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# The role of external interaction for innovation in Irish high-technology businesses

**Declan Jordan and Eoin O'Leary**

***Abstract:*** *There is growing empirical evidence that external interaction is an important source of knowledge for business innovation. This paper contributes to the innovation literature by using new measures of interaction to explore the relative importance of external interaction for innovation in Irish high-technology businesses. Based on survey data, the paper finds that external interaction increases the probability of product and process innovation, but the effect is inconsistent across all external interaction agents. Interaction along the supply chain has a positive effect on innovation, and interaction with competitors has an insignificant effect on innovation output. Notably, the paper finds that interaction with higher education institutions has a negative effect on the probability of product and process innovation.*

***Keywords:*** *innovation; networking; R&D; Ireland*

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## Theoretical and policy contexts

There is now broad and strong evidence that external interaction is an important source of knowledge for business-level innovation (Love and Roper, 2001; Freel, 2003; Tödtling, Lehner and Kaufmann, 2008; Doran and O'Leary, 2011). The external sources of knowledge for innovation include other businesses such as customers, suppliers and competitors, and publicly funded institutions such as higher education institutions (HEIs) or public research laboratories. Empirical studies that endeavour to explore the sources of business innovation must consider the range of potential sources of knowledge. This paper estimates the relative importance for Irish high-technology businesses of in-company research and development (R&D) activity and external interaction with other businesses, HEIs and support agencies for the probability of introducing new products and processes.

The experience of Irish innovation policy over recent years is an interesting case of a science-push policy in which, as part of a strategy to develop a 'knowledge and innovation-based economy', the Irish government is increasingly targeting investment in science and technology. The promotion of this is now at the heart of Irish enterprise development policy. The Irish government has committed almost €2 billion to fund research, a substantial majority of which (81%) is targeted at higher education infrastructure and research and commercialization in HEIs. The emphasis placed by Irish policy makers on innovation as a key source of future competitiveness has its origin at the beginning of the millennium, when the so-called 'Celtic Tiger' growth spurt looked to have ended. The policy shift towards funding research in HEIs has seen the foundation and funding of Science Foundation Ireland (SFI), based on the US National Science Fund. The findings of this paper have implications for businesses and for policy makers who seek to support business-level innovation. These are considered in the final section.

From a theoretical perspective, there is a growing consensus that static general equilibrium models do not adequately reflect the way in which businesses and consumers relate within a competitive market economy. Harper contends that 'modern Walrasian perfect competition theory does not explain market processes, which is the way in which competitive market forces bring about changes in prices and quantities and the introduction of new products and processes' (1996, p 8). The general equilibrium model of a competitive market economy has therefore been challenged by an alternative framework that places the growth of knowledge, and by extension innovation and entrepreneurship, at the centre of the competitive process (Schumpeter, 1934 and 1943; Hayek, 1945; Kirzner, 1973 and 1997). This framework presents the market system as a process of testing hypotheses regarding products and processes, resulting in a continuous cycle of knowledge creation. This is done through the discovery of new knowledge through testing and interaction within a market setting, since, as Hayek (1945) states, 'the economic problem of society…is a problem of the utilisation of knowledge not given to anyone in its totality' (1945, p 519). This knowledge, the basis for entrepreneurship and innovation, is generated and transferred by interaction within networks.

This paper contributes to the study of business-level innovation by analysing the sources of product and process innovation. The paper introduces a new measure of external interaction, which is the frequency of interaction with each of five interaction agents – suppliers, customers, competitors, HEIs and innovation-supporting agencies. This facilitates estimation of whether some interaction agents are more important for product and/or process innovation than others and whether more frequent interaction increases the likelihood of innovation. It uses original survey-based evidence on Irish high-technology businesses to explore the drivers of innovation in what are regarded by Irish policy makers as the key sectors for Ireland's competitiveness.

The next section sets the conceptual framework for the study, considering why external interaction may be expected to affect business-level innovation. The subsequent section comprises a description of the survey data. We then present the innovation production function model used to explore the determinants of product and process innovation. The penultimate section reports estimations of this production function for the incidence of product and process innovation. Finally, we summarize the findings and present our conclusions.

## Interaction for innovation

Several hypotheses have been suggested to explain the innovative performance of a business, including business size and market structure (surveyed in Cohen and Levin, 1989), the stage of the product life-cycle of the business (see Klepper, 1996), the extent of interaction between businesses and their suppliers and buyers (Lundvall, 1988; and Von Hippel, 1988), business capabilities (Nelson, 1991) and the institutional structure within which businesses operate (see Cooke, Gomez Uranga and Exteberria, 1997).

While earlier studies on innovation looked to the characteristics of the business to explain innovation performance (for example, Acs and Audretsch, 1988; and Mansfield, 1981), more recent studies have focused less on the business itself, and more on its position within a network or system of interactions and relationships (for example, Nieto and Santamaria, 2007; Arranz and de Arroyabe, 2008; Jordan and O'Leary, 2008; and Jordan, 2011).

The importance of interaction and networks for business-level innovation is based on knowledge spillovers. These derive from the public good nature of knowledge, which is non-rivalrous and partially excludable. One person's use of knowledge does not diminish the ability of another to use the same knowledge, though the use of patenting may prevent some from fully availing themselves of new knowledge. This raises the prospect of spillovers of knowledge and/ or positive externalities from new knowledge creation. In particular, the transfer of tacit, uncodified knowledge is facilitated by shared experiences and trust, which are developed through interaction.

Von Hippel (1988) and Lundvall (1988) stress interaction between users of knowledge and producers of knowledge as a source of innovation. The ability of businesses to innovate depends not only on internal capabilities and research effort, but increasingly on the ability of the business to identify, access and exploit external sources of knowledge (Cohen and Levinthal, 1990; Kline and Rosenberg, 1986). There is a growing acceptance that vertical supply-chain interaction with suppliers and customers is an important source of knowledge for business-level innovation (for example, Tether, 2002; Miotti and Sachwald, 2003; Roper, Du and Love, 2008). Alternative external sources of knowledge identified in the growing literature on business-level innovation include competitors, academically based researchers and publicly funded agencies (for example, Roper, 2001; Freel, 2003; Nieto and Santamaria, 2007; Arranz and de Arroyabe, 2008).

This paper provides evidence on the effects of interaction with each of these external sources of knowledge on product and process innovation. The paper estimates the effect on the likelihood of innovation of higher frequencies of interaction with customers, suppliers, competitors, HEIs and innovation-supporting agencies.

The public good nature of knowledge suggests a hypothesis, explored in this paper for Irish high-technology businesses, that businesses which interact with external organizations for innovation may be expected, ceteris paribus, to have a greater level of innovation.

## The data

The self-administered survey of 184 Irish high-technology businesses was conducted towards the end of 2004. The particular sectors chosen are classified as 'chemicals and pharmaceuticals', 'ICT' and 'electronic devices and engineering'. The focus on 'high-technology' sectors means that care must be taken in generalizing the results for other sectors. However, the choice of these sectors is motivated by their identification by the Enterprise Strategy Group (2004) and more recently the Irish government's Innovation Taskforce (2010) as having future growth opportunities.

Given the obvious differences in the development of both indigenous and foreign-owned businesses, it is important to note the different characteristics of these respondents. The 98 indigenous respondents had an average of 49 employees in 2003, 54% of whom had a third-level degree. The 86 foreign-owned respondents had an average of 182 employees, 29% of whom had undertaken tertiary education. The average age of indigenous businesses was 14 years, compared with 23 for foreign-owned ones. ICT respondents were significantly smaller businesses and a greater proportion of their workforce had undertaken tertiary education. These differences in age, employment and proportion with third-level qualifications are statistically significant at the 95% level.

In line with other surveys of business-level innovation, such as those of MacPherson (1998), Roper (2001), and the EU's Community Innovation Survey (Forfás, 2008), product innovation is defined as the introduction of new or improved goods/services that may be new to the market or new to the businesses in the reference period, 2001 to 2003. Process innovation, which is less visible from outside a business and, as a result, more difficult to measure, is defined as the introduction to the business of a new method of producing or delivering existing goods/services, the reorganization of support activities, management structures or distribution channels, the introduction of existing goods/services to new markets and the introduction of new sources of supply of materials or other inputs over the same period (Schumpeter, 1934; Kline and Rosenberg, 1986; and Gordon and McCann, 2005).

In order to determine the sources of product and process innovation, businesses were asked whether they performed R&D, either formally through dedicated R&D departments, or otherwise. They were then asked about their frequency of interaction with other group companies (which might be especially important for foreign subsidiaries), suppliers, customers, competitors, HEIs and innovation support agencies. Interaction is defined in the survey as including meetings, networking or other communications that affect innovation. It ranges from social or informal – perhaps unintentional – networking to formal or contractual collaboration that might generate new knowledge used for product or process innovation. Frequency of interaction was measured on a five-point scale from continuously, to frequently, regularly, rarely and never. This approach to the study of interaction is more detailed than generally found in the literature, which typically involves asking businesses whether or not they engage in interaction (see, for example, MacPherson, 1998; Freel, 2003; Roper, Du and Love, 2008), so that the intensity of interaction cannot be considered.

Before progressing to the estimation of an innovation production function, it is worthwhile to outline the innovation characteristics of the businesses in the sample. Eighty per cent of respondents are product innovators and 76% introduced process innovations on a regular, frequent or continuous basis between 2001 and 2003. There are no significant differences in the sample when classified by sector, ownership, age and size. These results are not out of line with those of the Community Innovation Survey for Ireland (Forfás, 2006), which reports innovation activity rates for the high-technology sectors of chemicals, medical instruments, computers and computer-related services of between 65% and 80% for the period 2002 to 2004.

Sixty-seven per cent of businesses indicate that they performed R&D between 2001 and 2003, with 62% of these having a dedicated R&D department. With two exceptions, there are no significant differences in the likelihood of performing R&D or having an R&D department across sectors, ownership, age and size. However, at the 99% confidence level, indigenous are more likely than foreign-owned businesses to perform R&D, while younger businesses are more likely to perform R&D than older businesses.

## The model

The standard approach to modelling innovation in the literature is to use an innovation production function (see, for example, McCann and Simonen, 2005; Roper, Du and Love, 2008; and Roper *et al*, 2010). This models innovation output as a function of the R&D effort of the business and external sources of knowledge through interaction. In addition, the model controls for characteristics of the business that might affect its innovation output, such as size, age and sector (variable definitions are set out in the Appendix).

In this paper, the innovation production function takes the form:

$$IO_i = \alpha_0 + \alpha_1 Z_i + \alpha_2 R\&D_i + \alpha_3 EI_i + \mu \qquad \text{[Equation 1]}$$

where:

$IO_i$ is an indicator of innovation output in business $i$;
$Z_i$ is a range of business-specific factors that may affect business $i$'s capacity to innovate;
$R\&D_i$ is an indicator of R&D effort in business $i$;
$EI_i$ is an indicator of the extent of interaction for innovation in business $i$ with customers, suppliers, competitors, HEIs and support agencies; and
$\mu_i$ is the error term.

In estimating this equation for the survey of high-technology businesses, the hypothesis being tested is that $\alpha_2$ and $\alpha_3$ are positive, implying that both internal and external sources of knowledge have a positive effect on innovation output.

The innovation production function is estimated for the incidence of product and process innovation. The incidence of product innovation refers to whether a business introduced at least one new or improved product during the reference period. The incidence of process innovation refers to whether a business introduced process innovations on at least a regular basis in the reference period.

## The role of interaction

This section explores the effectiveness of business R&D and external interaction for innovation output. First, the extent of interaction with external agents is presented, which shows notable differences in the level of interaction across agents. Second, results of the estimation of an innovation production function for the incidence of product and process innovation are presented and analysed with particular emphasis on comparing the relative importance of R&D and external interaction for both types of innovation.

Table 1 presents the frequency of interaction for product and process innovation by interaction agents in terms of percentage of respondents. The table shows a striking pattern, which does not vary by sector or ownership. Descriptive analysis of these data and policy implications are discussed in detail in Jordan and O'Leary (2005). For a clear majority of businesses engaging in either product or process innovation, regular, frequent or continuous interaction occurs with other group companies, suppliers and customers. This frequent interaction is in stark contrast to the noticeably infrequent interaction with competitors, HEIs and innovation support agencies, as indicated by the majority of businesses never or rarely interacting. This difference is significant at the 99% level.

Table 2 presents logit estimations of the probability of product innovation and regular process innovation. For product innovation, the dependent variable is a binary variable taking a value of 1 if the business indicates it introduced at least one new product in the reference period. For process innovation, the dependent variable is a binary variable taking a value of 1 if the business introduced new processes on a regular, frequent or continuous frequency and a value of 0 if the business never or rarely introduced new processes in the reference period.

In terms of the business characteristics (referred to as $Z_i$ in Equation 1), it can be seen in Table 2 that age is positively associated with the introduction of new products and negatively associated with the introduction of new processes on a regular basis. This indicates that older businesses are more likely to introduce new products and less likely to introduce new processes than younger ones. Larger businesses are more likely to introduce new processes on a regular basis. There is a significantly negative effect of foreign ownership on the probability of product innovation, indicating that indigenous businesses are more likely to introduce new products than foreign-owned businesses.

In terms of sectoral differences, the only significant effect is that businesses in the chemicals and pharmaceuticals sector are less likely to introduce new products

**Table 1. Frequency of interaction for product and process innovation by interaction agent (% of respondents).[a]**

| | Group | Suppliers | Customers | Competitors | HEIs | Agencies |
|---|---|---|---|---|---|---|
| *Product* | | | | | | |
| Never/rarely[b] | 11 | 17 | 9 | 68 | 67 | 56 |
| Regularly to continuously[b] | 89 | 82 | 90 | 31 | 33 | 44 |
| *Process* | | | | | | |
| Never/rarely[b] | 14 | 32 | 29 | 83 | 79 | 71 |
| Regularly to continuously[b] | 86 | 68 | 71 | 17 | 21 | 29 |

*Note:* [a]Numbers may not add to 100% due to rounding. [b]Respondents indicated frequency of interaction based on five categories: never, rarely, regularly, frequently and continuously. For the purposes of this table the categories are grouped.

**Table 2. Logit model of the probability of product innovation and regular process innovation.**

| | Product innovation | | Regular process innovation | |
|---|---|---|---|---|
| | Marginal effects (*dy/dx*) | Standard errors | Marginal effects (*dy/dx*) | Standard errors |
| *Business characteristics* (*Z*) | | | | |
| Age | 0.0029** | 0.0016 | –0.0053* | 0.0022 |
| Size | 0.0001 | 0.0001 | 0.0010* | 0.0005 |
| Turnover growth | 0.0072 | 0.0074 | 0.0141 | 0.0121 |
| Foreign ownership[a] | –0.1811** | 0.1119 | –0.0335 | 0.1357 |
| Workforce education | 0.0006 | 0.0010 | 0.0002 | 0.0015 |
| *Sector* | | | | |
| ICT[a] | –0.0561 | 0.0659 | –0.0743 | 0.1015 |
| Chemicals and pharmaceuticals[a] | –0.1266*** | 0.0798 | –0.0790 | 0.1170 |
| *R&D* | | | | |
| Perform R&D[a] | 0.0990* | 0.0784 | 0.4841* | 0.1154 |
| R&D department[a] | 0.0777 | 0.0636 | –0.1057 | 0.1093 |
| *External interaction (EI)* | | | | |
| Suppliers[a] | | | | |
| Rarely | 0.0218 | 0.0809 | 0.0531 | 0.1058 |
| Regularly | 0.0962* | 0.0453 | 0.2626* | 0.0660 |
| Frequently | 0.1191** | 0.0655 | 0.2735* | 0.0835 |
| Continuously | 0.1153* | 0.0416 | 0.2381* | 0.0635 |
| Customers[a] | | | | |
| Rarely | 0.0617 | 0.0500 | –0.1349 | 0.1833 |
| Regularly | 0.0901* | 0.0442 | 0.0647 | 0.0890 |
| Frequently | 0.1690* | 0.0709 | 0.2071* | 0.0758 |
| Continuously | 0.2030* | 0.0902 | 0.1776* | 0.0840 |
| Competitors[a] | | | | |
| Rarely | –0.0398 | 0.0724 | 0.0070 | 0.0936 |
| Regularly | –0.0709 | 0.0739 | 0.0785 | 0.0894 |
| Frequently | –0.2549 | 0.2134 | –0.3733 | 0.3148 |
| Continuously | –0.3747 | 0.3257 | | |
| HEIs[a] | | | | |
| Rarely | 0.0628 | 0.0460 | –0.3487* | 0.1384 |
| Regularly | –0.1279 | 0.1045 | –0.1875 | 0.1718 |
| Frequently | –0.2495*** | 0.1654 | –0.6748* | 0.1633 |
| Continuously | –0.9108* | 0.0509 | –0.3816 | 0.3130 |
| Agencies[a] | | | | |
| Rarely | –0.0186 | 0.0589 | 0.0897 | 0.1025 |
| Regularly | 0.1430* | 0.0430 | 0.0475 | 0.1050 |
| Frequently | 0.0889* | 0.0393 | | |
| Group membership[a,b] | 0.1724*** | 0.1085 | 0.0631 | 0.1378 |
| *Constant* | | | | |
| N | 169 | | 151 | |
| Log likelihood | –50.719 | | –63.1601 | |
| Pseudo $R^2$ | 0.4022[c] | | 0.3068[c] | |
| LR $X^2$ | 57.34 (0.0013) | | 62.66 (0.0001) | |

*Notes:* *Significant at the 5% level; **Significant at the 10% level. [a]*dy/dx* is for a discrete change of binary variable from 0 to 1. [b]The reference sector is electronic devices and engineering. [c]Pseudo $R^2$ reported is the likelihood ratio index (ie $1–\ln L/\ln L_0$, where $L_0$ is the log likelihood computed with only a constant term).

relative to the reference sector, electronic devices and engineering. None of the other business characteristic variables reported in the estimations are significant predictors of the probability of introducing new products. It is notable that workforce education, measured by the percentage of employees with a third-level degree or equivalent, has no effect on the probability of innovation. This surprising result may reflect the limitations of the measure. Workforce education, measured as the percentage of the workforce with tertiary education, is a proxy for the absorptive capacity of businesses. This is a common practice in the literature (see, for example, Roper, 2001; and Freel, 2003). The measure may be limited as it does not account for the capabilities that workers acquire 'on the job'.

Performing R&D is found to have a significant positive effect on the probability of product innovation and regular process innovation. There is no evidence that performing R&D within a dedicated R&D department affects innovation output. This indicates that R&D does not necessarily have to be formalized in an innovation-active business. Other measures of R&D effort such as number of employees dedicated to R&D or percentage of turnover dedicated to R&D proved to be insignificant. In addition, state aid for R&D proved to be insignificant in all the estimations.

Regarding external interaction, Table 2 shows that the frequency of interaction with suppliers and customers positively affects the probability of introducing new products and processes. There is also a positive effect on product innovation from interaction with support agencies. It is notable that greater frequencies of interaction with suppliers and customers have stronger effects on the probability of product and process innovation relative to those not interacting.

Also, the effect of interaction with suppliers is greater in relation to process innovation and the effect of interaction with customers is greater in relation to product innovation. This is not surprising since new processes may be tied to the adoption of new sources of supply or new equipment, while businesses are more likely to learn of market opportunities for new products through customer interaction.

A particularly noteworthy result is the significant negative association between the frequency of interaction with HEIs and the likelihood of both product and process innovation. In relation to product innovation, it can be seen that interacting frequently and continuously with HEIs reduces the probability of product innovation relative to not interacting at all. In relation to process innovation, it can be seen that interacting rarely or frequently reduces the probability of process innovation relative to no interaction.

This finding differs from that of Jaffe (1989) and Acs, Audretsch and Feldman (1992), who find a strong positive relationship between interaction with HEIs and innovation output in the USA. However, these studies do not control for the effect of interaction with other external interaction agents. (Also, they measure innovation output differently, using patent and commercial data respectively.) While other European studies find no significant effect of HEI interaction on business innovation (for example, McCann and Simonen [2005] on Finland; Roper, Du and Love [2008], and Jordan and O'Leary [2008] on Ireland), this is the first to find a negative effect of HEI interaction on innovation output.

There is evidence that HEI interaction may have a positive indirect effect on innovation output through complementarities in the sources of knowledge for innovation. Roper, Du and Love (2008) and Jordan and O'Leary (2008) find that interaction with HEIs increases the probability of interaction with some interaction agents that have a positive direct effect on innovation output.

The estimations reported in this section indicate that external interaction with customers, suppliers and innovation-supporting agencies is an important influence on the probability of a business being a product or process innovator. These external agents are a source of knowledge enabling businesses to introduce new products and processes successfully to the market.

## Conclusions and implications for businesses and policy makers

*Business implications*

This paper indicates that both R&D and external interaction for innovation are important drivers of innovation output in Ireland's high-technology businesses. They are positively associated with the probability of product and process innovation.

The primary objective of the analysis reported in this paper is to shed light on the relative importance of the factors driving innovation in Irish high-technology businesses. Based on the weighted elasticities of the estimated coefficients, interaction with other businesses and organizations is a more important predictor of the probability of product innovation than R&D. In order of magnitude of the weighted elasticities, the probability of product innovation is positively associated with the frequency of interaction with customers, suppliers, and innovation-supporting agencies, whether the business performed R&D and the age of the business. Performing R&D is the most important predictor of the probability of regular process innovation, followed by the frequency of interaction with suppliers and customers.

This paper's findings show that interaction among businesses and/or between businesses and innovation-supporting agencies is a significant source of knowledge for innovation in Ireland's high-technology sectors.

Interaction with customers and suppliers is positively associated with the probability of being a product innovator and a regular process innovator. Furthermore, interaction with customers is more important for product innovation than interaction with suppliers, suggesting that businesses learn of market opportunities for new products through customer interaction. On the other hand, interaction with suppliers is more important for process innovation than customer interaction, which suggests that new processes may be tied to the adoption of new sources of supply or new equipment.

The study finds a negative relationship between the probability of product and process innovation and the frequency of interaction with academically based researchers. This result and its policy implications are considered at greater length in Jordan and O'Leary (2008) and Jordan (2011). The negative effect may arise because businesses may turn to HEIs when faced with particularly complex problems during the process of innovation. Indeed the problem posed by the business may be insoluble. As a result, the likelihood of developing a commercial product or process from the interaction may be low. Alternatively, the result may reflect differences in work practice and objectives between businesses and academics that hamper the commercial development of new products and processes. These differences may be compounded by the lack of an ongoing relationship between businesses and HEIs that is a feature of business-to-business interaction.

This result highlights particular challenges for high-technology businesses that are engaging or intend to engage with researchers at HEIs. It suggests that attention should be paid to ensuring alignment of objectives and incentives between the business and the HEI researcher.

Overall, the results indicate that businesses may use a combination of internal (R&D) resources and external knowledge sourced through interaction to drive innovation. Product specification, development, production, marketing and service functions cooperate to enhance products and processes. This relates directly to Bhidé's (2008) suggestion that managers, salespeople and customers are potentially as important to the innovation process as researchers and scientists. Interaction between these functions and external agents, even informally, may lead to new learning and innovation. This may involve feeding customers' demands back to designers to enhance new products, as well as production operatives realizing new ways of organizing processes to enhance efficiency.

*Policy implications*

Interaction between businesses and other organizations has been identified for some time by Irish policy makers as an important element in supporting business-level innovation, particularly regional and local networks based on clusters such as Silicon Valley, Emilia-Romagna and Cambridge (Scott, 1988; Saxenian, 1990; and Castells and Hall, 1994), on which much of Irish innovation and regional policy draws (for example, Department of the Environment and Local Government, 2002, p 40; National Competitiveness Council, 2004, p 3). While this analysis is not concerned with the spatial aspect of interaction, the results provide support for the policy emphasis on the promotion of interaction among businesses to encourage innovation.

However, while interaction with competitors has been an important aspect of the celebrated examples of successful clusters mentioned above, in these cases businesses are small and flexible, thus enabling alliances to form easily. This study questions whether this aspect of these examples may be replicated in an Irish context. The lack of interaction between competitors in high-technology sectors in Ireland may reflect the particular features of the Irish economy. Typically high-technology businesses located in the country are a mix of very large foreign-owned and smaller indigenous businesses, operating in particular international market niches, with few competing with each other. Given this structure, it may not be reasonable to expect to observe similar levels of competitor interaction in the Irish case.

The finding that high-technology businesses performing R&D are more likely to innovate provides support to interventions from policy makers to raise both the number of businesses engaged in R&D and the level of R&D in high-technology businesses. The Strategy for Science, Technology and Innovation identified a number of measures to support in-company R&D, including simplification and rationalization of R&D grant structures and extending the R&D tax credit scheme (Department of Enterprise, Trade and Employment, 2006, p 49). The results do not provide any evidence that the existence of a dedicated R&D department increases the probability of innovation. This suggests that policy interventions ought to be flexible in supporting R&D that is not formalized or routine.

Innovation policy in many countries – especially in Europe – has sought to promote innovation through funding research at university level. A critical element of the Lisbon Agenda strategy is to achieve a target of research and development (R&D) spending of 3% of gross domestic product (GDP). This has resulted in a substantial increase in funding for basic research by government agencies across the EU. Similar policies are being implemented in the USA, where President Obama has committed to doubling the budgets for the three key basic-research agencies over the next decade (Office of Science and Technology Policy, 2009).

In these innovation policy frameworks, most of the funding for research from government is channelled through higher education institutes. It is hoped that research in these academic laboratories will generate technological breakthroughs and, in turn, new products, services and processes. The findings of this paper suggest that, at least in the Irish case, the strategy may not achieve the hoped-for returns and also that policies in this area should reflect specific characteristics of individual sectors and economies.

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# Appendix

**Table A. Definition of variables.**

| Variable | Definition |
|---|---|
| *Innovation output indicators* | |
| Product innovator | A dummy variable taking a value of 1 if the business introduced a new or improved product in the three-year reference period. |
| Regular process innovator | A dummy variable taking a value of 1 if the business introduced new or improved processes on a regular, frequent or continuous basis in the three-year reference period. |
| *Business characteristics indicators* | |
| Age | The number of years at the start of the reference period since the business began operations in Ireland. |
| Size | The number of employees (full-time equivalent) at the start of the reference period. |
| Foreign ownership | A dummy variable taking a value of 1 if the business is foreign-owned. |
| Group member | A dummy variable taking a value of 1 if the business is a parent or subsidiary in a larger group of companies. |
| Workforce education | The percentage of the workforce with a third-level degree or equivalent qualification. |
| Turnover growth | The rate of growth in turnover in the three-year period between 2001 and 2003. |
| Sector | A series of dummy variables; the sectors controlled for are ICT and chemicals and pharmaceuticals. The reference sector is engineering and electronic devices. |
| *R&D indicators* | |
| Perform R&D | A binary variable taking a value of 1 if the business performed R&D in the three-year period from 2001 to 2003. |
| R&D department | A binary variable taking a value of 1 if the business had a dedicated R&D department in the three-year period from 2001 to 2003. |
| *Interaction indicators* | |
| Interaction frequency | An ordinal variable for each interaction agent representing interaction frequency on a five-point scale, ranging from never to rarely, regularly, frequently and continuously. A value of 1 represents no interaction, and a value of 5 represents continuous interaction. The frequency of interaction is considered for both product and process innovation. |
| Incidence of interaction | A dummy variable for each interaction agent taking a value of 1 if the business indicates that it interacted at any frequency with the interaction agent in the reference period. |