Paper to be presented at the DRUID 2011

on

INNOVATION, STRATEGY, and STRUCTURE -
Organizations, Institutions, Systems and Regions
at
Copenhagen Business School, Denmark, June 15-17, 2011

The innovation value chain in advanced developing countries: An empirical study of Taiwanese manufacturing industry

Wan Lin Hseih
Aston University
Economics and Strategy
hsiehw@aston.ac.uk

Jim Love

Birmingham Business School
j.h.love@bham.ac.uk

Panagiotis Ganotakis

ganotap1@aston.ac.uk

Abstract

In the era of knowledge economy, innovation does not only depend on internal R&D, but is also complemented with external knowledge sources. Knowledge sourcing has been emphasized as a crucial input of innovation activities to create value for a firm. The Innovation value chain is a model inclusive of knowledge sourcing, innovation production and value production. It helps highlight important complementarities between different knowledge sources, their effect on innovation and the effect of the latter on firm performance. In this paper, 1806 innovative manufacturing firms from 2nd Taiwanese Industry Innovation Survey are used to demonstrate IVC model by adopting a combination of probit, tobit and robust regression models. This is the first paper on the IVC of manufacturing firms in an advanced developing country. Results show strong complementarities between the knowledge sources, and these knowledge sources have directly or indirectly positive contribution to both product and process innovation. Product innovation decision has a positive significant effect on all measures of a firm?s performance. The IVC model brings a better picture of the inputs and outputs of innovation activities in Taiwanese manufacturing firms and shows that the IVC differs between Taiwan and western countries such as the Ireland and Northern Ireland.

Jelcodes:O32,O31

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Abstract

In the era of knowledge economy, innovation does not only depend on internal R&D, but is also complemented with external knowledge sources. Knowledge sourcing has been emphasized as a crucial input of innovation activities to create value for a firm. The Innovation value chain (IVC) is a model inclusive of knowledge sourcing, innovation production and value production. It helps highlight important complementarities between different knowledge sources, their effect on innovation and the effect of the latter on firm performance. In this paper, 1806 innovative manufacturing firms from 2nd Taiwanese Industry Innovation Survey are used to demonstrate IVC model by adopting a combination of probit, tobit and robust regression models. This is the first paper on the IVC of manufacturing firms in an advanced developing country. Results show strong complementarities between the knowledge sources, and these knowledge sources have directly or indirectly positive contribution to both product and process innovation. Product innovation decision has a positive significant effect on all measures of a firm's performance. The IVC model brings a better picture of the inputs and outputs of innovation activities in Taiwanese manufacturing firms and shows that the IVC differs between Taiwan and western countries such as the Ireland and Northern Ireland.

1. Introduction

The traditional foundations of a firm's success have shifted markedly with business environments increasingly opening up to international competition. Innovation has been argued to be an important determinant of sustained international competitiveness and the extent of innovation in a firm has shifted to a more open structure. The open innovation paradigm is introduced as an innovation model that effectively utilizes a wider range of internal and external resources and knowledge (Chesbrough, 2003). In the era of knowledge economy, knowledge is one of the crucial elements that are needed in order for a firm to successfully innovate and maintain its competitive advantage. A firm's survival and prosperity depend on effective linkages to external sources of knowledge, or in other words, on a firm's ability to access a variety of organizations and identify valuable knowledge, something that can serve as a complement for a firm's existing knowledge assets (Grimpe and Sofka, 2009).

Linkages with a variety of external sources such as suppliers, customers, competitors, government laboratories and universities are opportunities that a firm can take advantage of in order to access and interpret new knowledge and implement it in its innovative activities (Dosi, 1988; von Hippel, 1988; Freeman and Soete, 1997; Muscio, 2007). Apart from of the above external linkages, external knowledge resources can also be obtained from subsidiaries and consultancy firms (Love and Mansury, 2007), through informal events such as exhibitions, industrial associations and technical standards (Harris and Li, 2009; Reychav, 2009).

Nevertheless inter-organizational knowledge flows do not materialize automatically and a firm needs to develop certain capabilities in order to access and successfully implement external technological sources (Vanhaverbeke et al., 2008) and market knowledge. In addition to knowledge flow between organizations, efficient knowledge distribution and effective integration within an organization are necessary for a firm to draw the benefits derived from collaboration and successfully innovate. A firm's level of absorptive capacity has been therefore considered to contribute to opportunity identification and to enable a firm to acquire, assimilate, transform and exploit knowledge at the commercial end, whilst enhancing a firm's ability to react quickly to environmental changes (Cohen and Levinthal, 1990; Zahra and George, 2002; Todorova and Durisin, 2007). It (Bowman and Hurry, 1993).

Taiwan is a small island country which lacks natural resource endowments but has a rich history of technological development. Innovation is considered to be vital for the nation's economic development and growth (Hsu, 2005; Hu and Mathews, 2005) something that led to the introduction of a number of successful governmental policies specifically designed to facilitate industrial innovation (Kraemer et al., 1992). According to the Global Competitiveness Index (2009 – 2010), Taiwan ranks 12th globally and 4th within Asian countries in terms of innovation factors, something that shows the dependence of the nation's economic competitiveness to innovative activities (Sala-I-Martin et al., 2009). Furthermore the importance of innovation is directly linked with Taiwanese firms' effort to enter foreign markets (see for example Roper and Love, 2002) as export sales are a significant proportion of their overall turnover and as Taiwan as an economy relies heavily on exports due to its relatively small domestic market[1]. It is evident therefore that it is important to investigate the factors that determine innovation for the case of Taiwan.

The innovation value chain (IVC) is a model that considers in a sequential order knowledge sourcing, innovation production and value production. It helps highlighting important complementarities between different knowledge sources, the way they affect a successful innovation and the effect of the latter on a firm's performance. The value of the IVC has been demonstrated in empirical studies undertaken in Ireland and Northern Ireland (Roper et al., 2008), Ireland and Switzerland (Roper and Arvanitis, 2009) and United Kingdom (Ganotakis and Love, 2010).

In summary, the IVC applied for the case of the Taiwanese manufacturing industries offers a better understanding of the inputs and outputs of innovation activities and demonstrates the value of the IVC for the case of those firms. Due to similarities that Ireland and Taiwan share (Lin et al, 2010), this paper will compare its findings with the ones of a study carried out in Ireland (2008) in order to contrast the difference of IVC in the two economies.

2. Conceptual framework

The objective of the whole concept is to model the process that generates knowledge linkages among different organizations; transforms knowledge and ultimately exploits it via innovation activities that generate added value and firm growth. According to the resource based view, a firm can generate a

[1] Table 1 shows export and import amounts between 2000 and 2009, excluding re-export and re-import.

competitive advantage if it possess resources that are unique and difficult for competitors to imitate (Wernerfelt 1984; Grant, 1991). Moreover the nature of the open innovation system and the extent of external knowledge linkages and flow (Chesbrough, 2003; 2006) forces a firm to enhance its absorptive capacity which in this study is captured by using three variables namely, employee degree, employee training and continuous R&D (Liao et al., 2007; Roper et al., 2008; Grimpe and Sofka, 2009). Therefore, the overall conceptual framework includes the perspectives of resources-based and capability of a firm with special focus on business growth and development (Cohen and Levinthal, 1990; Foss, 2004).

The innovation value chain was firstly introduced as a series of innovation processes comprising idea generation, conversion and diffusion (Hansen and Birkinshaw, 2007). It is considered as a strategic approach tool that a manager can use in order to assess the strength and weakness of the whole innovation process. Roper et al. (2008) incorporated the knowledge production function into the innovation value chain approach which brings a more embedded structure focusing on knowledge sourcing, knowledge transformation, exploitation of innovation activities and value production. The IVC presented by the same study also further explores potential factors influencing this process of value production.

2.1 Innovation inputs knowledge sourcing

The innovation value chain begins with knowledge sourcing activities which highlight the relationship between each knowledge sourcing activity. Crépon et al. (1998) and Lööf and Heshmati (2001, 2002) argued that in-house R&D is the only source of knowledge for innovation. However, more and more studies pay attention not only on internal R&D but also on other external knowledge sources and find evidence of a complementary relationship between them (Veugelers and Cassiman, 1999; Roper and Love, 2005; Roper et al., 2008; Ganotakis and Love, 2010). The complementary relationship between internal R&D and external knowledge in combination with a firm's absorptive capacity (Cohen and Levinthal, 1990; Zahra and George, 2002; Todorova and Durisin, 2007) enables a firm not only to recognize and acquire valuable external knowledge but also to shape it into innovative products.

The purpose of the first stage of the innovation value chain is therefore to establish the determinants of different types of (internal and external) knowledge sources, and to explore the nature and extent of any complementarities between them. In this paper, we identify seven different types of knowledge sourcing linkages which might shape firms' innovation: internal R&D (Shelanski and Klein, 1995; Roper et al., 2008; Ganotakis and Love, 2010), external R&D (Veugelers and Cassiman, 1999; Ganotakis and Love, 2010), forward linkages to customers (Joshi and Sharma, 2004; Roper et al., 2008), backward linkages to either suppliers or consultants (Horn, 2005; Smith and Tranfield, 2005; Roper et al., 2008), horizontal linkages to either competitors or other companies (Hemphill, 2003; Link et al., 2005; Roper et al., 2008), public linkages to either universities or public research centres (Roper et al., 2004; Del Barrio-Castro and Carcia-Quevedo, 2005) and informal linkages to exhibitions, professional association or technical standards (Harris and Li, 2009; Reychav, 2009).

Following the previous literature, a number of assumptions are made. First it will be assumed that firms with a strong internal stock of knowledge (firm size, group membership, employee skills), will be less inclined to use external sources of knowledge (Schmidt, 2005). Other external effects such as public financial support for innovation or R&D may increase knowledge sourcing activities (Edquist, 2005), and the chance of access to different resources may also increase during exporting activity.

The equations below are given in order to evaluate the probability that a firm will engage in each of the seven knowledge sourcing activities.

$$KS^{*}_{jit} \equiv \beta' KS_{kit} + \gamma'_0 RI_{jit} + \gamma'_1 CI_{jit} + \gamma'_2 GFS_{jit} + \gamma'_3 EX_{jit} + \varepsilon_{jit}, \quad j,k \equiv 1,7$$

$$KS_{jit} = 1 \text{ if } KS^{*}_{jit} > 0; \; KS_{jit} = 0 \text{ otherwise,} \qquad (1)$$

where; KS_{jit} stands for the i_{th} firm's knowledge sourcing activity j (or k) at time t, and $j,k = 1,2,3,4,5,6,7$, $i = 1,......,n$; $t = 1,......,T$. The error term ε_{jit} is assumed to follow a multivariate normal distribution with mean zero and variance-covariance matrix V, where V has values of 1 on the leading diagonal and $\rho_{jk}=\rho_{kj}$ for $j \neq k$. KS_{kit} represents the firm's other knowledge sourcing activities. If β is positive this would suggest a complementary relationship between the knowledge sourcing activities; negative β would suggest a substitute relationship. RI_{jit} and CI_{jit} are two set of indicators of the firm's resource base and capacity, as indicated earlier. γ_0 is expected to be negative. GFS_{jit} reflects access to government financial support for innovation and upgrading, and the coefficient here (γ1) is expected to be positive. The last element, EX_{jit}, is included in order to control for collaborative agreements that are formed purely because of the exporting behavior of some of the sampled firms. Except domestic environment and organizations, firms can derive knowledge from other countries through export activities. The possession of superior technological knowledge by foreign firms can be the main motivation for collaborative agreements to be formed between them and Taiwanese firms (see arguments on knowledge by exporting – Love and Ganotakis, 2010). It is therefore important for the effect of exporting in the formation of collaborative agreements to be controlled in order for complementarities between knowledge sources to be effectively singled out.

2.2 Innovation production

The second link in the innovation value chain is the process of knowledge transformation which translates the knowledge sourced by firms and exploits it into innovation outputs. In this process, an innovation or knowledge production function is used to model the knowledge transformation activities (eg. Geroski, 1990; Harris and Trainor, 1995) the effectiveness of which are believed to be influenced by a number of firm characteristics, the strength of the firm's resource-base and also the firm's managerial and organizational capabilities (Griliches, 1992; Love and Roper, 1999). Based on Pittaway et al. (2004) the innovation outputs will be measured by using three indicators; two dummy variables of product and process innovation in order to indicate whether or not a firm introduced a new or significantly improved product/process and a variable capturing innovation success which considers the proportion of sales derived from innovative products.

Knowledge derived from different sources is expected to have a different effect on product or process innovation (Joshi and Sharma, 2004; Roper et al., 2006) and the same is expected for firms with different internal resources and capacity (Cohen and Levinthal, 1990; Zahra and George, 2002). Furthermore, exporting activity and governmental financial support are also listed as factors affecting innovation (Love and Ganotakis, 2010). Therefore, the innovation production function is listed as below:

$$I_{it} = \phi_0{}' KS_{kit} + \phi_1{}' RI_{jit} + \phi_2{}' CI_{jit} + \phi_3 GFS_{it} + \phi_4 EX + \varepsilon_{it} \qquad (2)$$

Where I_{it} is an innovation output indicator *(k*=1,…,7), that indicates the alternative knowledge sources identified earlier, *EX* stands for a dummy variable of export, ε_{it} is the error term and other variable definitions are as above.

2.3 Innovation outputs- value added

The final link in the innovation value chain is that of knowledge exploitation, the process by which firm performance is influenced by innovation (Geroski et al., 1993). External knowledge acquired and transformed into specific product or process innovation and captured in innovation outputs can theoretically enhance firm performance. Moreover the process of innovation, that ultimately generates added value, provides the indirect link between firms' knowledge sourcing activities and performance. To model this value added process, an augmented production function is adopted that includes the innovation output measures together with a number of other variables proposed to affect a firm's performance, such as internal sources and capacity, (firm size, firm age, subsidiary, employee degree) as well as export activity, which has been suggested to not only affect a firm's innovative activity but to have a significant effect on a firm's performance (Love et al. 2010). In terms of the recursive innovation value chain, we regard the innovation output indicators as necessarily predetermined before the exploitation process which may lead to improvements in firm performance. The augmented production function is expressed as

$$BPERF_{it} = \lambda_0 + \lambda_1 INNO_{it} + \lambda_2 X_i + \tau_i \quad (3)$$

Where *BPERFi* is an indicator of business performance (e.g. labour productivity or output per employee, sales growth or employment growth), *INNOi* is a vector including innovation outputs measures for both process and product innovation, and *Xi* is a set of firm specific variables that are hypothesized to have effect on firm performance.

3. Data

The empirical analysis is based on the 2nd Taiwanese Industry Innovation Survey (TIIS), undertaken between 2007 and 2009. The survey gathered information on knowledge linkages, innovation activity, firm performance and firm specific characteristics over the period 2004 to 2006. The survey was based on the 4th CIS (Community Innovation Survey) by OECD (Organisation for Economic Co-operation and Development), however focusing on Taiwanese industries. Moreover the sample was based on the population of manufacturing firms identified by the Industry, Commerce and Service Census conducted by the Taiwanese government and it was proportionally and randomly selected from all manufacturing industries. The derived sample includes 4563 manufacturing firms however this paper focuses specifically on

1806 firms that have engaged in innovative activities. According to the industry classification in the 2nd TIIS, this paper combines some industries and reclassifies them into 13 industries (See Table 2).

This study focuses on process and product innovation, both of which are measured as dummy variables, as well as product innovation success that refers to the proportion of total sales derived from products newly introduced or significantly improved between 2004 and 2006. Within the 1806 innovative firms, 55% of firms were engaged in product innovation while 57% introduces a process innovation. The variables referring to knowledge sourcing activities showed that the most common linkages are internal R&D (82%), forward knowledge (73%), backward knowledge (63%) and horizontal knowledge (59%). Notably, there are also many firms that shared knowledge informally (63%)[2].

As it is argued that other firm specific characteristics such as firm age, size (Klette and Johansen, 1998) and group membership, have a potential impact on firms' knowledge gathering, transformation and exploitation, as does the quality of human resources (Freel, 2005) and additional external and internal resources, descriptive statistics for firm size, age, subsidiary, employee degree, employee training, government financial support will also be reported.

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[2] In order to gain a better picture of the knowledge sourcing and innovation activities by firm size, table 4 reports descriptive statistics according to firm size groups, (micro, small/medium and large firms).

4. Method

There are seven different types of knowledge sourcing activities proposed at the beginning of the innovation value chain. To estimate the simultaneous knowledge sourcing equations (Eq. 1), the most efficient approach would be multivariate probit (MVP). However, Greene (2005) states that the efficiency gains from MVP are reduced where the vectors of independent variable are strongly correlated. The suggested knowledge sharing activities here are similar to the added potential for simultaneity between knowledge sourcing activities. Except the issue of similarity of independent variables, difficulties are faced here when adopting MVP practically in using survey-based data. Firstly, any gains in statistical efficiency by using the simultaneous estimation approach will be offset due to a larger number of missing values. Secondly, in practice, achieving convergence with an MVP estimator places some limits on the degree of simultaneous which it is possible to include. However, it is undesirable because what is of interest here is the complementary or substitute relationship between knowledge sourcing activities. Thirdly, the derivation of marginal effects is important in order to gain a better understanding if the innovation value chain, something that is less straightforward with MVP in relation to simpler modeling framework. Therefore, seven single equation probit models are used instead of the MVP approach. While sacrificing some statistical efficiency, this approach provides substantial gains in terms of the number of observations used, the ability to reflect more fully the relationship between knowledge sourcing activities and the ability to identify readily interpretable marginal effects.

Depending primarily on the nature of the dependent variable of the innovation production function (Eq. 2), the appropriate estimation method is selected. As product or process innovation are dummy variables, simple bivariate probit models will be used, however for the case of innovation success (% of sales derived from new or significantly improved products) as the variable has both upper and lower bounds, (0 to 100 %), a Tobit model will be adopted (McDonald and Moffitt, 1980).

Two main econometric issues arise in operationalising equation (3): heterogeneity in performance results, and potential endogeneity of the innovation output measures. In terms of heterogeneity, very large variations can exist in business performance even in narrowly defined industries (see Caves, 1998 for a survey; and on innovation behavior see Lööf and Heshmati, 2002). A number of studies have discussed the potential endogeneity of innovation output measures in models of business performance, and many potential approaches have been adopted including two-stage estimation methods (e.g. Crépon et al., 1998) and the simultaneous estimation of the innovation and augmented production functions (e.g. Lööf and Heshmati, 2002). In order to investigate whether a firm's innovative activity is endogenous to firm performance a number of Hausman tests were carried out for different specifications of a firm's innovative activity (product/process innovation, innovation success) and for all measures of firm performance (sales growth, employee growth and productivity) and no evidence of endogeneity was found. Similarly Hekman tests were used in order to investigate the existence of sample selection bias for the case of innovation success, i.e. whether innovative firms cannot be regarded as a group of firms that is randomly selected. Again no evidence of sample selection bias was found.

5. Empirical analysis

5.1 Knowledge sourcing

The innovation value chain begins with firms' knowledge sourcing activities (Eq. 1). The results of probit models for each knowledge sourcing activity are reported in table 5. There are two issues of interest at this point: first, what pattern of complementarity or substitutability exists between firms' knowledge sourcing activities; and, secondly, what other factors determine firms' knowledge sourcing behaviour.

In terms of potential complementarity or substitutability among knowledge sourcing activities, we find strong evidence of complementary between the different sources of knowledge. More specifically firms with internal R&D are more likely to also engage in external R&D (Veugelers and Cassiman, 1999; Ganotakis and Love, 2010). This supports the finding of Cassiman and Veugelers (2002), but contradicts result from Schmidt (2010) and Love and Roper (2001) both of whom suggest a substitution relationship between internal R&D activity and external knowledge sourcing (see also Irwin and Klenow, 1996). Firms with internal R&D only have direct effect on external R&D while external R&D engaging directly not only with internal R&D but also public knowledge sources. The explanation could be that firms tried to outsource their R&D to reduce their cost also seek for the public support to derive the information/knowledge.

The strong complementary relationship between forward, backward and horizontal knowledge sourcing activities state that there is highly intensity of knowledge sharing between supply chain partners. The results also show that informal knowledge has positive complementary association with other knowledge sourcing except R&D knowledge. The possible explanation is firms tend to share knowledge with supply chain partners and public organizations during conferences, exhibitions, industry associations and other informal channels. Knowledge sharing has been demonstrated being a significant role in trade shows, albeit these events are always hasty, flowing and highly dynamic (Reychav, 2009).

In term of the determinants of knowledge sourcing, there is a weak effect of internal resources on external knowledge sourcing. Firm size only has positive significant influence on internal R&D and backward knowledge sourcing which shows that larger firms are still more willing to invest on R&D as well as with more funding to access the information or knowledge from consultants or private laboratories. At the same time, suppliers also tend to share information or knowledge and collaborate with those larger companies. What interesting here is that there is a negative significant effect of age on horizontal knowledge sourcing which means the younger firm the more probability of interaction with its competitors or other companies in order to enter the industry.

Furthermore, employee degree does not affect any internal or external knowledge sourcing activities, but firms with employee training are more likely to engage in internal and external R&D, and linkage with suppliers, which means that purpose of these training courses is to develop the employee professional skill and enable them to absorb suppliers' information or knowledge. Noteworthily, firms with internal R&D have positive linkage to external R&D while continuous R&D activities engage less in external R&D. The above results of internal resource and capacity provide little support to the argument that firms' knowledge sourcing strategies are related to the strength of their internal resource-base (Schmidt, 2010). Although firms' internal resource and capacity do not provide enough importance to their knowledge sourcing activities, there are still other aspects of factors like public financial support and firms' exporting. Public financial support has either positive or negative impact on different type of knowledge sources shown in table 5. The explanation can be that firms who receive financial support from government have less collaboration with other companies, but tend to access external R&D knowledge or public resources. Firms being an exporter have more chance to learn from foreign partners and markets, and to access to superior international technological knowledge (Love and Ganotakis, 2010).

In summary, the above result show the strong evidence of complementarities between firms' knowledge sourcing activities and it provides the support to one of our arguments. Furthermore, aspects of firms' resources and capacity affect differently significance to each knowledge sourcing activity, and so does government financial support and exporting activity.

5.2 Innovation activities

The second link in the innovation value chain is the transformation of knowledge into product and process innovation represented by the innovation production function (Eq. 2). The main interest here is the contribution of each knowledge source to a firm's innovative effort. Estimations of the innovation production function for the three innovation output measures of product innovation, product innovation success and process innovation, are reported in Tables 6 and 7 (results are expressed in terms of marginal effects).

Results highlight the importance of R&D investment in terms of product and process innovation. Internal R&D, as expected, has a positive and significant impact on product innovation as well as innovation success whereas external R&D has a positive significant effect on both product and process innovation. The estimates suggest that firms with internal R&D are 8.87% more likely to introduce a product innovation while at the same time internal R&D was found to increase the sales derived from innovative products by 14.57%. Firms that have engaged in external R&D are 6.61% more likely to introduce a product innovation and 8.96% to introduce a process innovation in relation to firms that have not. The fact that external R&D has a significant effect on process innovation whereas internal R&D does not is not a surprising result as external R&D is often used as a way of improving a firm's manufacturing/operation process while internal capabilities and skills are focused for the introduction of innovative products that can provide a firm with a competitive advantage over its competitors (Beneito et al., 2009; Ganotakis and Love, 2011).

Although the rest of knowledge sourcing activities have no direct impact on product and process innovation, indirect influence still exists due to the complementary relationship between knowledge sourcing activities. For example a firm with linkages to public knowledge sources has a positive indirect effect on product innovation through its complementary relationship with external R&D activity. Furthermore, informal knowledge sourcing activities will also have a weak positive indirect impact on product innovation through its complementary relationship with public knowledge sourcing activity which in turn has a complementary relationship with external R&D that directly influences product innovation. This indirect effect is an ‘absorptive capacity’ effect of the type envisaged by Cohen and Levinthal (1989, 1990) and Zahra and George (2002). Therefore, even where the direct effects of knowledge sourcing on innovation are insignificant, as in the case of internal and external R&D for the case of innovation, their overall effect may still be positive due to the balance between ‘direct’ and ‘absorptive capacity’ effects.

Apart from knowledge sourcing activities, other resources also prove to be important in shaping a firm’s innovation outputs. Firm size, measured by number of employees, has a significant impact (an inverted U-shaped relationship) on both product and process innovation. Firm age is positively associated to product innovation but with no significant effect on process innovation. There is no evidence showing that being a subsidiary benefits a firm in terms on accessing extra resources, on the contrary it appears to reduce the probability of a firm introducing a process innovation. In terms of a firm’s capacities, employee degree, continuous R&D and employee training all have positive significant impacts on product innovation while employee degree also significantly influences product innovation success. There are also other external resources such as government financial support which encourages a firm’s product and process innovation but what is surprising is its non-significant negative effect on product innovation success. Furthermore, the result also shows that a firm's export activity has a positive significant effect on product innovation (Table 6).

5.3 Firm performance

The final element of the innovation value chain is concerned with the relationship between innovation outputs and firm performance (Eq. 3). The main focus here is on the impact of innovative indicators on a firm's growth (sales and employment) and productivity (sales/employees). In the first half of table 8, the relationship between product innovation decision and performance (dummy) is modeled whereas the second half presents the relationship between firm performance and product innovation success (%). Product innovation decision is found to significantly affect all three measures of firm performance (employment and sales growth as well as productivity). Product innovation success only contributes to a firm's levels of employment growth. The above innovation payoff is similar to that uncovered by studies in western countries such as Ireland and Northern Ireland (Roper et al., 2008), Ireland and Switzerland (Roper and Arvanitis, 2009) and United Kingdom (Ganotakis and Love, 2010).

What is surprising here is the fact that process innovation has a negative and significant effect on productivity regardless of whether innovation is included as product innovation decision or innovation success. However as a new process innovation takes some time to be successfully implemented within an organization in the sense that it takes time for employees to train and adjust to the new process, it is reasonable to expect that its benefits will not be observed straight after its implementation and negative productivity can be often observed during this period of adjustment (Criscuolo and Haskell, 2003).

In terms of the control variables used, a U shaped relationship was observed between firm size and employment growth and productivity, something that tells us that very small and very large firms grow faster/are more productive in relation to medium sized ones (with the turning point being 50 employees for the case of employment growth). Similar results albeit with non-significant effect were found in Roper et al. (2008) for the case of employment growth.

Finally, export activity measured as a dummy indicator, was found not to significantly affect firm performance. Similar findings were found in studies carried out in German (Bernard and Wagner, 1997), Columbia, Mexico and Morocco (Clerides et al. 1998) and Italy (Castellani, 2002).

6. Conclusion

The key results of the estimation are summarized in fig. 1, 2 and 3. Because of the complex complementary relationship between knowledge sourcing activities, the knowledge sourcing activity process is presented separately in fig. 1. Figures 2 and 3 picture the relationship between knowledge sources, innovation outputs and different measures of performance depending on whether innovation decision or innovation success is used as a measure of product innovation output respectively.

Results point to the direction of a complementary relationship between internal R&D and external knowledge sources, as well as of a strong complementary relationship between all external knowledge sourcing activities themselves.

Moreover, the usage of informal knowledge approaches by a firm appears to increase the probability knowledge sourcing from suppliers, customers, competitors, universities and government research institutions will also take place. Investments in R&D regardless of whether they are internal or external, appear to have a direct impact on a range of innovative activities however other knowledge sources only exert an indirect impact on innovation through internal or external R&D. The surprising result was that the proportion of employees with graduate degrees does not lead to the usage of any of the knowledge sourcing activities considered, although it does appear to have an effect on product innovation. For the case of firm growth although a high percentage of employees with degrees has a negative effect, a firm's skill base can still indirectly through product innovation affect a firm's growth. Although firms that carry out internal R&D were also more likely to carry out external R&D, a firm that carries out continuous internal R&D is less likely to engage in external R&D. Government financial support, as expected, encourages firms to engage in the external as well as on innovative activities in general. Finally, the decision of a firm to export enhances not only a firm's likelihood of accessing R&D and external sources of knowledge but to also enhance its innovative activity.

Furthermore by investigating the entire innovation value chain (for the case of Taiwanese manufacturing firms), the direct and indirect role that variables such as a firm's internal resources and capacity, government financial support and export activity play on a firm's knowledge sourcing, innovative activity and performance is better understood and observed.

In comparison with the results of Roper et al. (2008) for Ireland and Northern

Ireland, Taiwanese firms' knowledge sourcing activities were found to impact product or process innovation at a smaller scale and this was the main differentiating factor between Irish and Taiwanese firms. That is as in contrary, for firms in Ireland and Northern Ireland all backward, forward and horizontal knowledge sources were found to have a direct effect on product or process innovation. This shows that the innovative effort of Taiwanese manufacturing firms is still influenced directly and mainly by R&D, something that suggests that Taiwanese manufacturing firms can significantly further enhance their innovative activity and performance if they directly involve customers, suppliers and other companies/institutions in their innovative effort and take advantage of the available knowledge, information and support that can be derived from them. The non direct inclusion of those organizations in their innovation process can only be regarded as an opportunity that is lost by those firms.

The decision of Taiwanese manufacturing firms to introduce innovative products was found to significantly affect all three measures of firm performance (as was the case for the Irish study). This result further suggests that any future potential direct involvement of other than R&D external sources of knowledge will not only enhance Taiwanese firms' innovative activity but their overall performance as well.

Figure 1. Knowledge sourcing

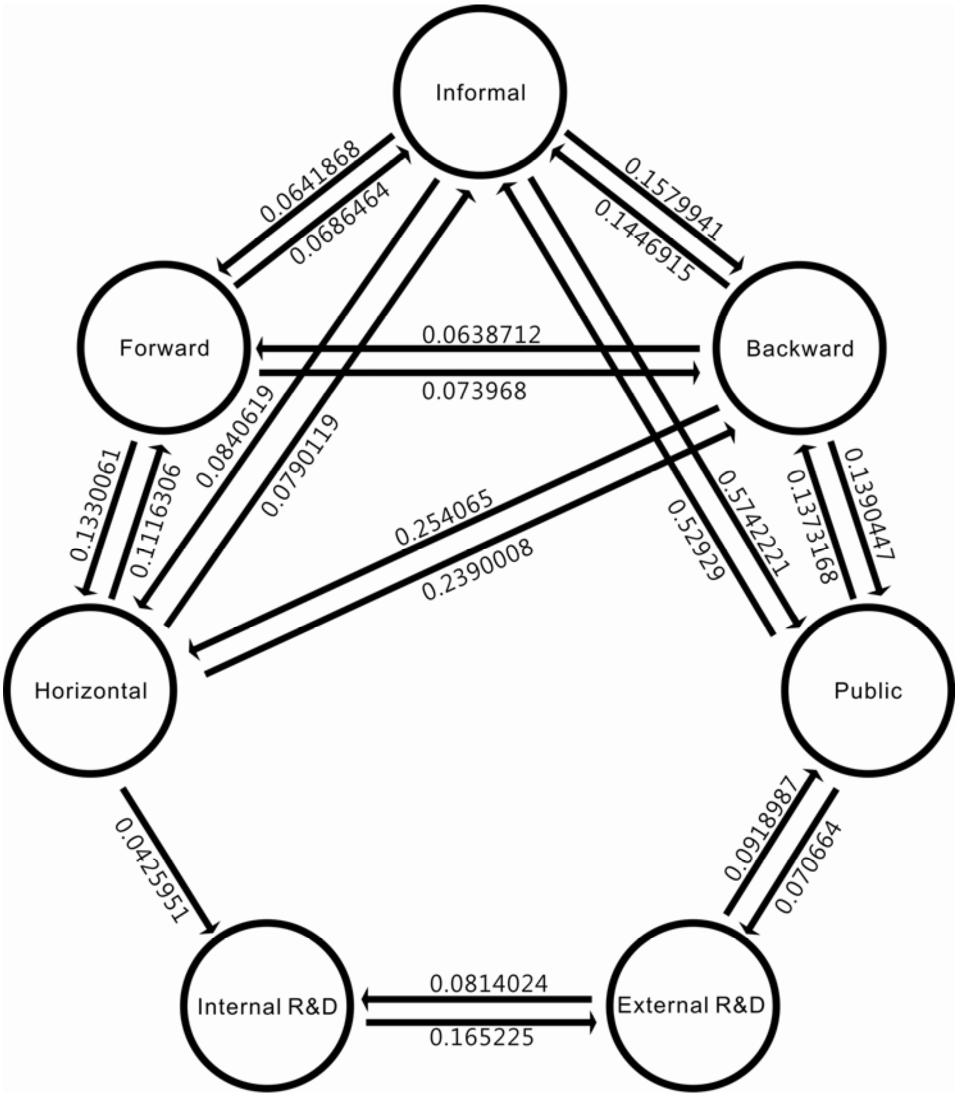

Figure 2. The innovation value chain of Taiwanese manufacturing

industry_ product innovation decision (dummy)

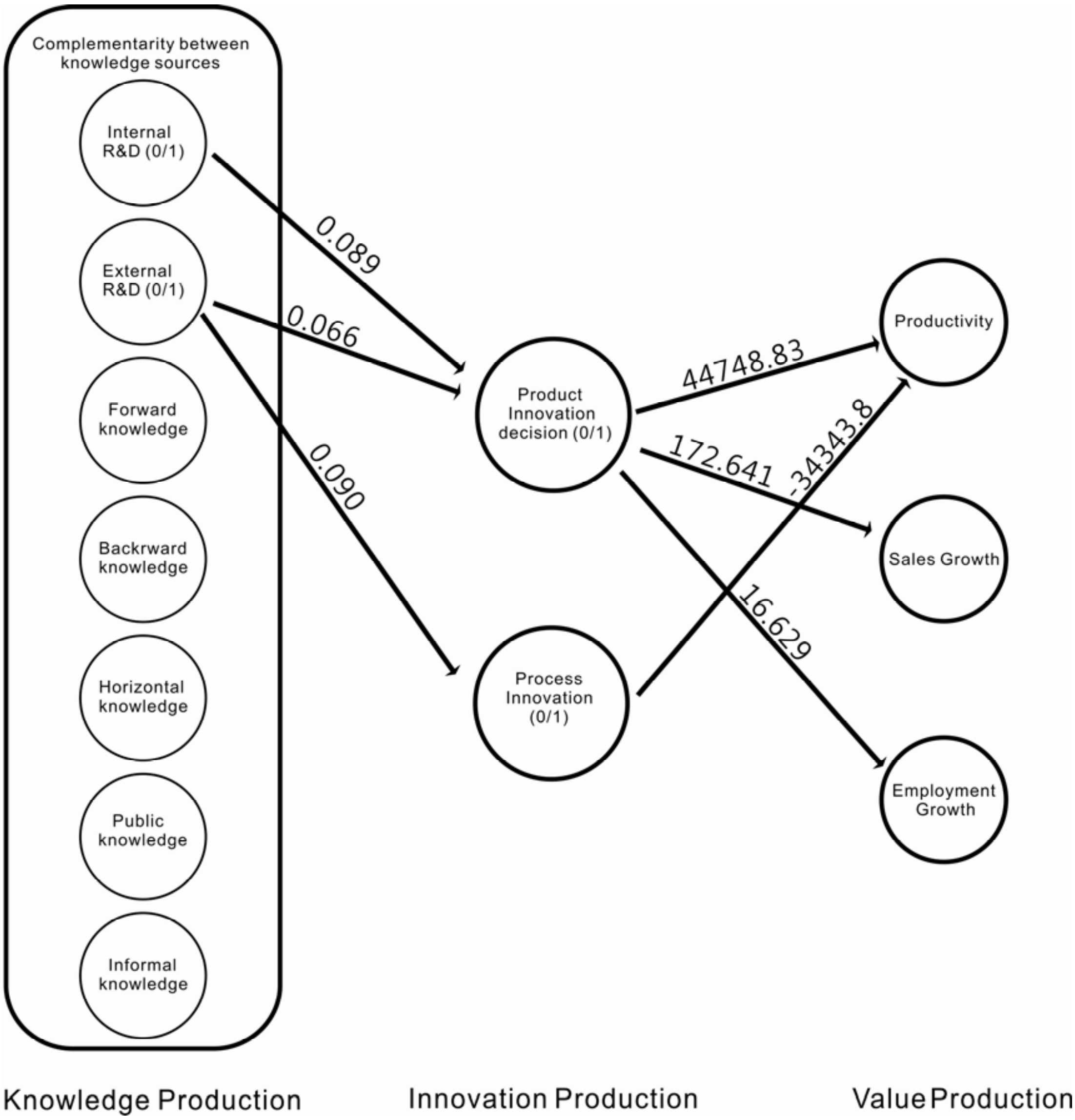

Figure 3. The innovation value chain of Taiwanese manufacturing

industry_ product innovation success (%)

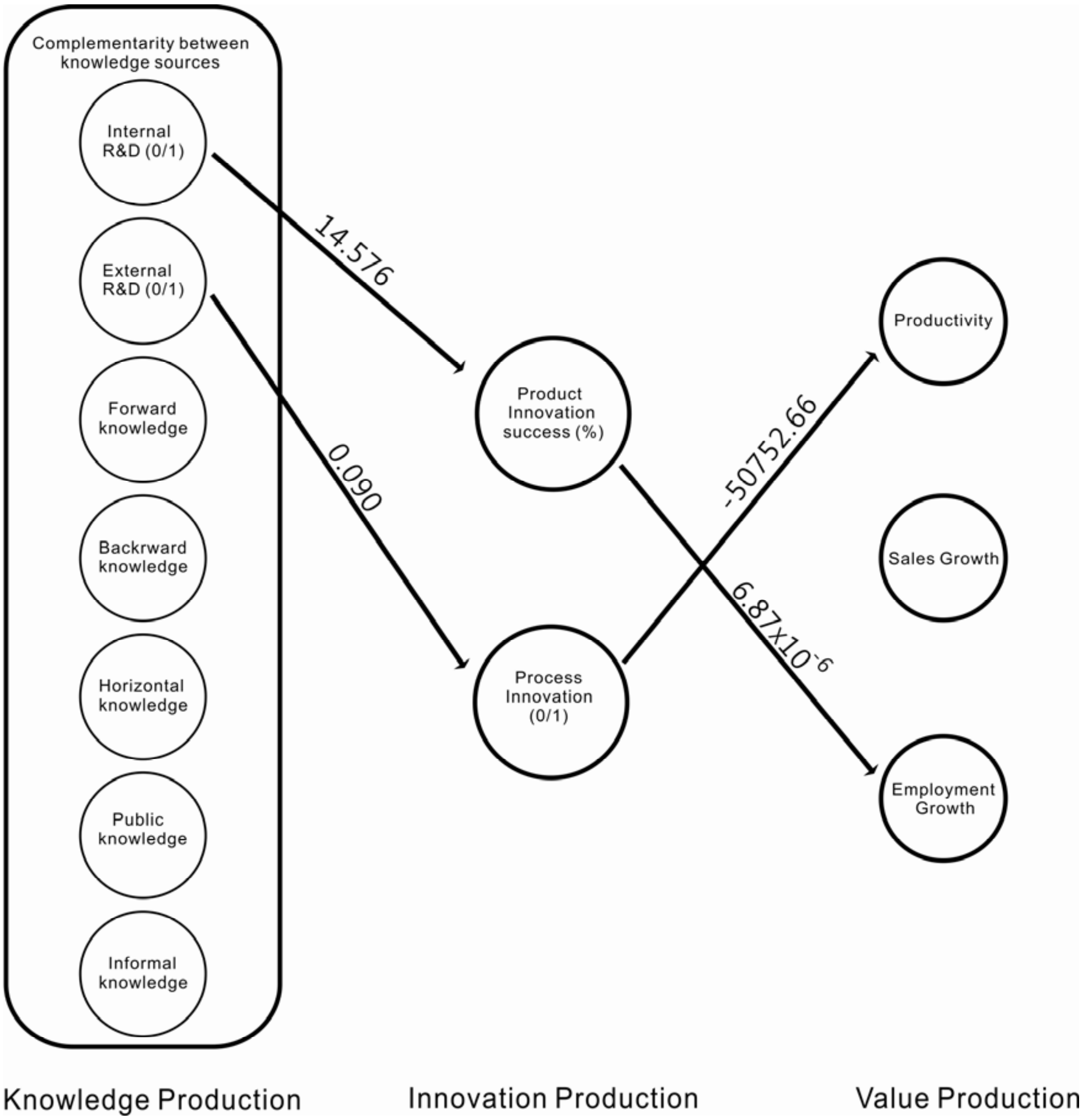

Table 1. Export and import of Taiwanese manufacturing firms from 2000 to 2009

YEAR/MONTH	TOTAL TRADE(re-imports & re-exports excluded)		EXPORT		IMPORT		SURPLUS/DEFICIT(re-imports & re-exports excluded)	
	AMOUNT	GROWTH RATE %>	AMOUNT	GROWTH RATE%	AMOUNT	GROWTH RATE%	AMOUNT	GROWTH RATE%
2000	288,321,181,753	24.130	148,316,282,245	21.983	140,004,899,508	26.490	8,311,382,737	-23.770
2001	230,098,311,922	-20.194	122,865,884,467	-17.160	107,232,427,455	-23.408	15,633,457,012	88.097
2002	243,115,677,206	5.657	130,592,779,128	6.289	112,522,898,078	4.934	18,069,881,050	15.585
2003	271,419,823,416	11.642	144,173,925,576	10.400	127,245,897,840	13.084	16,928,027,736	-6.319
2004	341,890,601,032	25.964	174,007,695,566	20.693	167,882,905,466	31.936	6,124,790,100	-63.819
2005	370,993,323,855	8.512	189,393,127,473	8.842	181,600,196,382	8.171	7,792,931,091	27.236
2006	414,757,314,126	11.796	213,164,326,531	12.551	201,592,987,595	11.009	11,571,338,936	48.485
2007	453,281,675,729	9.288	235,054,719,955	10.269	218,226,955,774	8.251	16,827,764,181	45.426
2008	483,248,600,410	6.611	243,799,352,202	3.720	239,449,248,208	9.725	4,350,103,994	-74.149
2009	367,342,369,609	-23.985	193,801,188,481	-20.508	173,541,181,128	-27.525	20,260,007,353	365.736

Table 2. Industry classification

(New industry code) Industry description	Amount	Industry code
(1) Non-metallic mineral and quarrying	40	6, 23
(2) Food, beverages and tobacco	75	8, 9, 10
(3) textiles, wearing apparel, leather, paper and printing	218	11, 12, 13, 14, 15, 16
(4) Natural resources (petrileum, coal, rubber, plastic and wood) manufacturing	93	17, 21, 22, 32
(5) Basic and fabricated metal	246	24, 25
(6) Others	48	33
(7) Machinery repair and insallation, energy supply, and wasterwater and pollution remediation	20	34, 35, 36, 37, 38, 39
(8) Construction	156	41, 42, 43
(9) Chemical material and products, medical goods	131	18, 19, 20
(10) Electronic Parts and Components Manufacturing	244	26
(11) Computers, Electronic and Optic Products Manufacturing	162	27
(12) Electrical Equipment Manufacturing	102	28
(13) machinery and transportation equipment	271	29, 30, 31

Table 3. Descriptive statistics 1

Firm size (amount)	**All innovative manufacturing firms (1806)**		
Knowledge sources	N	Mean	Std.
Internal R&D	1806	0.82	0.384
External R&D	1806	0.25	0.433
Forward	1806	0.73	0.444
Backward	1806	0.63	0.483
Horizontal	1806	0.59	0.491
Public	1806	0.47	0.499
Informal	1806	0.63	0.483
Strategy			
FastSecond	1806	0.14	0.345
Focus	1806	0.16	0.371
Innovation			
Product innovation (0/1)	1806	0.55	0.498
Process innovation (0/1)	1806	0.57	0.495
Innovation success (% sales)	1806	41.20	37.398
Other factors			
Subsidiary	1806	0.16	0.371
Size	1806	201.83	664.526
Employee degree	1735	75.32	163.280
Public financial support	1806	0.58	0.494
Training	1805	0.75	0.435
Export	1806	0.66	0.475

Table 4. Descriptive statistics 2

Firm size (amount)	Extra small firms (407)			Small and medium firms (1058)			Large firms (341)		
Knowledge sources	N	Mean	Std.	N	Mean	Std.	N	Mean	Std.
Internal R&D	407	0.76	0.430	1058	0.81	0.394	341	0.94	0.246
External R&D	407	0.22	0.416	1058	0.25	0.431	341	0.29	0.456
Forward	404	0.69	0.465	1022	0.73	0.445	308	0.76	0.428
Backward	404	0.40	0.491	1022	0.67	0.471	308	0.78	0.415
Horizontal	404	0.46	0.499	1022	0.60	0.490	308	0.70	0.460
Public	404	0.28	0.448	1022	0.51	0.500	308	0.61	0.489
Informal	404	0.42	0.493	1022	0.67	0.469	308	0.74	0.441
Strategy									
FastSecond	404	0.11	0.309	1022	0.14	0.347	308	0.14	0.347
Focus	404	0.13	0.333	1022	0.16	0.370	308	0.19	0.394
Innovation									
Product innovation (0/1)	404	0.59	0.493	1022	0.49	0.500	308	0.75	0.432
Process innovation (0/1)	404	0.55	0.498	1022	0.57	0.496	308	0.64	0.481
Innovation success (% sales)	404	44.07	37.502	1022	38.36	37.802	308	47.00	35.242

Table 4. Descriptive statistics 2 cont.

Firm size (amount)	Extra small firms (407)			Small and medium firms (1058)			Large firms (341)		
	N	Mean	Std.	N	Mean	Std.	N	Mean	Std.
Other factors									
Subsidiary	407	0.06	0.245	1058	0.17	0.374	341	0.27	0.446
Employee degree	405	52.33	58.132	1022	89.39	199.410	308	58.86	110.735
Public financial support	407	0.70	0.461	1058	0.54	0.498	341	0.56	0.497
Training	406	0.59	0.492	1058	0.75	0.431	341	0.90	0.296
Export	407	0.43	0.495	1058	0.71	0.454	341	0.77	0.421
Productivity	407	146463.84	8.89701	1058	31326.18	109355	341	9372.10	20906.385

Table 5. Knowledge sourcing

Variables	Internal R&D	External R&D	Forward knowledge	Backward knowledge	Horizontal knowledge	Public knowledge	Informal knowledge
Knowledge sources							
Internal R&D	-	0.165225*** (0.02788)	-0.0313599 (0.03764)	0.0514977 (0.04652)	0.0508369 (0.04564)	0.0287567 (0.0508)	-0.0192469 (0.04605)
External R&D	0.0814024*** (0.01687)	-	0.026346 (0.02521)	0.0044391 (0.02936)	0.0218993 (0.0286)	0.0918987*** (0.0322)	-0.0232862 (0.03177)
Forward knowledge	-0.0093939 (0.01799)	0.0288749 (0.02366)	-	0.073968*** (0.02831)	0.1330061*** (0.02841)	0.0211723 (0.03271)	0.0686464** (0.03002)
Backward knowledge	0.0188106 (0.01935)	0.0114855 (0.02435)	0.0638712** (0.02512)	-	0.254065*** (0.02652)	0.1390447*** (0.03095)	0.1446915*** (0.02844)
Horizontal knowledge	0.0425951** (0.01769)	0.0156761 (0.02254)	0.1116306*** (0.02365)	0.2390008*** (0.02498)	-	0.004986 (0.0308)	0.0790119*** (0.02794)
Public knowledge	0.0290551 (0.02039)	0.070664*** (0.02698)	0.0227218 (0.02732)	0.1373168*** (0.02958)	0.0101856 (0.03153)	-	0.52929*** (0.02026)
Informal knowledge	-0.0201431 (0.02065)	-0.0146534 (0.02901)	0.0641868** (0.02878)	0.1579941*** (0.03124)	0.0840619** (0.03267)	0.5742221*** (0.02015)	-
Resource indicators							
Employment	0.0003307 ***(0.00006)	0.00001167 (0.00003)	$9.40x10^{-6}$ (0.00003)	0.0000705* (0.00004)	0.0000293 (0.00004)	$-2.30x10^{-06}$ (0.00004)	-0.000012 (0.00006)
Employment-squared	$-1.55x10^{-08}$*** (0.00000)	$-2.51x10^{-09}$ (0.00000)	$1.21x10^{-11}$ (0.00000)	$-2.97x10^{-09}$ (0.00000)	$-6.79x10^{-10}$ (0.00000)	$9.19x10^{-10}$ (0.00000)	$1.93x10^{-08}$ (0.00000)
Firm age	0.0646639* (0.02447)	0.0895534* (0.04825)	0.0430602 (0.04228)	0.0177147 (0.05082)	-0.1476964*** (0.05218)	-0.0634079 (0.05778)	0.0396373 (0.04982)
Subsidiary	-0.0381271 (.0252)	-0.0603926** (0.02708)	-0.0132377 (0.03069)	-0.0176076 (0.03513)	0.0217672 (0.03374)	0.0727927* (0.0399)	-0.0430785 (0.03633)
Capacity indicators							
Employee degree	0.0000194 (0.00005)	-0.0000204 (0.00006)	$-2.20x10^{-06}$ (0.00006)	0.0000407 (0.00007)	0.0000386 (0.00008)	-0.0001231 (0.00009)	$-8.83x10^{-06}$ (0.00008)
Continuous internal R&D	-	-0.0629037* (0.03252)	0.0205146 (0.0336)	-0.0127819 (0.03749)	0.039805 (0.03842)	0.028945 (0.04198)	-0.0027449 (0.00008)
Employee training	0.086105*** (0.02216)	0.0489626** (0.02443)	0.0384231 (0.02652)	0.0944285*** (0.02964)	0.0328669 (0.02967)	0.0020335 (0.03444)	-0.0027449 (0.03892)
Government financial support	0.0223378 (0.01832)	0.0921849*** (0.02145)	0.0216493 (0.02325)	-0.0996293*** (0.02566)	-0.0057275 (0.02641)	0.0619906** (0.02925)	-0.0941466*** (0.02622)
Export	0.0795127*** (0.01994)	0.049722** (0.02294)	0.0368061 (0.02438)	0.0378819 (0.02767)	-0.001111 (0.02776)	0.0634751** (0.03111)	0.0351093 (0.02875)
Observations	1734	1734	1734	1734	1734	1734	1734
Log likelihood	-727.74	-933.83	-969.71	-952.57	-1057.49	-823.14	-749.62

Note: Standard errors in parentheses; ***p<0.01, **p<0.05, *p<0.1. All the figures in the table are marginal effects generated from probit models. All models include industry dummies

Table 6. Innovation production_internal & external R&D (0/1)

Variables	Product innovation: decision	Product innovation: success	Process innovation: decision
Knowledge sources			
Internal R&D (0/1)	0.0887278* (0.04551)	14.5763** (5.91738)	0.0139105 (0.04414)
External R&D (0/1)	0.0660508** (0.02899)	-0.5999665 (3.48568)	0.0896421*** (0.02769)
Forward knowledge	0.0061715 (0.02604)	0.6222198 (3.09739)	0.0030877 (0.02499)
Backward knowledge	0.0416904 (0.02812)	2.543214 (3.30461)	-0.0160583 (0.02749)
Horizontal knowledge	0.029538 (0.02944)	2.059322 (3.40883)	-0.003946 (0.02874)
Public knowledge	0.0098158 (0.03613)	-5.861495 (4.17425)	0.0099114 (0.03396)
Informal knowledge	0.0010715 (0.02847)	2.352395 (3.33806)	0.0138323 (0.02708)
Resource indicators			
Employment	0.0003264*** (0.00008)	0.0107873* (0.00641)	0.0001001*** (0.00004)
Employment-squared	-4.60×10^{-08}*** (0.00000)	-1.83×10^{-06} (0.00000)	-7.21×10^{-09}*** (0.00000)
Firm age	0.1200525** (0.04653)	2.416462 (6.07196)	-0.0503717 (0.05072)
Subsidiary	-0.0315293 (0.03505)	3.792935 (4.11363)	-0.0620368* (0.03372)
Capacity indicators		.	
Employee degree	0.000199** (0.00008)	0.21309** (0.00945)	-0.0000958 (0.00007)
Continuous internal R&D	0.0658087* (0.0378)	6.564436 (4.82476)	0.0151257 (0.03722)
Employee training	0.0857722*** (0.02992)	3.74891 (3.72421)	-0.0445379 (0.02855)
Government financial support	0.1337757*** (0.02606)	-4.118836 (3.17998)	0.0551793** (0.02543)
Export	0.1040554*** (0.02722)	-0.2967201 (3.42022)	-0.0196712 (0.02685)
Observations	1734	1734	1734
Log likelihood	-1070.6647	-6203.2388	-1150.2542

Note: Standard errors in parentheses; ***p<0.01, **p<0.05, *p<0.1. All the figures in the table are marginal effects generated from Probit/Tobit models. All models include industry dummies.

Table 7. Innovation production_internal & external R&D (%)

Variables	Product innovation: decision	Product innovation: success	Process innovation: decision
Knowledge sources			
Internal R&D (%)	0.0001435 (0.00054)	0.1207671* (0.07301)	0.0002374 (0.00054)
External R&D (%)	0.0001719 (0.00072)	0.0235918 (0.09651)	0.0009848 (0.00074)
Forward knowledge	0.0049662 (0.02624)	-0.5054836 (3.30528)	0.0011417 (0.02637)
Backward knowledge	0.0237218 (0.02824)	2.383049 (3.55275)	-0.0046338 (0.02896)
Horizontal knowledge	0.0452876 (0.02979)	1.274936 (3.63086)	-0.0100422 (0.03076)
Public knowledge	-0.0310353 (0.0355)	-6.739361 (4.44204)	0.0233548 (0.03526)
Informal knowledge	-0.0138335 (0.02858)	3.193338 (3.59439)	0.0069027 (0.02856)
Resource indicators			
Employment	0.000209*** (0.00007)	0.0136658** (0.00686)	0.0000682 (0.00006)
Employment-squared	-2.24×10^{-08} (0.00000)	-2.22×10^{-06} (0.00000)	2.57×10^{-09} (0.00000)
Firm age	0.0995831** (0.04715)	6.85175 (6.58232)	-0.0319408 (0.05394)
Subsidiary	0.0102286 (0.03761)	-0.0793816 (4.60874)	-0.0275509 (0.03814)
Capacity indicators			
Employee degree	0.00014* (0.00008)	0.0187199* (0.00987)	-0.000108 (0.00008)
Continuous internal R&D	0.1042272*** (0.03229)	9.897827** (4.18386)	0.0221904 (0.03247)
Employee training	0.0784838** (0.03409)	9.465658** (4.38239)	-0.0127336 (0.03415)
Government financial support	-0.0035366 (0.02802)	-0.5455957 (3.48289)	0.0476592* (0.02821)
Export	0.0373841 (0 .02923)	5.081714 (3.77195)	-0.0279286 (0.02904)
Observations	1493	1493	1493
Log likelihood	-940.59864	-5330.3717	-986.16975

Note: Standard errors in parentheses; ***p<0.01, **p<0.05, *p<0.1. All the figures in the table are marginal effects generated from Probit/Tobit models. All models include industry dummies.

Table 8. Performance estimations

Variables	Product innovation decision indicators			Product innovation success indicator		
	Employment growth	Sales growth	Productivity	Employment growth	Sales growth	Productivity
Constant	-16.58255*** (6.284083)	219.9097 (188.4394)	143236.7 (44363.49)	1507.918*** (922.62)	232.6011 (169.8627)	178441.8 (65423.73)
Innovation activities						
Product innovation	16.62907*** (5.644616)	172.6409* (98.05811)	44748.83* (25160.52)	6.87×10^{-06}*** (2.21×10^{-06})	1.109664 (1.129708)	-413.8179 (342.7409)
Process innovation	6.031595 (5.84828)	-130.806 (123.17)	-34343.8** (16571.09)	4.604892 (5.95647)	-152.9174 (133.2098)	-50752.66** (24655.66)
Resource indicators						
Employment (2004)	-0.0401822*** (0.0150953)	-0.0203805 (0.0490344)	-82.44346*** (27.17348)	-0.0367228*** (0.0139741)	0.0191212 (0.0615421)	-66.95718*** (21.7003)
Employment-squared (2004)	7.36×10^{-06}*** (2.38×10^{-06})	8.07×10^{-06} (6.48×10^{-06})	0.0130836** (0.0057761)	6.87×10^{-06}*** (2.21×10^{-06})	2.27x10-06 (7.57x10-06)	0.0105648** (0.0052956)
Firm age	-2.305753 (6.335897)	625.8439 (687.3273)	-366.1537 (53847.14)	-0.4403346 (6.080026)	646.1041 (692.5872)	6192.475 (53390.02)
Subsidiary	32.8652** (15.98908)	-148.5271 (93.09994)	-31698.69** (14326.77)	31.56487** (15.69084)	-161.3002 (98.90015)	-33946.65** (15316.5)
Capacity indicators						
Employee degree	-0.0156651** (0.0074367)	-0.4599088* (0.248948)	-11.60798 (36.97327)	-0.0144934** (0.0073017)	-0.4428125* (0.2413599)	0.0372153 (31.78963)
Employee training	2.184057 (4.002783)	-55.04374 (185.4651)	-7029.081 (23018.34)	3.303075 (4.050304)	-41.96051 (185.7708)	-1493.882 (24525.11)
Export	-5.104088 (4.183162)	-211.6956 (163.143)	-44901.6 (31917.69)	-3.192958 (4.45026)	-191.3343 (153.1321)	-38863.03 (29242.24)
Observations	1734	1734	1734	1734	1734	1734
Adjusted R2	0.0313	0.0302	0.0266	0.0290	0.0294	0.0255

Note: Standard errors in parentheses; ***p<0.01, **p<0.05, *p<0.1.

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