been raised through the know-how supplied by foreign subsidiaries (Keller and Yeaple 2003). Training effect is present if there are movements of highly skilled staff from MNEs to domestic firms; these employees may take with them knowledge which may be usefully applied in domestic firms (see, for instance, Görg and Strobl 2004, Griffith, Redding and Simpson 2004, Keller and Yeaple 2003, Lim 2001 etc.). Not all spillovers are positive as FDI can generate negative externalities when foreign firms with superior technology force domestic firms to exit, since they attract away demand from them. These negative externalities of the competition effect are also often called crowding-out effect or business-stealing effect (see, for instance, Aitken and Harrison 1999, Haddad and Harrison 1993, Djankov and Hoekman 2000 etc.).

FDI spillovers' literature further distinguishes bettween technology spillovers through FDI that occur between firms that are vertically integrated with the MNE (vertical, inter-industry spillovers to domestic firms in upstream and downstream industries) or in direct competition with it (horizontal, intra-industry spillovers). Since MNEs have an incentive to prevent information leakages that would enhance the performance of their local competitors, but at the same time may want to transfer knowledge to their local suppliers, spillovers from FDI are more likely to be vertical than horizontal in nature[9] (Smarzynska 2003). The empirical literature captures mainly those occurring between firms within the industry. The reason is that competitive effects within an industry are much easier to measure than linkage effects across industries. The authors, who explicitely bring the notion of vertical and horizontal spillovers in the literature are Blalock (2001), Schoors and van der Tol (2001), Smarzynska (2001), Smarzynska (2003), Smarzynska and Spatareanu, (2002), and Damijan, Knell, Majcen and Rojec (2003), which all provide evidence of positive FDI spillovers through backward linkages[10].

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[9] For a theoretical justification of spillovers through backward linkages see Rodriguez-Clare (1996), Markusen and Venables (1999), and Saggi (2002), for case studies see Moran (2001).

[10] Lall (1980) identifies the following MNE/supplier interactions that can help increase the productivity and efficiency of local firms: (i) helping prospective suppliers set up production facilities; (ii) demanding from suppliers reliable, high quality products that are delivered on time, while also helping the suppliers to improve

Imports and learning-by exporting. International trade works as a channel of technology transfer either through imports of intermediate products and capital equipment (Feenstra, Markusen and Zeile 1992) or through learning-by-exporting into industrial countries (Clerides, Lach and Tybout 1998)[11]. Several authors have recently examined the issue of technological externalities associated with trade. A first set of papers has looked for international R&D spillovers driven by imports. According to Keller (2004), overall evidence supports the notion that importing is associated with technology spillovers, but we do not know how strong diffusion through embodied technology in intermediate goods versus other technology diffusion associated with imports are. Keller and Yeapl (2003) and Keller (2004) provide a survey of literature on technology spillovers via imports: Eaton and Kortum (2001) claim that differences in relative price of equipment account for 25% of the cross-country productivity differences in a sample of 34 countries; Coe and Helpman (1995) for a sample of 22 OECD countries find that country's productivity is increasing in the extent to which it imports from high- as opposed to low-R&D countries[12]; Coe, Helpman and Hoffmesister (1997) find similar effects for technology diffusion from highly industrialized to less developed countries; Xu and Wang (1999) emphasize that it is imports of differentiated capital goods (machinery), which have a positive impact on productivity[13], while Keller (2000) came to the same results for specialized machinery imports; Lumenga-Neso, Olarreaga and Schiff (2001) also demonstrate positive spillovers from imports. More recent research has sought to provide a more powerful empirical framework by employing more disaggregated data and allowing for alternative spillover channels in addition to imports. This has produced mixed results so far; for instance, Keller's (2002b) industry-level analysis of technology spillovers among the G-7 countries finds evidence in support of imports-related effects, while Kraay, Isoalaga and Tybout (2001) in their study of firm productivity dynamics in three less developed countries do not.

Comparing to imports there is much less evidence for knowledge spillovers via learning-by-exporting. Conventional wisdom is that learning-by-exporting effects are non-existent and this is consistent with current evidence. According to Keller (2004), learning-by-exporting effects have been found in the case study literature, whereas authors of econometric studies take a much more sceptical view. In a meta analysis of recent studies Wagner (2005) finds no conclusive evidence in favor of the learning by exporting hypoheses.

R&D subsidies. In the context of the research questions which we tackle in the present paper, the crucial issue of R&D subsidies is whether there are any positive spillovers from public to private R&D expenditures, i.e. from R&D subsidies given by the government to firms' own R&D expenditures (David, Hall and Toole 1999). In other words, in evaluating the effect of the R&D subsidy, the government should know, or at least have an idea, how much the firm would have spent on R&D had it not received the subsidy (Lach 2000). Are R&D subsidies stimulating or displacing company-financed R&D? Is public spending complementary and thus

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the products or facilitate innovations; (iii) providing training and help in management and organization; and (iv) assisting suppliers to find additional costumers including subsidiaries in other countries.

[11] Hoppe (2005) distinguishes three types of effects that trade has on technology transfer. First, direct effects resulting from import of capital goods, including modern technology, and intermediate goods of increasing variety and quality. Second, dynamic gains from trade resulting from an integrated world market that leads to higher production, mastering of better techniques and increase of productivity. Third, trade increases the set of technologies that are available in a country.

[12] They also show that these benefits are larger the more open an economy is to trade.

[13] Keller (1998) generates almost as strong results with counterfactual instead of observed imports data. This undrelines that the evidence for imports-related technology spillovers on the basis of these regressions is not very strong.

»additional« to private R&D spending, or does it substitute for and tend to »crowd out« private R&D? The standard rationale for government support of R&D is rooted in the belief that some form of market failure exists that leads the private sector to underinvest in R&D (Arrow 1962, Nelson 1959). Underinvestment in R&D occurs because the social benefits from new technologies are difficult to appropriate by the private firms bearing the costs of their discovery, and because imperfect capital markets may inhibit firms from investing in socially valuable R&D projects (Griliches 1998, Romer 1990). The output of R&D is characterised by its public good nature, which implies that benefits are not fully appropriable by the investor but generate domestic and international spillovers that might be captured by competitors. Economic incentives therefore do not generally lead firms to undertake the first best level of R&D spending. The aim of government intervention in R&D activity is to estabilh efficiency.

Therefore, publicly supported R&D is suppose to augment or complement private R&D expenditures. Yet the empirical evidence suggests that there is some subsitution between private and government funded R&D. Wallsten (2000) showed that a subset of publicly traded, young, technologicaly intensive US firms, reduced their R&D spending in the years following the award R&D subsidieis, while in about 30% of the Spanish firms analysed by Busom (2000) public funding fully crowds out privately financed R&D. On the other hand, Klette and Moen (1997) claim that the R&D susbsidies significantly expanded R&D expenditures of a sample of high-technology Norwegian firms and there was little tendency for crowding out. Lach (2000) concludes that R&D susbsidies to Israeli manufacturing firms stimulated long-run company-financed R&D expenditures; an extra dollar of R&D subsidies increases long-run company-financed R&D expenditures by 41 cents. The principal reasons for the substitution effect of R&D subsidies on private R&D expenditures are: (i) subsidizing of projects that firms would undertake even in the absence of subsidies, (ii) firms adjust their portfolio of R&D projects by closing or slowing-down non-subsidized projects, (iii) increased prices of R&D inputs due to increased demand arising from R&D subsidies (Lach 2000, David, Hall and Toole 1999).

David, Hall and Toole (1999) survey the body of available econometric evidence and also find ambivalent results. The survey does not offer a definite empirical conclusion regarding the sign and magnitude of the relationship between public and private R&D. One third of the studies they analysed report that R&D funding behaves as a substitute for private R&D investment. The substitution effect result is far more prevalent among the studies conducted at the line-of-business and firm level, than among those carried out at the industry and higher aggregation levels[14]. Of 19 analyses at the firm level 9 report substitution, however, this is mostly due to the USA: of 12 studies based on US data 7 report substitution, while of 7 studies on other countries' data only 2 report substitution. Complementarity is thus much stronger in the case of non-US studies and vice versa in the case of US studies. These results point to the methodological problems which influence the results of econometric studies. They are related to (i) possible mutual interdependence of public and private R&D expenditures because of simultaneity and selection bias in the funding process, or because of omitted latent variables that are correlated with both the public and private R&D investment decisions, (ii) unobserved inter-industry differences in the technological opportunity set, which are likely to induce positive covariation in the public and private components of total industry level R&D expenditures, (iii) at the aggregate level the likely positive effect on R&D input prices of expanded government funding contributes to the appearance of complementarity movemements in the private and public components of nominal R&D expenditures.

[14] The similarity with the empirical findings on FDI spillovers is more than obivous. The methodology – sectoral versus firm level econometrics – obviously has an important impact on the results.

4. Determinants of firms' innovation and

In this section we make use of the official Community Innovation Surveys (CIS1, CIS2, CIS3) in order to reveal the determinants of the innovation activity by Slovenian firms. Innovation surveys in Slovenia are being conducted by the Slovenian Statistical office every second year, starting in 1996. Up to now there have been four such extensive innovation surveys carried out – in 1996, 1998, 2000 and 2002. These innovation surveys are being carried out among a wide sample of manufacturing and non-manufacturing firms with no conditions put on actual R&D activity by these firms. Hence, these surveys allow for a broad picture of determinants of the innovation activity and its impact on performance of Slovenian firms.

4.1. Descriptive statistics of innovation activity by Slovenian firms

In this sub-section we show some descriptive statistics of innovation activity by Slovenian firms. Innovation activity of individual firms has been analysed with regard to the type of ownership, firm's size as well as technological intensity of sectors. Table 1 reveals that the rate of innovation activity, which captures both product innovation and process innovation,[15] is comparatively low in Slovenia[16]. Only about 20% of Slovenian firms innovate, i.e. have claimed to have conduct at least one innovation of products and services or innovation of processes in the respective 2-year period. What is striking is the negative trend of innovation activity of Slovenian firms, showing that the share of innovative Slovenian firms is shrinking from 1998 to 2002.[17] This is predominantly due to the low innovation activity of indigenous firms (only 17% of firms with domestic owners are innovative). Among foreign owned firms (firms with 10% or higher foreign equity share) the share of innovative firms is twice as high as in domestic firms. This indicates a more competitive and innovation conducive environment in foreign owned firms.

Table 1: R&D expenditures and innovation activity of Slovenian firms by type of ownership, 1996-2002 (%)

	N	R&D/Sales (Innovative firms)	R&D/Sales (Non-Innovative firms)	Fraction of Innovative firms
All firms				
1996	1,454	1.5	0.026	21.7
1998	1,777	1.6	0.003	23.0
2000	2,518	6.0	0.021	21.2
2002	2,564	6.5	0.015	20.6
Domestic				
1996	1,148	1.4	0.027	18.6
1998	1,371	1.5	0.003	19.5
2000	1,923	7.1	0.023	17.5
2002	1,935	6.4	0.004	17.3
Foreign				
1996	306	1.8	0.023	33.3
1998	406	1.9	0.003	34.7
2000	595	4.1	0.012	32.9
2002	629	6.6	0.055	30.5

Source: Statistical office of Slovenia; own calculations.

[15] Throughout this section we don't discriminate between innovation of products (services) and innovation of processes. The analysis of determinants of both types of innovation activity (see sub-section 5.1.2) shows no major differences between them, therefore we treat them together in one single variable.

[16] Comparing the share of innovating firms with the one reported for Italy (Parisi et al. 2006) one can see that the share of innovating firms is substantially smaller in Slovenia. About 80% of the firms in the Italian sample declared themselves as innovators, whereby it should be noted that the sample in question was restricted to manufacturing firms only.

[17] The share of innovative firms is shrinking in spite of the fact that total R&D expenditure is increasing.

Table 2: R&D expenditures and innovation activity of Slovenian firms by size and ownership type, 1996-2002 (%)

	N		R&D/Sales (Innovative firms)		R&D/Sales (Non-Innovative firms)		Fraction of Innovative firms	
	Dom	For	Dom	For	Dom	For	Dom	For
Small								
1996	578	67	1.6	2.2	0.011	0.000	8.8	13.4
1998	790	121	1.0	2.2	0.000	0.000	10.5	11.6
2000	1,358	265	9.4	5.4	0.021	0.000	11.4	14.7
2002	1,424	281	9.0	16.1	0.000	0.016	12.4	11.7
Medium								
1996	438	146	1.4	1.9	0.017	0.011	22.6	27.4
1998	447	183	2.1	1.8	0.008	0.000	25.5	35.5
2000	445	215	5.5	4.5	0.030	0.005	26.3	40.9
2002	406	222	4.1	4.9	0.019	0.144	24.9	36.9
Large								
1996	132	93	1.2	1.8	0.198	0.087	48.5	57.0
1998	126	102	1.0	1.9	0.003	0.022	56.3	60.8
2000	120	115	4.7	2.9	0.025	0.092	54.2	60.0
2002	105	126	2.6	4.3	0.010	0.000	54.3	61.1

Source: Statistical office of Slovenia; own calculations.

Breaking down the sample according to firm size into small (less than 50 employees), medium (50 - 250 employees) and large firms (more than 250 employees) shows that there are on average three- to four-times more innovative firms among the medium-sized enterprises than among the smaller firms, while among large firms the share of innovative firms is five- to six-times larger than among small firms. Again, Table 2 reveals significant differences among domestically and foreign owned firms in Slovenia. Firms with foreign ownership, especially if they are of medium or large size, are more likely to be innovative than firms with domestic owners. More precisely, on average 30% - 35% of foreign owned medium sized firms are innovative, while this ratio falls to about 25% for firms with no foreign ownership. With large firms this difference is smaller as 60% of foreign owned firms relative to 55% of domestically owned firms are innovative.

Table 3: R&D expenditures and innovation activity of Slovenian firms by technology defined sectors and ownership type, 1996-2002 (in %)

	N		R&D/Sales (Innovative firms)		R&D/Sales (Non-Innovative firms)		Fraction of Innovative firms	
	Dom	For	Dom	For	Dom	For	Dom	For
Low tech								
1996	314	98	0.7	0.6	0.026	0.003	17.8	31.6
1998	333	110	0.8	0.9	0.004	0.000	20.1	39.1
2000	423	138	4.2	3.1	0.004	0.002	15.6	39.1
2002	413	147	3.5	4.8	0.004	0.015	14.8	40.1
Medium-low tech								
1996	451	96	0.7	0.5	0.005	0.015	12.0	18.8
1998	548	149	0.8	1.0	0.001	0.000	11.1	23.5
2000	867	256	5.4	3.7	0.007	0.020	11.0	20.7
2002	923	266	5.6	4.5	0.005	0.000	10.7	18.8
Medium-high tech								
1996	154	61	2.3	2.6	0.011	0.062	31.2	50.8
1998	203	71	2.0	2.3	0.000	0.025	35.0	49.3
2000	245	103	5.4	4.1	0.000	0.012	30.6	47.6
2002	243	101	4.1	3.4	0.000	0.101	34.2	39.6
High tech								
1996	229	51	2.0	3.6	0.087	0.047	24.5	43.1
1998	287	76	2.2	4.0	0.007	0.000	24.0	36.8
2000	339	90	9.6	5.9	0.117	0.000	25.4	42.2
2002	329	107	11.3	7.2	0.002	0.240	26.1	35.5

Source: Statistical office of Slovenia; own calculations.

Table 3 looks at the differences in innovation activity among firms in different technology intensity cohorts.[18] It turns out that the most innovative firms are those in the medium high technology sectors, such as electrical appliances, automotive production, machinery and chemical production. But there again, foreign owned firms exhibit up to 20 percentage points higher figures of innovation activity. High technology sectors' firms also exhibit above average innovation activity, but substantially lower than those in medium high technology sectors (25% relative to 35%, respectively). For foreign owned firms these differences in innovation activity across sectors are less prominent, since, with the exception of the medium low technology sectors, foreign owned firms seem to be equally inclined to innovation activity at a rate of about 40% - 50%.

What is especially striking in Tables 1 – 3 is that higher innovation activity by foreign owned firms is not necessarily backed by their higher own R&D expenditures (relative to total sales). The fact is that in the last two innovation surveys (2000, 2002) foreign owned firms show proportionally less R&D expenditures comparative to domestically owned firms. Hence, their higher propensity to innovate must be driven by other factors, such as constant transfer of technology and other knowledge spillovers from their parent companies. Next sub-section explores the issue further.

4.2. Determinants of firms' innovation in Slovenia

In this sub-section we explore the factors driving innovation activity of Slovenian firms. Table 4 describes the sample characteristics with respect to the determinants of innovation activity. It is revealed that innovation activity of firms is persistent over time, i.e. firms that have innovated two years ago are more likely to innovate in the present. Table 4 also demonstrates that innovative firms are likely to be larger in terms of employment, invest much more into R&D and also attract higher proportion of subsidies, either public of foreign.[19] At the same time, innovative firms also export a larger share of their sales and are more likely to be foreign owned. Surprisingly, innovative firms do not seem to be more productive in terms of value added per employee (measured in terms of the individual sector average).

Table 4: Determinants of firms' innovation in Slovenia, 1996-2002 (in %)

	N	INOV_ t-2	rVA/ Emp	Emp	R&D/ Sales	R&D/VA	Total sub./R&D	Public sub./ R&D	Foreign sub./ R&D	Ex/ Sales	IFDI
Innovative firms											
1996	316	-	1.26	346.7	1.55	5.39	5.39	3.12	0.27	43.9	0.388
1998	409	0.643	0.84	312.9	1.62	5.96	4.07	2.42	0.85	43.1	0.397
2000	533	0.554	1.11	278.5	6.02	19.22	4.33	3.42	0.59	38.1	0.368
2002	527	0.694	1.09	283.6	6.47	18.42	4.98	3.14	1.08	43.7	0.364
Non-Innovative firms											
1996	1138	-	1.19	122.8	0.026	0.101	0.180	0.066	0.054	25.7	0.254
1998	1368	0.095	1.11	96.5	0.003	0.006	0.004	0.004	0.000	27.3	0.237
2000	1985	0.122	1.01	68.5	0.021	0.047	0.013	0.013	0.000	21.6	0.201
2002	2037	0.113	0.99	67.5	0.015	0.038	0.016	0.000	0.001	22.8	0.215

Source: Statistical office of Slovenia; own calculations.

In order to reveal the importance of these individual factors on firms' innovation activity we estimate the probability to innovate of a firm *i* in period *t* ($INOV_{it}$):

[18] Individual sectors are classified into four technology intensity groups (low technology, medium-low technology, medium high technology and high technology) according to OECD methodology.

[19] However, R&D subsidies on average do not represent significant share of R&D expenditure. According to innovation survey innovation expenditure were mostly covered by own funds.

$$\Pr(INOV_{it} = 1 | \mathbf{M}_{it}) = G(\omega \mathbf{M}_{it}), \quad (3)$$

where $\mathbf{M}_{it}$ is a matrix of operational characteristics of firms. We assume that errors are IID distributed and have an independent extreme-value distribution. The dependent variable $INOV_{it}$ is equal to 1 if a firm has made any innovation of products (services) or production processes in period *t*, and 0 otherwise. The control variables contained in $\mathbf{M}_{it}$ are those listed in table 4, i.e. a dummy for past innovation activity (lagged one period, i.e. two years), firm size (number of employees), firm relative productivity (firm value added per employee relative to the average productivity of particular sector), share of R&D expenditures in total sales, export propensity and dummy for foreign ownership as well as three variables for the importance of R&D subsidies (total R&D subsidies, public R&D subsidies and R&D subsidies received from abroad, all as share of total firm's R&D expenditures). In the model we also include horizontal and vertical spillovers from innovation activity of other firms. Horizontal spillovers are being measured by the number of innovations done in the same sector. Vertical spillovers indicators are constructed as the number of innovations conducted in a related sector multiplied by the respective input-output coefficient, where the latter reflects the strength of input – output relationship between the sectors. In other words, the more interlinked the two sectors are through bilateral supply and demand links and the higher the innovation activity in both sectors the larger is the scope for positive vertical knowledge spillovers between the both sectors. The model also takes into account the technology intensity of the sectors in which firms are operating. It is expected that firms operating in more technologically intensive sectors will be more likely to innovate in order to remain competitive or to build their technological competitive advantage over the competitors. Due to a short and non-balanced panel we do not include time dummies.

Table 5: Firms' probability to innovate* in Slovenia, 1996-2002
(Results of a probit model)

	Model 1		Model 2	
	Coef.	z-stat	Coef.	z-stat
$INOV_{t-2}$	0.821	***11.5	0.822	***11.5
Size	0.495	***10.0	0.497	***10.0
rVA/Emp	0.003	0.4	0.003	0.4
R&D/Sales	117.259	***25.2	118.173	***25.2
Total sub./R&D	7.217	***5.1		
Public sub./R&D			8.497	***4.3
Foreign sub./R&D			17.678	*1.7
IFDI	0.119	*1.7	0.117	*1.7
EX/Sales	0.112	1.1	0.103	1.0
HS_INOV	0.008	***3.3	0.009	***3.4
VS_INOV	-0.003	-0.4	-0.002	-0.4
ML tech	-0.043	-0.4	-0.056	-0.5
MH tech	-0.035	-0.3	-0.045	-0.4
H tech	-0.133	-1.0	-0.162	-1.2
Const.	-2.602	***-18.7	-2.603	***-18.7
Number of obs	4167		4167	
LR chi2(12)	2888.5		2897.6	
Prob > chi2	0.00		0.00	
Pseudo R2	0.616		0.618	

Dep.var.: $INOV_t$

* Product and process innovation are treated equally.

We estimate a probit model using the bi-annual data for a set of manufacturing as well as non-manufacturing firms in Slovenia in the period 1996 – 2002. Results for two separate probit estimations are given in Table 5. Both estimations show that firms' current innovation activity is heavily dependent on its previous innovation activity. More specifically, there is an 82% probability that a firm will innovate either a product or process if it was innovative in the previous period. Firm size positively affects firm's ability to innovate, most likely due to the scale effect, i.e. large scale of sales allows for raising enough funds for substantial R&D expenditures. This is confirmed by a highly significant and positive sign of the firm own R&D expenditures. While the literature is inconclusive regarding the importance of R&D subsidies, our results indicate that both public R&D subsidies as well as R&D subsidies received from abroad (measured as a share of firm's total R&D subsidies) significantly improved firm ability to innovate.

Foreign ownership stimulates firms to innovate, while exporting is not shown to have a significant impact of firm's innovation activity. Horizontal knowledge spillovers seem to drive firm innovation activity, while vertical knowledge spillovers are shown not to be important. This can be interpreted in the sense that highly competitive environment in terms of high innovation activity of competitors pushes individual firm to engage in R&D and innovation activity. On the other hand, technological linkages to other sectors seem to be rather weak.

Contrary ro expectations, labor productivity and technological intensity of sectors in which a firm operates do not determine their innovation activity. Endogenous growth theory namely suggests that innovating firms base their productivity on innovative effort, which could, given high serial correlation of productivity measures, translate into more productive firms also being more innovative. In addition, it is surprising that firms engaged in medium-high and high technology intensive sectors are no more likely to be innovate than their counterparts from less technologically intensive sectors. Especially since the share of innovation expenditure in sales was also considerably higher in high technology class.[20]

In addition to the above estimations, where we do not descriminate between product and process innovations, we also run separate estimation for each of these types of innovation activity. However, results (see Table A1 in Appendix) are almost identical for both types of innovation activity, which justifies our decision to treat both types of innovation in one common variable. There are only some minor differences in both separate estimations in the sense that process innovations require a slightly larger firm size, while product innovations seem to be more pronounced in foreign owned firms and seem to give slightly higher return to public subsidies.

5. Impact of innovative activity on firms' productivity growth in Slovenia

While the previous sub-section has shown the efficiency of firms' own R&D expenditures and R&D subsidies in stimulating firms' innovation activity, this sub-section is aimed at exploring the efficiency of innovations for firms' total factor productivity (TFP) growth.

In empirical work we are following a great body of literature on the contribution of R&D to firms' TFP growth. Typically, a growth accounting approach in the form of a standard Cobb–Douglas production function is used in this type of analysis (see Griliches, 1991; and Mairesse

[20] 8,5% compared to 2,5% for medium-high, 2,7% for medium low and 1,4% for low technology sectors for total sample.

and Sassenou, 1991 for comprehensive overview of the empirical studies on R&D contribution to growth). We start from the following production function:

(4) $$Y_{it} = Ae^{\lambda t} K_{it}^{\alpha} L_{it}^{\beta} R_{it}^{\gamma} e^{\varepsilon_{it}} ,$$

where Y_{it} is value added in firm i at time t, and K, L, and R represent the capital stock, employment and research capital used in production, respectively. A is a constant and λ represents the rate of disembodied technical change; e is the error term capturing all firm specific disturbances as well as measurement errors, etc. The production function is homogenous of degree r in K, L and R, such that $g = \alpha+\beta+\gamma\neq 1$, which implies that Y may have non-constant returns to scale. α , β and γ are the elasticities of production with respect to capital, labor and R&D capital. Our main focus is placed toward the estimated elasticity γ, which reflects the marginal productivity or rate of return of output to R&D capital.

By log-linearizing one can easily rewrite (2) in the form of first differences:

(5) $$\Delta y_{it} = \lambda + \alpha \Delta k_{it} + \beta \Delta l_{it} + \gamma \Delta r_{it} + \Delta \varepsilon_{it} .$$

Note that after controlling for standard inputs (labor and capital) the estimate of γ returns the contribution of R&D capital to total factor productivity (TFP) growth. We assume that R&D capital contains a set of factors that enhance innovation activity and are either internal or external to the firm. Hence, one can write R as a function of firm's internal R&D capital $\mathbf{F}_{it}$ and of various spillover effects $\mathbf{Z}_{it}$:

(6) $$R_{it} = f^{i}(\mathsf{F}_{it}, \mathsf{Z}_{it}) ,$$

where $\mathbf{F}_{it}$ contains firm own R&D expenditures, measured as a share of R&D expenditures relative in firm's total sales. $\mathbf{Z}_{it}$ captures all spillover effects that enhance firm's ability to innovate, such as foreign ownership, learning by exporting (exports to sales ratio), public R&D subsidies received either from national or international sources as well as innovation spillovers received from other firms within the same sector or from other sectors.

Note that in a panel data framework equation (2) is typically subject to firm specific time invariant disturbances, which one can take control of by using one of the standard panel data estimation techniques (within or between estimators). Alternatively, one can get rid of firm specific effects by estimating the equation as in (3), where by first-differencing the time invariant firm specific effects are simply eliminated. Another problem with the time-series cross-section specification of (2) is a potential endogeneity between the inputs and the output, which may lead to biased estimation of input coefficients. However, in such a short and unbalanced panel dataset with mostly two to three observations per firm there is little one can do about it. Correcting for this endogeneity both by using the Olley-Pakes method or general method of moments (GMM) requires longer time series of input and output data in order to be efficiently used as lagged instruments for firm's present performance.

In the next subsections we first present results obtained by using simple OLS estimations of (3), but then proceed by using more sophisticated matching techniques with propensity score in order to verify the robustness of the OLS results.

5.1. Effect of innovation on productivity growth using OLS estimations

In this subsection we present results obtained by applying simple OLS estimations of (3). In the first specification we follow other empirical studies and estimate (3) by including only R&D expenditures (relative to sales) as a measure of R&D capital. This estimate gives us the upper bound of possible return of output to R&D capital. Indeed, as shown in Table 6 (see Model 1) the estimated elasticity of R&D capital with respect to output growth for Slovenian firms in the period 1996-2002 is about 0.24. This estimate is within the bounds of returns – between 0.04 and 0.56 - found by other empirical studies with similar model specification (see Table 7).

Table 6: Impact of R&D and innovation on firm's TFP growth of Slovenian firms, 1996-2002

	Model 1		Model 2		Model 3	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
Δ Capital	0.029	***4.5	0.025	*3.4	0.021	***3.0
Δ Labor	0.446	***13.4	0.446	***13.2	0.451	***13.4
Δ R&D/Sales	0.238	*1.9				
INOV			0.069	*1.8		
p[INOV]					0.083	**2.2
IFDI			0.062	*1.8	0.051	*1.8
INOV * IFDI			-0.051	-0.8		
EX/Sales			0.052	1.3		
HS_INOV			0.001	1.5		
VS_INOV			0.002	1.4		
ML tech			-0.055	-1.2		
MH tech			0.036	0.7		
H tech			0.054	0.5		
Const.	-0.205	***-3.0	-0.302	***-3.6	-0.185	***-2.6
Time dummies	No		Yes		Yes	
Number of obs	3144		3073		3073	
F-test	72.81		21.63		45.65	
Adj R-sq.	0.064		0.069		0.068	

Dep.var.: Δ VA

*, ** and *** denote significance of coefficients at the 10%, 5% and 1%, respectively.

Table 7: Estimates of rate of return to R&D capital in some previous studies

	Sample of firms	Rate of return to R&D
Mansfield (1980)	US chemicals and petroleum firms (1960-76)	0.27
Griliches and Mairesse (1983)	US and French firms (1973-78)	0.28
Clark and Griliches (1984)	US business units (1971-80)	0.20
Sassenou (1988)	Japanese firms (1973-81)	0.22
Lichtenberg and Siegel (1989)	US firms (1972-85)	0.13
Fecher (1989)	Belgian firms (1981-83)	0.04
Griliches and Mairesse (1990)	US firms (1973-80)	0.41
	Japanese firms (1973-80)	0.56

Source: Griliches 1998.

However, in our second specification (see Model 2 in Table 6) we go one step further by estimating the impact of innovations, which is the effective result of R&D, on firm TFP growth. This is our preferred estimation returning the estimate of the rate of return to innovation of 0.069. It demonstrates that in an average Slovenian firm innovation results in TFP growth by 6.9%. In addition to it, foreign ownership enhances firm's TFP growth by additional 6.2%. Our results also show that foreign ownership does not additionally impact TFP growth through innovations (see interaction term INOV*IFDI). Foreign ownership therefore enhances firm's ability to innovate that was demonstrated already in the previous sub-section, but then it also contributes additionally to firm's TFP growth via superior organization techniques, etc.

Other external spillover variables included in our specification of model 2, such as export propensity and vertical innovation spillovers, do not seem to have any further impact on firm's TFP growth. As was demonstrated in the previous sub-section, it is very likely that these external knowledge spillovers only enhance firm's ability to innovate but do not affect firm's TFP growth *per se*. We check for this by including the predicted value of innovation that we have estimated in the probit model of "innovation production" (we take predicted values of model 1 in Table 5). The results of including this predicted innovation variable (see model 3 in Table 6) returns a bit higher estimate of the return to innovation (estimate of γ increases to 0.83). But again, foreign ownership is shown to contribute additionally 5.1% to firm TFP growth.

According to the above findings, we can draw three important conclusions for Slovenian firms. First, firm's own R&D expenditures as well as external knowledge spillovers, such as national and international public R&D subsidies, foreign ownership and intra-sector innovation spillovers, do enhance firm's ability to innovate. Second, innovations as a result of firm's R&D seem to contribute substantially to firm's total factor productivity growth. And third, foreign ownership has a dual impact on firm's TFP growth - it enhances firm's ability to innovate, but then it also contributes additionally to firm's TFP growth via superior organization techniques, etc.

5.2. Effect of innovation on productivity growth using nearest neighbor matching and average treatment effects

The results presented so far indicate that innovation and R&D expenditure may be of crucial importance as determinants of firm productivity dynamics. However, our approach so far did not control for the exact differences between innovative and non-innovative firms. In order to determine the actual effect innovative activity has on firm productivity growth one should estimate the effect of innovative activity on firm performance by comparing a sample of virtually similar firms. A way of doing this is to employ matching techniques to construct a controlled experiment. Using firm propensity to innovate we match innovating firms with otherwise similar non-innovating firms to evaluate the importance of innovation on productivity growth.[21] In order to ascertain firms' probability to innovate we run a probit regression similar to the one presented in Table 5:

$$\Pr(INOV_{it}=1)=\alpha+\beta_1 INOV_{it-2}+\beta_2 Size_{it}+\beta_3\frac{rVA}{Emp}_{it}+\beta_4\frac{RD}{Sales}_{it}+\beta_5\frac{EX}{Sales}_{it}+\beta_6 IFDI_{it}+\varepsilon_{it} \qquad (7)$$

Conditional on satisfying the balancing property of the propensity score the fitted values obtained from estimating the above equation (probit estimation) are used to pair up innovators with non-innovators and those matched pairs are subsequently used to estimate the average treatment effect of innovation on firm productivity growth. The balancing property ensures that once the observations have been stratified into blocks according to the propensity score the right hand side variables of (7) do not differ significantly between the groups of treated and non-treated observations within a block. The more closely the firms are matched with respect to

[21] Ideally, one would be able to observe the same subject with and without the treatment action to pinpoint the impact of the treatment.

regressors in (7), the more likely it is that the observed productivity differences will result from the fact that some firms managed to innovate while others did not. We match innovating firms with their non-innovating counterparts using nearest neighbor matching (with random draws) which pairs up treated with closest, with respect to the propensity score, non-treated observations. Given that our sample size is very small in some instances; all the standard errors reported were generated by bootstrapping with 100 repetitions.

Table 8-13 presents the results of average treatment effects estimates of innovation on different specifications of growth in value added per employee. In each of the tables we differentiate between manufacturing and services firms as well as take explicit account of firm size classes. Tables 8 presents the average treatment effects of innovation on labor productivity growth in the first two years after the innovation has been introduced.

$$(8) \qquad growth\left[(t+2)-t\right] = \ln\left(\frac{VA}{Emp}\right)_{t+2} - \ln\left(\frac{VA}{Emp}\right)_{t}$$

In contrast to some of the subsequent results we do not discriminate between product and process innovation and consider any form of determinant of productivity growth.

Table 8: Growth in VA/Emp (difference in logs) two periods after innovation (*t+2*) - *t*

Firm size	Manufacturing (NACE 15-37)			Services (NACE 45-90)		
	ATT	SE	No. of obs. treatm.(control)	ATT	SE	No. of obs. treatm.(control)
Emp ≤ 50	-0.295	0.330	73 (19)	-0.045	0.199	49 (16)
50 < Emp ≤ 100	0.097	0.179	91 (20)	-0.325	0.384	8 (4)
100 < Emp ≤ 200	-0.034	0.233	105 (18)	-0.327***	0.119	6 (4)
Emp > 200	0.225	0.238	403 (71)	0.195	0.250	70 (28)

Note: ***,**,* denote statistical significance at 10%, 5% and 1% level. The number of observations is given in terms of both the number of treatment and control observations (the latter is in parentheses). SE- bootstrapped standard errors

Contrary to expectations no significant positive effects of innovation on labor productivity growth is revealed in Table 8. Moreover, services firms with between 100 and 200 employees even experienced a significant negative “treatment” effect of innovation on labor productivity growth. Given a very small number of actual respondents in that cohort of services firms one should not put too much emphasis on this result as it may be driven by specific circumstances in one or two of the firms in question. These factors may not be adequately controlled for within our propensity score specification. The other possible issue driving the results may also be that we are not capturing the actual growth period. It may take longer than two years after the initial innovation for firms to internalize all the benefits of it. To control for this issue we redefined productivity growth so that we explore the growth in labor productivity between the second and fourth year after the innovation:

$$(9) \qquad growth\left[(t+4)-(t+2)\right] = \ln\left(\frac{VA}{Emp}\right)_{t+4} - \ln\left(\frac{VA}{Emp}\right)_{t+2}$$

Table 9 presents estimates of the average treatment effect of innovation on labor productivity growth between the second and fourth years after the innovation was initially made. By changing the period of observation we hope to capture the effects of innovation on productivity that were not apparent in the first two years after the moment of innovation. As before, we can see that innovating firms did not grow significantly faster (in terms of productivity) than comparable non-innovating firms. As was the case before, we also observe a significant negative effect of innovation in the case of large services firms.

Table 9: Growth in VA/Emp (difference in logs) between two and four periods after innovation (*t+4*) - (*t+2*)

Firm size	Manufacturing (NACE 15-37)			Services (NACE 45-90)		
	ATT	SE	No. of obs. treatm.(control)	ATT	SE	No. of obs. treatm.(control)
Emp ≤ 50	0.205	0.341	73 (7)	-0.068	0.327	49 (8)
50 < Emp ≤ 100	0.303	0.285	91 (14)	0.635	1.725	8 (1)
100 < Emp ≤ 200	0.150	0.240	105 (12)	0.150	0.489	6 (2)
Emp > 200	0.052	0.187	403 (54)	-0.324**	0.155	70 (14)

Note: ***,**,* denote statistical significance at 10%, 5% and 1% level. The number of observations is given in terms of both the number of treatment and control observations (the latter is in parentheses).
SE- bootstrapped standard errors

In order to further disentangle the cause for this lack of evidence on the effects of innovation on productivity growth, we opt for a more specific definition of innovation by explicitly discriminating between product and process innovations in Tables 10-13. Namely, Parisi et al. (2006) find that process innovations significantly impacted the productivity growth of Italian firms in the late 1990s, while product innovations had a much less significant effect. Tables 10 and 11 present estimates of the average treatment effect of process innovation on labor productivity growth. It should be noted that the change in the definition of innovation also has to be reflected in the propensity score specification in equation 7. In this case the propensity score actually represents the probability to innovate a new or improved production process. Results do not differ substantially from those presented for innovations as a whole as there is, again, little evidence of innovations positively affecting productivity growth. As was the case before, most of the estimates are not significantly different from zero, whereby in some instances the innovating services firms actually grew slower than their non-innovating counterparts.

Table 10: Growth in VA/Emp (difference in logs) two periods after innovation (*t+2*) – *t* [Process innovation]

Firm size	Manufacturing (NACE 15-37)			Services (NACE 45-90)		
	ATT	SE	No. of obs. treatm.(control)	ATT	SE	No. of obs. treatm.(control)
Emp ≤ 50	-0.174	0.130	73 (19)	-0.252	0.173	49 (16)
50 < Emp < 100	-0.263	0.283	91 (20)	-0.639***	0.244	8 (4)
100 < Emp < 200	0.031	0.067	105 (18)	-0.207	0.213	6 (4)
Emp > 200	0.065	0.072	403 (71)	-0.012	0.119	70 (28)

Note: ***,**,* denote statistical significance at 10%, 5% and 1% level. The number of observations is given in terms of both the number of treatment and control observations (the latter is in parentheses). SE- bootstrapped standard errors

Table 11: Growth in VA/Emp (difference in logs) between two and four periods after innovation (*t+4*) - (*t+2*) [Process innovation]

Firm size	Manufacturing (NACE 15-37)			Services (NACE 45-90)		
	ATT	SE	No. of obs. treatm.(control)	ATT	SE	No. of obs. treatm.(control)
Emp ≤ 50	0.671**	0.316	73 (7)	-0.374*	0.230	49 (8)
50 < Emp ≤ 100	0.259	0.242	91 (14)	0.027	2.576	8 (1)
100 < Emp ≤ 200	0.087	0.097	105 (12)	0.041	0.220	6 (2)
Emp > 200	0.125	0.090	403 (54)	-0.305**	0.153	70 (14)

Note: ***,**,* denote statistical significance at 10%, 5% and 1% level. The number of observations is given in terms of both the number of treatment and control observations (the latter is in parentheses). SE- bootstrapped standard errors

Finally, we also present results using product innovations as the treatment indicator and find that that barely makes a difference as the results fail to yield any indication of a significantly positive effect of innovation on firm productivity growth. Again, the only somewhat robust finding is the slower productivity growth of larger services firms that innovated compared with those that did not. Possibly the reasons for lack of results may be that the effects of innovation are not adequately captured by labor productivity and that total factor productivity should have been used instead. Additionally, our productivity proxy fails to control for contemporaneous growth in inputs which may conceal the actual productivity dynamics. Given that we are interested in the differences in productivity growth between different, this may be a crucial factor in formation of the estimates. Furthermore, perhaps an even longer period of observation is needed to observe the complete spectrum of innovation effects.

Table 12: Growth in VA/Emp (difference in logs) between two and four periods after innovation (*t+4*) - (*t+2*) [Product innovation]

Firm size	Manufacturing (NACE 15-37)			Services (NACE 45-90)		
	ATT	SE	No. of obs. treatm.(control)	ATT	SE	No. of obs. treatm.(control)
Emp ≤ 50	0.300	0.232	73 (19)	0.151	2.859	49 (8)
50 < Emp ≤ 100	0.269	0.266	91 (20)	0.432	0.364	8 (1)
100 < Emp < 200	0.126	0.100	105 (18)	-0.260	0.265	6 (2)
Emp > 200	0.014	0.319	403 (71)	-0.463***	0.038	70 (14)

Note: ***,**,* denote statistical significance at 10%, 5% and 1% level. The number of observations is given in terms of both the number of treatment and control observations (the latter is in parentheses). SE- bootstrapped standard errors

Table 13: Growth in VA/Emp (difference in logs) two periods after innovation (*t+2*) – *t* [Product innovation]

Firm size	Manufacturing (NACE 15-37)			Services (NACE 45-90)		
	ATT	SE	No. of obs. treatm.(control)	ATT	SE	No. of obs. treatm.(control)
Emp ≤ 50	-0.118	0.515	73 (19)	0.076	0.280	49 (16)
50 < Emp ≤ 100	-0.009	0.223	91 (20)	-0.451	0.378	8 (4)
100 < Emp ≤ 200	-0.204	0.169	105 (18)	-0.002	0.188	6 (4)
Emp > 200	0.033	0.076	403 (71)	0.163	0.275	70 (28)

Note: ***,**,* denote statistical significance at 10%, 5% and 1% level. The number of observations is given in terms of both the number of treatment and control observations (the latter is in parentheses). SE- bootstrapped standard errors

6. Conclusions

In spite of a growing number of studies dealing with innovation, numerous question related to the process of innovation remain unresolved. Along with an increasing number and complexity of determinants of innovation activity as well as channels of knowledge diffusion identified, exploring their relative importance and simultaneousness effects remains an important research challenge.

The evidence presented in this paper is based on a biannual innovation survey of Slovenian firms (1996-2002). Using firm-level information we estimate the importance of internal and external sources of innovation and evaluation of their impact on productivity growth. Own R&D expenditures and past innovation activity (used as variables of internal sources) are consistently confirmed as significant determinants of innovation activity. However, they turn out to be much more efficient when accompanied by diffusion of knowledge from outside sources. External knowledge spillovers, either domestic or international are thus found as important and innovantion incentive. R&D subsidies, both domestic and from international sources of innovative activity and intra-sectoral innovation spillover complement internal sources and significantly increase the ability of Slovenian firms to innovate. Inward FDI as well significantly increases the ability to innovate, while foreign owned firms compared to those owned by domestic investors even show lower average level of R&D expenditures, suggesting that innovation acivity must be driven by other factors such as knowledge and technology spillovers. Exporting, on the other hand, has not been found to be an important chanell of knowledge diffusion, or an innovation inducement. Productivity and technological intensity as well do not confirm significant influence on innovation activity.

The importance of the external factors suggests that firms, though being productive, technologically intensive and innovative in the past and in spite of their own R&D activity, are less likely self-sufficient in their current and future innovation activity. As R&D activity is frequently a result of a non-cooperative strategy and the character of technology and innovation is non-rival, spillovers are particularly important. External innovation incentives resulting from (foreign and domestic) R&D subsidies, foreign investment and a competitive business environment (horizontal innovation spillovers) should thus be taken into account as important complementary sources. Exploiting external spillovers also complements the major effect of R&D sources, which is reflected in a notable increase of total factor productivity. For Slovenia, the estimated rate of return to R&D capital by using the growth accounting approach amounts to 0.24 and range within the boundaries find by other studies with similar model estimations. Foreign ownership thus has, similarly as R&D, a dual impact on firm's TFP growth - it enhances firm's ability to absorb knowledge and innovate, but then it also contributes additionally to firm's TFP growth via superior organization techniques and other channels of knowledge difussion.

Future research of innovation activity might broaden the set of external determinants and examnine domestic and international spillovers in greater detail (vertical and horizontal FDI spillovers, spillovers through imports, more detailed technology spillovers through trade and asimetry of spillovers) which would additionally explain their relative importance. The eventual changes in importance of determinants and effects of innovation activity should also be explored in a dynamic context.

In the second part the paper explores the relationship between innovation activity and firm's performance. Here, the findings are less conclusive. Using a simple OLS estimation approach on the sample of manufacturing and services firms we find that innovations resulting from firm's R&D contribute substantially to its total factor productivity growth. We then proceed by employing more sophisticated econometric approaches, such as matching techniques to construct a controlled experiment. Using firm propensity to innovate we match innovating firms with otherwise similar non-innovating firms to evaluate the importance of innovation on productivity growth. Conditional on satisfying the balancing property of the propensity score the fitted values obtained from the estimated probit model are used to pair up innovators with non-innovators and thenthose matched pairs are subsequently used to estimate the average treatment effect of innovation on firm productivity growth. The more closely the firms are matched with respect to regressors, the more likely it is that the observed productivity differences will result from the fact that some firms managed to innovate while others did not.

Our preliminary results of average treatment effects estimates of innovation on different specifications of growth in value added per employee on sample of manufacturing and services firms as well as after taking explicit account of firm size classes, however, are far from being robust. One possible explanation for this may lay in the fact that we are dealing with very small groups of exact matched innovative and non-innovative firms which may limit the efficiency of the matching approach. Hence, more work is needed in the future in terms of merging the sample of firms surveyed in the CIS with the non-surveyed firms in order to obtain more matching observations.

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Appendix

Table A1: Firms' probability to innovate products and processes in Slovenia, 1996-2002 (Results of a probit model)

	Product innovation				Process innovation			
	1		2		3		4	
	Coef.	z	Coef.	z	Coef.	z	Coef.	z
INOV_t-1	1.136	18.5	1.137	18.5	0.868	13.1	0.866	13.1
Size	0.438	9.9	0.442	10.0	0.532	12.1	0.531	12.0
rVA/Emp	0.003	0.4	0.003	0.4	0.007	1.0	0.007	1.0
R&D/Sales	18.842	18.0	19.217	18.4	18.489	17.4	18.504	17.5
Total sub./R&D	4.413	6.9			2.851	7.3		
Public sub./R&D			5.115	6.4			3.268	6.2
Foreign sub./R&D			4.771	2.5			2.273	3.5
IFDI	0.146	2.4	0.140	2.3	0.106	1.7	0.103	1.7
EX/Sales	0.241	2.8	0.228	2.6	0.175	2.0	0.171	1.9
HS_INOV	0.007	3.4	0.008	3.4	0.011	5.0	0.011	5.1
VS_INOV	-0.008	-1.5	-0.008	-1.5	0.002	0.3	0.001	0.3
ML tech	-0.030	-0.3	-0.035	-0.4	-0.206	-2.1	-0.214	-2.2
MH tech	0.144	1.5	0.135	1.4	-0.150	-1.5	-0.158	-1.6
H tech	0.188	1.6	0.177	1.5	-0.184	-1.6	-0.183	-1.6
Const.	-2.426	-19.8	-2.424	-19.8	-2.612	-21.2	-2.596	-21.2
Number of obs	4166		4166		4166		4166	
LR chi2(12)	1931.6		1938.3		1536.4		1527.5	
Prob > chi2	0.00		0.00		0.00		0.00	
Pseudo R2	0.438		0.440		0.382		0.380	

Dep.var.: $INOV_t$