

# Boosting Innovation and Productivity in Enterprises: What Works?

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# Boosting Innovation and Productivity in Enterprises: What Works?

## Abstract

A return to economic growth and higher employment requires growth in the number and sustainability of Irish enterprises. Innovation at enterprise level is essential for sustainability and competitiveness and plays a major role in increasing overall productivity. Understanding the determinants of enterprise innovation and how it affects productivity is important for designing effective innovation policies. The tight fiscal constraints and the urgency of achieving successful outcomes require that government policies aimed at enhancing enterprise innovation and raising productivity need to be very effective. This paper draws on recent international theoretical and empirical literature based on enterprise level data to explore four questions: Does innovation contribute to higher productivity? Which types of enterprises invest in innovation? Which enterprises have higher innovation expenditure per employee? Which types of enterprises are more likely to innovate successfully? We then look at what these findings imply for policy in relation to indigenous enterprises, whether the current policy mix is appropriate and how it might become more effective.

## 1. INTRODUCTION

While there is considerable disagreement about what Ireland needs to do in order to promote faster economic recovery, there is universal agreement that we must foster economic growth. Given the open nature of the economy and the collapse in domestic demand, exports are widely seen as the key to growth as we return to the pattern of the 1990s. Expanding export markets at a time of global uncertainty is challenging. Enterprises need to become more competitive if they are to gain market share, and this requires a combination of reduced costs and greater productivity. For OECD economies, innovation at enterprise level is viewed as having a major role to play in increasing overall productivity (OECD, 2006; OECD 2009a) operating through new product/service creation, process development and organisational change. Such innovation is not limited to enterprises' own innovation efforts, but is also the result of collaborations with other entities on the supply chain (suppliers and consumers) and with knowledge institutions (higher education and research). Furthermore, innovation is not limited by national boundaries or systems, as today's knowledge networks are both global and local.

There has been a growing emphasis on innovation over the past two decades in all developed countries, and this focus is now increasingly found in developing countries.<sup>1</sup> The importance of having framework conditions in place that are conducive to innovation within countries and within regions (e.g., European Union) is recognised in the policy environment and is strongly supported by empirical evidence (see Box, 2009).<sup>2</sup> The key framework conditions include: a stable macroeconomic policy environment; international openness to flows of goods, services, capital and knowledge (embodied in both technologies and people); appropriate levels of competition and regulation; a developed and well functioning financial system; a coherent intellectual property system; flexible labour markets; a well-performing education system and a high-performing infrastructure. Policies that improve the framework conditions in a particular economy will also support innovation, and consequently ignoring the impact of these framework conditions can undermine other policy efforts to increase innovation. While Ireland has committed to improving the framework conditions facing the enterprise sector, it has still some considerable distance to travel (OECD, 2009b; OECD, 2011). Furthermore, the current international crisis is

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<sup>1</sup> The increased emphasis on innovation in the EU dates back to the Lisbon Strategy in 2000, as the lag between innovation rates in the EU compared with the US and Japan were noted. This emphasis was reinforced at the European Council meeting in Spring 2006 when investment in knowledge and innovation was identified as one of the four priority areas in the revised strategy.

<sup>2</sup> The importance of framework conditions is also emphasised in Porter (1990), who looks at innovation from an enterprise-strategy perspective, drawing on case studies to explore innovation processes. Our approach complements Porter's.



particularly damaging because of the global uncertainty it has generated, and the difficulties with financial institutions in Ireland pose particular problems for financing of enterprise innovation.

Market and systemic failures in the innovation process can also result in the levels of investment in innovation within enterprises and industries being less than socially optimal (OECD, 2006). The key market failures identified in the literature are well known. Positive externalities, due to knowledge spillovers, mean that the private returns to an enterprise investing in innovation are less than the total returns to society from that investment. These knowledge externalities, which reflect the public good aspect of knowledge generation, also underpin government funding of basic research in most countries. Information asymmetry regarding the risks associated with investments in innovation makes it difficult for enterprises to raise funds for innovations that have a high research component, and hence market processes generate less investment in innovation than is optimal. This problem is exacerbated in the case of small and medium size enterprises (SMEs) which cannot attract the funds needed to support their investments and hence cannot achieve the economies of scale needed for growth.

In addition there are several systemic failures that can undermine the development of an innovation eco-system and hence reduce the level of innovation below its optimal level and/or undermine its potential efficiency. These arise from several sources: successful innovation often requires the cooperation of market and non-market institutions (e.g., enterprises and universities) which have incompatible incentives; knowledge flows can be restricted by suboptimal networking and personnel mobility; enterprises may not have the capability to absorb knowledge that could enhance their capacity to innovate and remain competitive; SMEs may not have the resources to allow them to benefit from international developments in science, technology and innovation, etc.

Throughout the OECD economies, these market and systemic failures are seen as providing the rationale for governments to develop policies designed to support innovation and higher productivity levels within enterprises. However, government intervention is not automatically justified by such failures as the costs of the intervention, both direct and indirect, may be high relative to the benefits. This is more likely to be the case where interventions are complex and administratively burdensome, giving rise to the risk of replacing market or systemic failures with government failures (OECD, 2006). So whether such policies in any particular country will be effective, i.e., generate net benefits

relative to their costs, depends on their being appropriately targeted to address the specific failures that are present. To succeed, these policies must recognise how enterprise characteristics and performance vary between and within industries and understand the determinants of innovation and productivity at enterprise level.

Ireland only began to focus on innovation in the early 1990s (Mjøset, 1992) and from the late 1990s onwards there has been significant support given to the development of the country's scientific, technological and innovative capacity (ICSTI, 1999; Forfás, 2004). Direct support has been given for research and innovation capacity within the enterprise sector, and the funding challenges faced by SMEs have led to considerable investment by the State in venture capital funds and a series of tax changes that have enhanced the attractiveness of Ireland as a base for enterprise-led R&D and innovation.

The competition for internationally mobile innovation intensive projects has also influenced the government's emphasis on building research excellence in the last decade, where earlier and more limited support had simply focused on the relevance of research in universities to enterprise interests. Consequently there has been a significant up-scaling of the research capacity and science and technology infrastructure in Ireland's universities, colleges and other public research organisations.

Notwithstanding the pressure on public expenditure, the 2007-2011 government signalled its intention to continue to support research as part of its economic strategy (Department of An Taoiseach, 2008) and this emphasis is contained in the *Programme for Government* of the 2011-2016 government. This support is set to continue both at enterprise level and in the public research system, with the focus increasingly on investment in those areas that are most likely to yield measurable returns in the medium term (Report of the Steering Group of the Research Prioritisation Exercise, 2011).

The tight fiscal constraints and the urgency of achieving successful outcomes require that government policies aimed at enhancing enterprise innovation and raising productivity need to be very effective. This means understanding the relationship at enterprise level between productivity and innovative sales and between investment in innovation and innovation performance. Specifically we draw on the new international literature based on enterprise level data to explore:

- Does innovation contribute to higher productivity?
- Which types of enterprises invest in innovation?
- Which enterprises have higher innovation expenditure per employee?
- Which types of enterprises are more likely to translate innovation inputs into innovation outputs (innovate successfully)?

We then look at what these findings imply for policy in relation to indigenous enterprises, whether the current policy mix is appropriate and how it might develop to be more effective. While crucially important, the evaluation of the impacts of R&D and innovation policies is beyond the objectives of this paper.

Section 2 of the paper sets out the conceptual framework underpinning the analysis, while Section 3 summarises the data sets used. Section 4 summarises the findings of the international literature in relation to the four questions while Section 5 explores these questions specifically in the context of the indigenous sector. Finally Section 6 presents some brief conclusions.

## **2. ANALYTICAL FRAMEWORK**

To answer the questions this paper addresses, we propose a conceptual framework to contextualise the large existing empirical evidence on the complex relationships between innovation inputs, innovation outcomes and productivity. This framework derives from four literature strands which are relevant to the four questions this paper addresses.

### ***Size, market power and innovation***

The importance of technological change and innovation for economic growth was largely ignored until the writings of Schumpeter (1942). In addition to linking technological change to economic growth, he argued that large enterprises operating in concentrated markets are more likely to innovate. Following on from Schumpeter's contribution, the literature on industrial organisation has focused on the relationships between enterprise size, market structure and innovation (measured by R&D expenditures) and neglected other determinants of technological change and innovation (Cohen, 2010).

The arguments most often made for a positive relationship between enterprise size and innovation are as follows (Cohen and Levin, 1989, Symeonidis, 1996, Ahn, 2002):

- *Economies of scale in R&D*: the returns to investment in R&D are higher for enterprises with a large volume of sales over which to spread the fixed costs of innovations;
- *Economies of scope in R&D*: large enterprises are likely to be more diversified and to be able to benefit from positive spillovers between the various research programmes;
- *Diversification of risks*: large enterprises can undertake several projects at the same time and hence diversify the risks associated with R&D investment;
- *Availability and stability of external and internal funds*: large enterprises with market power are more likely to secure finance for risky R&D.

However, as enterprises grow large, efficiency losses with respect to performing R&D might occur, in particular from losing managerial control and diminished ability of innovators to appropriate the benefits from their innovative efforts (Cohen and Levin, 1989).

Many empirical studies have interpreted Schumpeter's argument about the advantage of large enterprises at innovating as a hypothesis that innovative activity increases more than proportionately with enterprise size and have tested the relationship between measures of innovative activity and enterprise size. However, Schumpeter (1942) did not claim that a continuous relationship exists between enterprise size and performing R&D. Rather, he noted the qualitative differences between innovation activities of small entrepreneurial enterprises and large corporations with formal R&D laboratories (Cohen, 2010).

With respect to the relationship between market power and innovation, Schumpeter's view can be summarised as follows (Cohen and Levin, 1989; Ahn, 2002):

- *Ex ante* market power favours innovation: with imperfect capital markets, the rents from market power provide enterprises with internal financial resources for innovative activities;
- Incentives to invest in R&D are linked to expected *ex post* market power.

Empirical evidence on the relationship between market concentration and innovation is mixed with most recent studies suggesting that this relationship is

non-linear and market structure is influenced by innovation (Cohen and Levin, 1989; Geroski and Pomroy, 1990; Sutton, 1996, 1998;) rather than being exogenous (an independent determinant) as often assumed in earlier studies.

More recent studies have considered additional enterprises and industry characteristics to explain innovation activity beyond enterprise size and market concentration<sup>3</sup>.

### ***R&D investment, knowledge spillovers and productivity growth***

The endogenous growth literature (Romer, 1990; Grossman and Helpman 1991; Griliches, 1996; Aghion and Howitt, 1998) has established that technological change is endogenous and that private R&D investment and knowledge spillovers affect productivity growth. The point of departure of the theories of endogenous growth are two related characteristics of knowledge: (i) knowledge is non-rival (the marginal costs for an additional technology user is negligible); (ii) knowledge is partially non-excludable due to imperfect intellectual property protection which implies that the return to investments in knowledge/innovation is partly private and partly public (social).

Existing empirical evidence at enterprise and industry levels suggests that social rates of return to R&D/innovation investment are higher than the private rates of return (Griliches, 1992). Jones and Williams (1998) relate the theoretical models of new growth theory to empirical results of the productivity literature and show that these results can be taken as lower bounds for the social rate of return to R&D.

A key policy message of this literature is that government intervention can foster innovation and productivity growth.

### ***Innovation systems***

The main contribution of the literature on innovation systems (Freeman, 1987; Lundvall, 1992; Nelson, 1993) is the finding that, at the national aggregate level, innovation is the result of interactions between enterprises and institutions at the micro level which are governed by both market forces and non-market institutions. Five main insights on innovation have emerged from this literature (Soete, et al. 2010): (i) the role of non-R&D inputs beyond R&D influences on

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<sup>3</sup> A recent review of this literature is Cohen (2010).

innovation; (ii) the role of institutions and organisations; (iii) the role of interactive learning; (iv) the role of interactions between agents involved in innovation; (v) the role of social capital.

The efficiency of the innovation system depends on the performance of individual actors and the institutions that govern their interactions. The main policy message of this literature is the central role the government can play as coordinating agent to correct systemic failures. One policy limitation of this national innovation system concept is its failure to take account of the growing internationalisation of R&D and innovation and in relation to this of the need to consider the international context in which innovation takes place.

### *International trade with heterogeneous firms*

The most recent international trade theory (New-New Trade Theory) has established that enterprises with international linkages are more productive than enterprises serving only the domestic markets. Existing empirical evidence indicates that enterprises with international linkages (exporters, importers and multinational firms) differ systematically from enterprises that serve only the national market<sup>4</sup>. They are larger, generate higher value added, employ more capital per worker, have higher skilled workers and have higher productivity.

A large empirical literature has established that exporters are more productive than non-exporters and they often have higher productivity growth<sup>5</sup>. This productivity advantage of exporters could be explained by two hypotheses (Bernard and Jensen, 1999; Bernard and Wagner, 1997: (i) more productive enterprises self-select into export markets; (ii) learning-by-exporting. Self-selection of more productive enterprises into export markets can be explained by the presence of fixed and variable costs of exporting (Melitz, 2003). This fact implies that only enterprises with a productivity level above a critical threshold find it profitable to export. Exporting could make enterprises more productive through two channels: (i) export starters could improve their post-entry performance due to knowledge flows from international buyers; (ii) international competition may put pressure on exporters to improve their productivity faster than firms selling only on domestic markets. Helpman et al. (2004) show that in the presence of fixed costs of exporting and of undertaking foreign direct

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<sup>4</sup> Recent micro-econometric evidence has been surveyed by Helpman (2006), Greenway and Kneller (2007) and Wagner (2007)

<sup>5</sup> Wagner (2007) and Martins and Yang (2009) surveyed recent empirical studies

investment, multinationals are the most productive enterprises in their country of origin, followed by domestic exporters.

A growing empirical literature has focused on the links between importing and productivity and found that importers are more productive than firms that do not trade internationally.<sup>6</sup> Enterprises that export and import are more productive than enterprises that import only and enterprises that export only, or do not trade internationally. Importers are the next most productive group followed by exporters. Enterprises serving only the domestic markets come last. The theoretical explanations for the productivity advantage of importers are similar as in the case of exporters: self-selection of more productive firms into imports and learning-by-import effects (Kasahara and Lapham, 2008; Andersson et al, 2008; Castellani et al., 2010).

While this literature has assumed that enterprise productivity is exogenous, more recent theoretical contributions allow for the possibility of enterprises increasing their productivity through innovation activities (Yeaple, 2005; Bustos, 2011). A positive correlation between exporting and innovation activity has been found in several studies (Wagner, 1996; Roper and Love, 2002). In addition, a number of recent empirical studies have found that exporters are more likely to introduce product innovation (Liu and Buck, 2007; Salomon and Shaver, 2005; Bratti and Felice, 2010). Furthermore, additional recent empirical evidence suggests that foreign-owned enterprises and exporters are more likely to innovate (Crisuolo et al, 2010; Siedschlag et al, 2010).

In summary, this analytical framework allows us to think of innovation as a complex and non-linear process which is the result of many interactions between enterprises and institutions including government. Innovation takes place in the context of increased internationalisation of economic activities including a growing internationalisation of R&D and innovation activities. Furthermore, this analytical framework highlights the rationale for government intervention to foster innovation and productivity in enterprises. However, the cost of government intervention needs to be also taken into account when policy choices about allocation of scarce public financial resources are made.

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<sup>6</sup> Vogel and Wagner (2010) review this new and growing empirical literature.

### 3. MEASUREMENT AND DATA

Until the beginning of the 1990s, innovation was measured and analysed using two measures, namely, R&D expenditures and patents. Data on R&D expenditure have been collected since 1950s while data on patents are available from national patent offices and go back to the nineteenth century (Mairesse and Mohnen, 2010). However, it became apparent in the late 1980s that both R&D expenditures and patents have major shortcomings as measures of innovation. R&D expenditure measures just one input, albeit a major one, into innovation. Patents cover only a subset of invention successes and the extent of patent use varies widely across industries. With the exception of pharmaceuticals and instruments, patents are seldom used by other industries as an innovation strategy. In addition, most patents describe inventions of little value (Hall, 2011). Both measures are more suited to measuring technological innovation and innovation in manufacturing.

With the growing share of services in the economic activity of developed economies, innovation in services and, more broadly, non-technological innovation have become increasingly important. Innovation in services is less directly dependent on R&D expenditures and, given the intangible nature of services, less likely to be patented. To capture these new economic developments and to overcome the shortcomings of the traditional measures of innovation, qualitative and quantitative data on innovation at enterprise level have been collected through innovation surveys. In Europe, these innovation surveys are known as the Community Innovation Surveys (CIS).<sup>7</sup>

The concept of innovation has been developed over the past decade and different types of innovation are set out formally in the Oslo Manual (OECD, 2005). The Manual defines innovation as:

*“the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations”.*

This definition distinguishes four types of innovation: product innovation, process innovation, organisational innovation, marketing innovation. Using this conceptual framework, an innovative enterprise is an enterprise that had successfully introduced one of these types of innovations in the period under

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<sup>7</sup> Between 1990 and 2005, the CIS were conducted every 4 years. Since 2007, CIS are conducted every 2 years and enterprises are asked questions in relation to their innovation activities over the previous 3-year period.



consideration. Alternatively, using an input-based definition, an innovative enterprise is a one that engages in R&D/innovation investment.

The Oslo Manual has also broadened the definition of innovation expenditures beyond R&D expenditure to include expenditure on training, purchasing of equipment, designs and licences.

#### **4. EMPIRICAL EVIDENCE ON INNOVATION AND PRODUCTIVITY IN ENTERPRISES**

There is a growing empirical literature that explores links between innovation inputs (R&D/ innovation expenditure), innovation outcomes and output/productivity. This strand of research is based on an econometric framework developed by Crépon, Duguet and Mairesse (1998), hereafter referred to as the CDM model, and most studies use data from the Community Innovation Survey (CIS).

The CDM model estimates three sets of relationships. The first set consists of two equations relating to the innovation investment phase, viz., the propensity of enterprises to invest in innovation and the innovation expenditure intensity conditional on innovation investment. The second set relates the various types of innovation outcomes to innovation expenditure intensity (innovation expenditure per employee) and other enterprise and industry characteristics. The third set links output/productivity to innovation outcomes and other enterprise characteristics. There are two econometric issues associated with estimating the CDM model. First, selection bias might arise due to the fact that a number of questions are asked in surveys only to innovative enterprises and this set of enterprises might be non-random. Second, innovation inputs, innovation output and productivity might be simultaneously determined. These econometric issues are corrected for using appropriate estimation techniques<sup>8</sup>. In contrast to univariate correlation analyses, the multivariate econometric analyses reviewed here allow one to distinguish the influence of each relevant factor on the key outcome variables over and above the influence of other factors (covariates). Hence this type of evidence is more robust. The CDM econometric model is described in more detail in Appendix A.

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<sup>8</sup> Selection bias is corrected by using a Heckman two-step estimator. To correct for simultaneity, innovation output and productivity are estimated using the expected (predicted) values of innovation input and innovation output respectively.

A summary of empirical evidence from selected country studies is given in Appendix B. We selected those studies that estimate a variant of the CDM model and use CIS data from developed European countries. The countries covered in this summary include large ones (France, Germany, United Kingdom, Spain, Italy) and small countries (Sweden, Finland, Norway, Switzerland, Denmark, the Netherlands, Belgium, Austria, Luxembourg) as well as Ireland.<sup>9</sup> Market and systemic failures in relation to innovation are likely to be greater in smaller countries because of the size distribution of enterprises.

While the selected studies address the same issues, they differ with respect to the types of innovation that are considered; the explanatory variables used; and the econometric methods used to account for selectivity and simultaneity. Given the fact that the Community Innovation Surveys do not observe the same firms over time, most of the reviewed studies use cross-sectional data which implies that the estimates can be interpreted as correlations and not necessarily as causal relationships. In contrast, Polder et al. (2010) and Siedschlag et al. (2010) linked two or three CIS waves to analyse the links between innovation and productivity. The added value of these two studies is that they account for unobserved firm heterogeneity and dynamic responses to lagged explanatory variables. However, it is noteworthy that the results obtained with panel data models are qualitatively broadly similar to those using contemporary measures of innovation and productivity.

Because of data availability, most studies focus on the intensity of *product innovation*, i.e., innovative sales share; innovative sales per employee; and patents per employee. However, some recent studies have considered additional types of innovation – process, organisational and marketing innovation. Specifically, they look at innovation output in terms of the probability that the enterprises introduce product, process, or organisational innovations.

Given that productivity gains are often related to efficiency improvements due to process and organisational innovations, we report the results of both of these where available. The analyses in most cases cover manufacturing enterprises

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<sup>9</sup> The CDM model has been estimated for developing countries as well. See for example Benavente (2006) for Chile; Raffo et al. (2008) for Argentina, Brazil, and Mexico; Chudnovsky et al. (2006) for Argentina; Jefferson et al. (2006) for China. Given the fact that these countries have different underlying structural characteristics in comparison to developed countries, we do not review them here. The evidence provided by these studies suggests that enterprises in developing countries tend to have weaker interactions with their national innovation systems. In particular the weak links between academic research and industry limit the innovation performance of enterprises in these countries. The lack of domestic innovation networks might be overcome by links with international networks as is the case in Argentina.

only but we also report the small number that cover services (for example Polder et al. 2010 for the Netherlands; Siedschlag et al 2010 for Ireland; Mairesse and Robin, 2010 for France; Lööf and Heshmati, 2006, for Sweden).

We consider the empirical findings in relation to each question in turn (see Appendix B):

### ***What is the innovation productivity link?***

The existing empirical evidence indicates that enterprises with product innovation do have higher productivity levels (measured as sales per employee, value added per employee). Higher productivity may reflect higher price/quality or higher quantity. There is also evidence, albeit more limited, of a positive link between process innovation and productivity levels. The very limited available evidence (for example, Polder et al. 2009, for the Netherlands; Siedschlag et al. 2010 for Ireland) uncovers a positive link between organisational innovation and productivity that is stronger than that for product and process innovation.<sup>10</sup> The estimated productivity elasticity with respect to the product innovation intensity (innovation sales share) in manufacturing ranges from 0.07 (France) to 0.26 (Norway) and in services the corresponding elasticity is 0.09 (Sweden). The corresponding estimates for Ireland (0.09/0.10) imply that on average, a doubling of the share of sales due to new products is associated with a labour productivity that is higher by 9 per cent in manufacturing and by 10 per cent in services. The productivity elasticity with respect to the probability of introducing new product innovation in manufacturing ranges from 0.05 (France) to 0.69 (Italy) while the corresponding elasticity in services is lower (0.17 for France). In Ireland the corresponding productivity elasticities imply that being a product innovator is associated with a labour productivity higher by 26 percent in manufacturing and 61 per cent in services. In effect, the evidence supports a strong emphasis on innovation as a key driver of productivity at enterprise level.

### ***Which enterprises are more likely to invest in R&D/innovation?***

The most robust result across the reviewed empirical evidence is that larger enterprises have a greater propensity to invest in R&D/innovation. Over and above size, enterprises operating in international markets (exporters) are more likely to invest in innovation. Other factors positively associated with the propensity of enterprises to invest in innovation include higher innovation

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<sup>10</sup> The role of organisational innovation has been less analysed due to unavailable data in earlier CIS and innovation surveys.

capability<sup>11</sup>, previous successful innovation, formal and strategic protection of intellectual property, larger market shares, more diversified activities, receiving public funding, and belonging to a group.

Specifically, the empirical evidence for Ireland indicates that the propensity of enterprises to invest in innovation is positively linked to size, the internationalisation of enterprises (foreign ownership and exporting) and a higher innovation capability. The Irish results are in line with the international evidence. While other studies have not specifically modelled the role of foreign ownership, given the large share of foreign affiliates in the business R&D in Ireland (70% in 2005, European Commission, 2008), this variable was included for Ireland to avoid biased estimates.

### ***Which enterprises have higher innovation expenditure per employee?***

While larger enterprises are more likely to invest in innovation, existing empirical evidence suggests that the innovation expenditure intensity (R&D/innovation expenditure per employee) decreases with or is independent of enterprise size. Other factors found to be positively linked to the R&D/innovation effort intensity include larger market shares, more diversified activities, international competition (from exporting), engagement in co-operation for innovation, receiving public funding for innovation, formal and strategic protection of intellectual property, continuity of R&D investment, previous successful innovation, and higher innovation capability.

The evidence from Ireland indicates that, for a given probability of investing in innovation, smaller enterprises have higher innovation expenditures per employee. A similar result is found in other small countries such as Finland, Sweden and the Netherlands. Not surprisingly, innovation expenditure per employee is found to be positively correlated with foreign-ownership and higher innovation capability.

### ***Which enterprises are more likely to innovate successfully?***

Successful innovation implies that innovation inputs are translated into innovation outputs such as product, process or organisational innovation. In relation to enterprise size, the empirical evidence on this question is mixed. While several studies find that larger enterprises are more likely to have

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<sup>11</sup> Innovation capability is measured as the productivity gap between enterprise productivity and the productivity of global leaders (top 10% most productive enterprises) in the same industry.

successful innovations, in particular product innovation, a number of studies find that size is not significantly linked to innovation outcomes. Furthermore, while some studies find that higher R&D/innovation expenditure intensity appears positively linked to successful innovation, especially product innovation, other studies find that R&D/innovation expenditure does not translate into innovation output directly. This result is particularly sensitive to model specification and econometric methods used. Interactions with national innovation systems, as captured by co-operation in innovation activities with other agents, in particular suppliers and customers and research institutions (universities and R&D institutes), appear in most cases to be beneficial to successful innovation. Other factors with a positive influence on successful innovation include formal and/or strategic protection of intellectual property, greater ICT investment and greater ICT use (particularly in services).

The evidence for Ireland indicates that enterprises with international linkages are more likely to have product, process and organisational innovation as well as a higher intensity of product innovation (innovative sales share). While larger enterprises are more likely to be innovators, the innovative sales associated with product innovation are not significantly linked to enterprise size. With the exception of organisational innovation, enterprise level R&D/innovation expenditure intensity is not significantly linked to innovation outcomes over and above foreign linkages, enterprise size and interactions with the national innovation system.<sup>12</sup> A similar results is found in the cases of process and organisational innovation in the Netherlands (Polder et al, 2010) and in the case of product innovation intensity in Austria, Switzerland, Luxembourg (OECD 2010). This finding suggests that the relationship between R&D/innovation expenditure intensity and innovation outcomes is a complex one and that particular care is needed when drawing policy implications from the existing evidence. One possibility behind this finding is that there are lagged effects between innovation expenditure intensity and innovation outcome which cannot be captured due to data limitations. Another possible explanation might be the fact that service enterprises represent a larger number in the analysed sample in comparison to manufacturing enterprises and innovation in services is less dependent on R&D/innovation expenditure. Further, the growing internationalisation of R&D and innovation might substitute for enterprises' own innovation efforts/inputs.

Existing empirical evidence suggests that co-operation in innovation activities has become increasingly important for enterprise innovation. Siedschlag *et al.* (2010)

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<sup>12</sup> OECD (2010) and Doran and O'Leary (2011) using cross-section data, different CDM model specifications and different econometric methods find that product innovation intensity was higher in enterprises with higher R&D intensity.

find that all types of innovation outcomes are positively related to co-operation in innovation activities with suppliers, with consultants, commercial laboratories or private R&D laboratories; with universities; co-operation with customers is linked positively with product innovation; co-operation with other enterprises within the same enterprise group is positively associated with product and process innovation. Innovative sales intensity was higher for enterprises co-operating with enterprises within the same enterprise group; with suppliers; with customers; with consultants, commercial labs, or private R&D laboratories; with universities. Innovative sales intensity was lower for enterprises co-operating with the government or public research institutes.

In summary, the international empirical evidence as well as evidence from Ireland suggests three key policy relevant findings:

- Innovation is positively linked to productivity, and this link appears to be robust to different data sets, model specifications, and econometric methods;
- The impact of innovation on productivity varies by innovation type and enterprise scale:
  - Product, process and organisational innovation, individually and in combination, impact differently on enterprise productivity;
  - While larger firms are more likely to invest in innovation, smaller firms have higher innovation investment per employee. Furthermore, while size appears positively correlated with successful innovation, (product) innovation intensity (innovative sales share, innovative sales per employee) declines with or is not influenced by size;
- The relationships between innovation inputs, innovation outcomes and productivity are complex, non-linear and unlikely to be contemporaneous.

## 5. KEY POLICY MESSAGES FOR INDIGENOUS INNOVATION

While the international evidence reviewed above informs our understanding of how innovation is linked to productivity and growth, its purpose is not to evaluate the relevant R&D and innovation policies. Nonetheless it is possible to explore the key policy messages associated with these findings and we do this now for indigenous enterprises. We recognise that these enterprises account for the smaller share of investment in innovation<sup>13</sup> but we suggest Ireland needs to raise the productivity of indigenous enterprises if it is to achieve sustainable economic renewal. In order to contextualise the international results discussed, we have

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<sup>13</sup> In 2009 indigenous enterprises accounted for 30 percent of business expenditure on R&D in Ireland. <http://www.forfas.ie/media/BERD%202009-2010.pdf>

estimated the CDM model for the indigenous sector only and these results are reported in Table 1.<sup>14</sup>

In this Section, we look at these findings in relation to indigenous enterprises and draw out policy messages in the context of current policies. While we do not attempt to evaluate the impact of the policies currently in use, we do raise questions as to whether the current suite of policies achieves its goals effectively, and suggest that evidence-based evaluation is needed.

We now review the four questions discussed above for the indigenous sector and the policies currently being operated by Enterprise Ireland.<sup>15</sup>

**Table 1: Innovation and Productivity in Irish Owned Enterprises in Ireland, 2004-2008**

Question	Research Findings
Is there a link between innovation and productivity (sales per employee) at enterprise level?	Positive link for enterprises engaging in process innovation; organisational innovation; product + organisational innovation; process + organisational innovation Negative link for product innovation intensity (innovative sales share)
Which enterprises are more likely to invest in R&D/ innovation?	Larger enterprises Enterprises that export
Which enterprises have higher innovation expenditure per employee?	Enterprises with higher innovation capability
Which enterprises are more likely to innovate successfully?	Larger enterprises (in the cases of process innovation; organisational innovation; process + organisational innovation) Smaller enterprises in the case of product innovation intensity Enterprises with higher innovation expenditure intensity in the case of organisational innovation only. Enterprises with lower innovation expenditure intensity in the case of product innovation; product + process innovation; and innovative sales share Enterprises with export markets, except in the case of product innovation; product + process; and innovative sales share Enterprises engaged in co-operation in innovation activities with other enterprises within same group (no link with product innovation; with organisational innovation); with suppliers; with customers (product innovation.; product + organisational innovation); with consultants, commercial labs or private R&D institution; with universities or other higher education institutions; Enterprises not engaged in co-operation with competitors in product innovation; product +organisational innovation; and innovative sales share

*Data Source:* CIS 2004-2008, panel data, (N=957)

*Note:* reported estimates are at least 10 per cent level of significance

<sup>14</sup> We carried out a similar analysis for foreign-owned enterprises; these results are available on request

<sup>15</sup> The data used in the econometric analysis come from the CIS; all data related to current policies come from Enterprise Ireland.

### *What is the link between innovation and productivity at enterprise level?*

The striking results for Irish-owned enterprises are (a) the strong link between organisational innovation and productivity, (b) that product innovation is only associated with higher productivity when combined with organisational innovation<sup>16</sup>, and (c) that the effect of process innovation is stronger when combined with organisational innovation.<sup>17</sup> Taken together, these results suggest that, among Irish indigenous enterprises, higher productivity has been generated more by improvements in the efficiency of production than by the introduction of new and improved products.

The overall results in Section 4 validate the government's commitment to supporting innovation at enterprise level. This commitment is reflected in the suite of programmes operated by Enterprise Ireland and the introduction of tax-relief against corporate profits tax for R&D expenditures. However, this validation does not necessarily imply that the particular programmes being operated are the most cost effective means of supporting the link between investment in innovation and productivity.<sup>18</sup> The international results in relation to enterprise-level heterogeneity support the adoption of a 'policy mix' approach to innovation<sup>19</sup> in order to take account of scale, capability, exporting and cooperation with external bodies. Such an approach, as has been adopted by Enterprise Ireland, means that individual enterprises are likely to receive funding under several different programmes. This has implications for how data on enterprises are maintained,<sup>20</sup> how projects are appraised, how agency effectiveness is measured and how programmes are evaluated.<sup>21</sup> While, as noted in the Introduction the evaluation of the impacts of such R&D and innovation policies is beyond the scope of this paper, we highlight in Section 6 the need for developing appropriate evaluation methodologies to take account of the complexity of the innovation process and the mixture of interventions in place.

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<sup>16</sup> It appears that product innovation intensity, measured as the share of sales from new or improved products, is negatively associated with enterprise productivity. The CIS data do not allow us to distinguish price and quantity effects of product innovation and so we could not explain what determines this relationship.

<sup>17</sup> This result contrasts strongly with the finding for foreign-owned enterprises, where product innovation is associated with higher productivity while the process innovation has no significant impact on productivity

<sup>18</sup> EI budgets averaged €250-300m in 2005-2007; following the onset of the economic crisis, they jumped to over €400m in 2008 and averaged €464 in 2009/10. The bulk of the increase in funding was directly related to job retention schemes [allowed by the EU Commission] for vulnerable enterprises. These schemes are due to terminate in 2011. The data from EI suggest that the ratio of net operating costs to total expenditure in EI will rise sharply if these costs do not fall following the termination of these expenditure programmes. <http://www.enterprise-ireland.com/ereader/corporate/annualreport2010/#/22/>.

<sup>19</sup> There are, as yet, no studies that focus on marketing innovation, which may prove to be particularly important in the Irish context given the enterprises have to export at an early stage of development because of the small size of the domestic market.

<sup>20</sup> According to EI, information on all aspects of enterprises' development strategies is held centrally.

<sup>21</sup> Martin (2009) notes the complications in relation to programme evaluation.



### *Which enterprises are more likely to invest in R&D/innovation?*

One of the most striking results from the international evidence and linked back to Schumpeter (1942) is the strong impact of enterprise scale on the decision to invest in innovation – put simply, smaller enterprises are less likely to invest in innovation than large enterprises.<sup>22</sup> This result, which is confirmed in Table 1 for the indigenous sector, is unsurprising given that innovation activities, especially in relation to product innovation, are associated with risk and with financial requirements that are likely to be more challenging for smaller enterprises. The importance of scale suggests that policies that promote enterprise growth or reduce impediments to enterprise growth will enhance the probability of enterprises engaging in innovation. Indigenous enterprises that are exporters are also more likely to invest in R&D/innovation.<sup>23</sup>

Enterprise Ireland (EI) operates a two-pronged approach to increasing the numbers of enterprises engaging in R&D and innovation (RDI). The first approach provides support to encourage existing enterprises to begin to invest in RDI. This comprises: R&D Stimulation Grants to SMEs to support investigation of the potential for an R&D project (up to €150k) and Innovation Vouchers to support exploratory collaborations with researchers in Institutes of Technology (5k). The second approach aims to establish new enterprises that engage in significant RDI investments *ab initio*. To qualify, these enterprises, High Potential Start-Ups (HPSUs), must produce an export-focused product or service based on a new innovative idea/technology, and must have the potential to achieve €1m sales and employ ten people within three years. Over 70 HPSUs have been established in each year since 2005, and these now provide a sufficiently large pool to evaluate whether or not this programme is effective. EI provides direct equity funds to these HPSUs up to a maximum of €1.25 million in the BMW region and €1 million in the rest of the country.<sup>24</sup> The average equity investment is in the region €250-350k, and this investment typically leverages significant private sector investment from venture capital funds. They also receive strong business

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<sup>22</sup> A similar result is found for foreign-owned industry in Ireland. Innovation capability is found to be a significant determinant of the decision to invest in innovation among foreign-owned enterprises but not among Irish-owned enterprises. Foreign-owned industry also has the option of undertaking innovation in other countries in which it is located.

<sup>23</sup> The empirical evidence is not sufficient to determine unambiguously the direction of causation between innovation and exporting but it does suggest that policies that promote exporting are likely to support innovation behaviour.

<sup>24</sup> These maxima are set by EU state aid rules.

supports directly from EI and the opportunity to locate in some of EI-funded incubation units in the higher education institutions (HEIs).<sup>25</sup>

Enterprise Ireland operates several schemes to promote export sales and the annual spend on these schemes averaged €12m in the period 2005-2010. They include the Business Accelerator Programme, the Market Research programme, Trade Fair Participation programme, and the Going Global programme.

### ***Which enterprises have higher innovation expenditure per employee?***

While scale affects the decision of Irish-owned enterprises to invest in innovation, it does not impact proportionately on innovation expenditure per employee.<sup>26</sup> In fact, smaller enterprises are more likely to spend relatively more on innovation per employee than larger enterprises. The key determinant of innovation expenditure per employee in Irish indigenous enterprises is the enterprise's innovation capability. This suggests that any support given to promote increased innovation needs to take account of the enterprise's capacity to innovate and that a starting point for encouraging enterprises to innovate is the assurance that they have the skill capacity to reap the benefits of such innovation investments.

Enterprise Ireland takes a twin-track approach to encouraging enterprises to expand their investment in RDI. The first track is to provide R&D grants to co-finance the R&D cost; these typically go up to a maximum of €650k.<sup>27</sup> They can be supplemented by training grants for RDI skills under the Innovation Management Initiative. For these to contribute to increasing the intensity of investment, they need to add to the innovation capacity of the enterprises.<sup>28</sup> The second track is much more indirect. EI invests in private sector seed and venture capital funds - between 2005 and 2010 such investments averaged €11m per annum. These venture capital funds operate primarily in innovation-intensive industries and hence the support for this investment acts indirectly as a support for growing RDI enterprises. Starting in 2011, investment in a new venture capital

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<sup>25</sup> In addition, the Business Partners Programme provides supports for researchers to spin out companies from their research. EI estimates that in the four years 2007-2010 there were 86 spin outs generated, with 66 of these in 2009/10.

<sup>26</sup> A similar result is found for foreign-owned industry.

<sup>27</sup> Applications for higher sums can be granted by the EI Investment Committee, the EI Board and in the case of very large amounts by the Government.

<sup>28</sup> International evidence suggests that knowledge spillovers are not automatic and are conditioned and enhanced by enterprises' absorptive capacities including past R&D/innovation investments and human capital (Cohen and Levinthal, 1989; Geroski et al., 1993; Mancusi, 2008). Furthermore, existing empirical evidence indicates that domestic expenditure on R&D and innovation improves the capacity to absorb foreign country technology (Fagerberg, 1994; Verspagen, 1991; Griffith et al 2004; Cameron et al 2005; Kneller, 2005).

fund, the Innovation Fund Ireland, will ramp up significantly.<sup>29</sup> In due course, it is essential that these investments are properly evaluated.

EI uses two metrics to gauge the increase in R&D activity (both in-house and out-sourced): the number of clients engaging in meaningful R&D (over €100k per year) and in significant R&D (over €2 million per year). In the period 2005-2010 these numbers increased from 482 to 664 and from 33 to 51 respectively.<sup>30</sup> The question that now arises is to whether these investments are being converted into successful innovations.

### *Which enterprises are more likely to innovate successfully?*

Once again, the evidence that enterprise scale matters is found for Irish indigenous enterprises. Larger enterprises are more likely to have successful process innovation, organisational innovation and process and organisational innovation combined. However, smaller enterprises have higher product innovation intensities (innovative sales share). In terms of the impact of innovation expenditure per employee on innovation, in the case of Irish-owned enterprises only organisational innovation appears significant.<sup>31</sup> Irish exporters are more likely to have successful innovation outcomes than non-exporters in the case of process innovation, organisational innovation, product combined with organisational innovation, and process combined with organisational innovation. However, in the case of product innovation, and product combined with process innovation, we do not find this result. Furthermore, there is no evidence that exporters' shares of new products in total sales are higher than non-exporters' shares.<sup>32</sup> These results raise questions for whether current policy is succeeding in growing indigenous exporting enterprises that are successfully creating new products for export markets.<sup>33</sup>

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<sup>29</sup> This significant EI support for indigenous companies by way of venture capital is in line with Risk Capital Guidelines and State Aid rules.

<sup>30</sup> To avoid double counting we have not included the 'significant' R&D enterprises in the numbers for the 'meaningful' R&D enterprises. Some of the qualifying enterprises will be in receipt of EI R&D grants which are counted towards that criterion. For example, 8 of the significant R&D enterprises in 2010 would have received EI funding in that year.

<sup>31</sup> This contrasts with the case of foreign-owned enterprises, where innovation expenditure per employee is positively associated with product innovation, with product and organisational innovation combined and with the intensity of product innovation.

<sup>32</sup> This result contrasts with the foreign-owned sector where enterprises with higher innovation expenditure per employee are more successful at product innovation.

<sup>33</sup> EI estimates new export sales – a gross measure – each year. This metric saw a drastic decline in 2009 but recovered significantly in 2010. These sales include innovative sales in addition to sales of existing products.

The fact that enterprise characteristics, such as size and exporting behaviour, impact strongly on innovative success points to the importance of formulating policy at enterprise as well as at sectoral level. This enterprise-centred approach is deeply ingrained in EI operations as it has been a defining feature of the Irish industrial policy since the 1950s. Ireland benefits from the integration of all aspects of enterprise development within one agency as it facilitates an integrated approach to enterprise supports and the application of sophisticated project-appraisal methods.

The importance of scale points to the benefits of growing Irish indigenous enterprises. In addition to the programmes above, EI operates a Business Development Programmes aimed at 'scaling up' existing enterprises with the potential to become significant middle-sized entities. Since a targeted approach is adopted, involving the selection of a small number of enterprises annually, the mechanisms for enterprise selection are crucial.

The operational framework in Enterprise Ireland integrates exporting and innovation – in effect virtually all EI companies are exporters or soon to be exporters.<sup>34</sup> EI identifies several factors as being crucial to successful exporting: sales and marketing capabilities, innovation and R&D activity, continuous competitiveness through lean improvements, and on-going leadership and management development. On average, EI has funded training for 200 managers a year to support the building of capability and funding for such capability building has increased from €4.3m to €14.7m over the period.<sup>35</sup> However, from an efficiency perspective, it should be noted that funds which pass through the EI budget to County Enterprise Boards (€31m in 2010) do not appear to have the same export mandate. Furthermore, the large number of such Boards (36) seems unlikely to be the most effective manner of using these funds.

Table 1 also indicates that co-operation linked to innovation activities<sup>36</sup> appears to contribute significantly to successful innovation by Irish-owned enterprises.<sup>37</sup> The exceptional case is co-operation with competitors which is found to be negatively associated with innovative success.<sup>38</sup> This finding could be interpreted

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<sup>34</sup> This is one of the positive results of the integration of agencies in the 1990s

<sup>35</sup> The EI data suggest that the average spend in nominal prices has increased from 25k per trained manager in 2005 to €63k per trained manager in 2010.

<sup>36</sup> One of the key achievements of the CIS has been to capture these inter-agent relationships.

<sup>37</sup> The impact appears to be greater than for foreign-owned enterprises.

<sup>38</sup> The contrary is the case for foreign-owned enterprises where such cooperation is positively associated with innovation outcomes.

as Irish-owned enterprises with a weak innovation performance turning to co-operation with competitors as a strategy for survival or growth. The strong influence of co-operation on innovative success reflects the impact of the innovation eco-system, as discussed in Section 2. In other words, while enterprises' innovative activities and their innovative successes are influenced by their own characteristics, they are also influenced by their interactions with outside agents in the system. Consequently, policy that supports co-operation between target enterprises and other agents will have differential effects depending on the type of agent involved and the type of innovation being supported.

The major support from EI for co-operation with the Higher Education Institutes sector comes primarily in two forms.<sup>39</sup> The first is the Competence Centre Initiative established to assist enterprises in accessing the expertise of researchers in the Institutes of Technology. The second is a research networks programme, which supports groups of enterprises in linking to HEIs via a shared research programme; in effect, it promotes inter-enterprise co-operation as well as enterprise-HEI co-operation. The annual expenditure on these initiatives increased from €13m in 2005 to €29m in 2010. In addition, EI provides in the region of €35m per year to support commercialisation activities (technology transfer offices and commercialisation funds). The rationale for such programmes is supported by the evidence of the positive link between innovation success and cooperation with HEIs. However, it is a separate research question that lies beyond the scope of this paper as to whether the specific supports in place are the most cost effective and whether the metrics required to monitor these are adequate. The experience of the 1990s suggests that such evaluations are essential.

Overall, there is a positive alignment between EI's strategic approach to providing direct support for innovation in indigenous enterprises and what emerges from the international literature and from the analysis of innovation in the Irish indigenous sector. Three key issues for policy merit further consideration:

- The likelihood of innovation success depends crucially on the capacity of enterprises to internalise knowledge spillovers. Are indigenous enterprises growing that capability?

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<sup>39</sup> The major direct supports to HEIs comes through Science Foundation Ireland's programme for Centres for Science, Engineering and Technology and through the HEA's Programmes for Research in Third Level Institutions, which over the past decade have built up the physical and human capital in the HEIs. A significant portion of this investment has been focused on research areas directly relevant to Ireland's enterprise sector.

- While the current policy mix approach makes sense in terms of addressing heterogeneity, it may be timely to review whether or not existing schemes could be rationalised to provide more focus and reduce the Exchequer costs associated with supporting innovation?<sup>40</sup>
- Are measures and methodologies in place to evaluate objectively the effectiveness of policy measures (including returns to innovation investment)?

## 6. CONCLUSIONS

As noted in the introduction, the international evidence points to the fact that successful innovation is more likely to occur when enabling framework conditions are in place. These include a stable macroeconomic policy environment; international openness to flows of goods, services, capital and knowledge (embodied in both technologies and people); appropriate levels of competition and regulation; a developed and well functioning financial system; a coherent intellectual property system; flexible labour markets; a well-performing education system and a high-performing infrastructure (Box, 2009).

The international literature shows that productivity is positively affected by innovation, which in turn depends on a range of factors which vary by enterprise both across and within sectors. Research in this area is still at a relatively early stage and most analysis is still based on cross-sectional data. Analyses based on longitudinal data are required to ensure that the findings are fully robust.

The messages coming from the international and national research literature point to complexity of the innovative process and to the potential for policy to support innovation. This complexity means that a mix of policies is likely to be more successful than a single policy approach. However, the mixture of policies should be carefully designed and assessed and new programmes should be piloted. It may be timely to review how policies in relation to both foreign and indigenous enterprises might be further integrated to promote synergies. Furthermore, with a complex mix of policies, the selection of metrics used to measure performance must be made carefully, and appropriate methods used to evaluate success/failure.

Crucially, and not an area where international evidence is yet helpful, evaluation of policy success should seek to take greater account of the time period over

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<sup>40</sup> The counter argument in relation to having a large number of schemes is that they can handle the heterogeneity better, i.e., deal with companies at different stages of development.

which success/failure should be evaluated, i.e., how many years does it take to realise the benefits of investment in innovation within the enterprise or in cooperation with a HEI, as measured in terms of productivity, output growth, enterprise survival rates, export sales and employment? Multi-period panel analysis is required to explore the causal factors underpinning the relationship between innovation expenditure, innovation performance and productivity. For Ireland, it would be important that future waves of the CIS provide the basis for a strong longitudinal element which will allow policy to be informed by such analysis, realistic expectations to be formed about what can be expected from expenditure on innovation, and programmes refined to be as efficient and effective as possible.

In relation to systemic failures, Irish policies continue to promote co-operative agreements, both among enterprises in Ireland, between enterprises in Ireland and HEIs and between enterprises and HEIs in Ireland and suitable partners outside Ireland. Strategies have been put in place to enhance knowledge flows, by supporting researcher mobility and developing career opportunities, etc. However, much remains to be done in this area as noted by Martin (2009).

Many Irish innovation policy documents identify the market and systemic failures in the innovation process in Ireland that underpin the actions introduced to address these. Knowledge spillovers are seen as justifying the very significant investment in research and development in the past decade, and the current focus of that investment on areas relevant to Ireland's growth potential (Report of the Steering Group of the Research Prioritisation Exercise, 2011). The potential for knowledge spillovers also underpins the decision to invest in fostering HEI-enterprise linkages through the Centres for Science, Engineering and Technology and the Competence/ Technology Centres. However, as noted above, international evidence suggests that knowledge spillovers are not automatic but are conditioned and enhanced by enterprises' absorptive capacity including past R&D/innovation investments and human capital.

The evidence also suggests that domestic expenditure on R&D and innovation improves the capacity to absorb foreign country technology. Taken together, Irish innovation policy has strong evidential support from the international literature. However, while a policy mix is appropriate, the number of EI schemes is large and they merit review.<sup>41</sup> Given this number of schemes, it is not easy or indeed meaningful to measure the effectiveness of any one scheme. Evaluation of the

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<sup>41</sup> The availability of funding in the years of fiscal expansion meant that piloting of new schemes was not essential and there has been little by way of independent review of different programmes.

success/failure of these schemes is possible using carefully chosen metrics and econometric methodologies, estimated on the integrated EI data base. Such an analysis would assist in measuring impact and in refining the schemes in place.<sup>42</sup>

In essence, the key policy messages that emerge from our review of the international literature are:

- Government needs to keep focus on the framework conditions that enable innovation. This includes actions that generally support enterprise growth, that strengthen the national innovation system, and that promote international links with the international innovation system.
- Policy to promote innovation at enterprise level needs to take account of differences across enterprises and especially in their capacity to absorb new knowledge.
- In the current context with limited budgets, all programmes should be evaluated for effectiveness, using metrics and methods that take account of complexity of the innovation process and the mixture of policies in place.

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<sup>42</sup> The evaluation of the impacts of R&D and innovation policy interventions is beyond the scope of this paper.



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## APPENDIX A: THE CDM EMPIRICAL MODEL

### *The Innovation Investment Equations*

This stage of the model comprises two equations which explain in turn the firms' decision to invest/not invest in innovation and, if investing, the amount of innovation expenditure per employee. We only observe the innovation expenditure reported by firms. To the extent that this group of firms is not random, this implies a possible selection bias. To account for this potential bias, the propensity of firms to invest in innovation is given by the following selection equation:

$$y_i = \begin{cases} 1 & \text{if } y_i^* = x_i\gamma + u_i > \tau \\ 0 & \text{if } y_i^* = x_i\gamma + u_i \leq \tau \end{cases}$$

$y_i$  is an observed binary variable which equals one for firms engaged in innovation investment and zero for the rest of the firms. Firms engage in innovation and/or report innovation expenditure if  $y_i^*$  is above a certain threshold level  $\tau$ .  $x_i$  is a vector of variables explaining the innovation decision,  $\gamma$  is the vector of parameters and  $u_i$  is the error term.

Conditional on investing in innovation, the amount of innovation expenditure per employee ( $w_i$ ) is given by the following equation:

$$w_i = \begin{cases} w_i^* = z_i\beta + \omega_i, & \text{if } y_i = 1 \\ 0 & \text{if } y_i = 0 \end{cases}$$

$w_i^*$  is an unobserved latent variable,  $z_i$  is a vector of firm characteristics and  $\omega_i$  is an error term.

### *The Innovation Output Equations*

This second stage of the model explains the innovation outcomes given by the following innovation production function:

$$g_i = w_i^*\alpha + h_i\delta + e_i$$

where  $g_i$  is innovation output proxied by product, process, and organisational innovation indicators.  $w_i^*$  is the predicted innovation expenditure per employee estimated from the selection model. These values are predicted for all firms and not just the sample reporting innovation expenditure. By using the predicted values of this variable to instrument the innovation effort  $w_i$ , we account for the possibility that innovation expenditure per employee and the innovation outputs

could be simultaneously determined. The selection and innovation expenditure intensity equations thus correct for this endogeneity.  $h_i$  is a vector of other determinants of innovation output,  $\alpha$  and  $\delta$  are the parameter vectors and  $e_i$  is the error term.

### ***The Output Production Equation***

The last stage of the model explains the output production as a function of labour, capital, and innovation outcomes as follows:

$$p_i = k_i \lambda + g_i \mu + v_i$$

$p_i$  is labour productivity (log of output per employee),  $k_i$  is the log of physical capital per worker and  $g_i$  denotes innovation outcomes (product, process, organisational innovation),  $v_i$  is the error term and  $\lambda$  and  $\mu$  are vectors of parameters. To correct for the fact that productivity and innovation output could be simultaneously determined,  $g_i$  are the predicted innovation output probabilities estimated in the previous stage.

## Appendix B: Summary of International CDM Research on the Innovation/Productivity Link

Authors Country and data	Is there a link between innovation and productivity?	Which enterprises are more likely to invest in R&D/ innovation?	Which enterprises have higher innovation expenditure per employee?	Which enterprises are more likely to innovate successfully?
Crépon, Duguet, Mairesse (1998) France Innovation Survey 1986-1900 Manufacturing	<i>Value added per employee:</i> Positive link with share of innovative sales	Larger enterprises With larger market shares With more diversified activities	No significant size effect With larger market shares With more diversified activities	<i>Patents per employee and innovative sales share:</i> No significant size effect With higher R&D intensity
Mairesse, Robin (2009) France CIS 1998-2000 Manufacturing CIS 2002-2004 Manufacturing and services	<i>Sales per employee:</i> Positive link with product innovation Negative link with process innovation in services	Larger enterprises Facing international competition With formal and strategic intellectual property protection	Facing international competition With formal and strategic intellectual property protection Engaged in co-operation (only manufacturing) Receiving EU funding for innovation (only manufacturing) Receiving national funding (only services)	<i>Product, process innovation:</i> Larger enterprises With higher R&D intensity (only for product innovation) With lower R&D intensity for process innovation in services With formal (only for product innovation in manufacturing) and strategic protection for innovation (only manufacturing)
Hall, Lotti, Mairesse (2009) Italy Survey of Manufacturing Firms Mediocredito-Capitalia 1995-2003 SMEs, manufacturing	<i>Sales per employee:</i> Positive link with product, process innovation	Larger enterprises With European and international competitors	Smaller enterprises With European and international competitors With public funding support With involvement in group	<i>Product, process innovation:</i> Larger enterprises With higher R&D intensity
Griffith, Huergo, Mairesse, and Peters (2006)  France, Germany, Spain, the United Kingdom (UK) CIS 1998-2000 Manufacturing	<i>Sales per employee:</i> Positive link with product innovation (France, Spain, the UK) Positive link with process innovation only for France	Larger enterprises With international competition In industries with greater formal or strategic intellectual property protection With public funding support	With international competition (France and Spain) Engaged in co-operation Receiving national funding (Germany and Spain) Receiving EU funding (France)	<i>Product, process innovation:</i> Larger firms (no size effect for product innovation in the UK) With higher R&D intensity In industries with greater formal or strategic intellectual property protection (no effect in the UK; less important for process innovation)

Authors Country and data	Is there a link between innovation and productivity?	Which enterprises are more likely to invest in R&D/ innovation?	Which enterprises have higher innovation expenditure per employee ?	Which enterprises are more likely to innovate successfully?
Raffo, Lhuillery, Miotti (2008) France (F), Spain (ES), Switzerland (CH) CIS 1998-2001 (F, CH) CIS 2002-2004 (ES) Manufacturing	<i>Sales per employee:</i> Positive link with product innovation	Larger enterprises With public funding support With domestic group involvement (F) With foreign group involvement (F) With no foreign group involvement (ES)	Engaged: in co-operation with group (ES); with customers (F, ES); with competitors (F); with universities (SP, CH); with international co-operation (F, CH); With domestic group involvement (F, ES); With foreign group involvement (F); Receiving public funding (F, ES)	<i>Product innovation:</i> Larger enterprises With higher R&D intensity Engaged in co-operation with group (ES, CH); with suppliers; with customers; with competitors (ES); with exhibitions; with no co- operation with universities (F); outside a domestic group (F); outside a foreign group (F, CH)
Löf and Heshmati (2006) Sweden CIS 1996-1998 Manufacturing (mfg.), services (serv.)	<i>Value added per employee:</i> Positive link with innovation sales per employee	Larger enterprises With higher capital intensity (mfg.) With higher human capital (mfg.) With high quality of the products With high delivery security (serv.) With trademark (mfg.) With higher knowledge content in products With unique products (serv.)	Smaller enterprises With higher capital intensity (mfg.) With export markets (serv.)	<i>Innovation sales per employee:</i> Larger enterprises (serv.) With higher innovation investment per employee With strong main market growth With knowledge for innovation from professional conf., meetings, journals (serv.); from information technology (mfg.); from suppliers (serv.); with no internal knowledge (serv.) With products new to the market developed cooperatively (serv.) With products new to the firm developed without cooperation



Authors Country and data	Is there a link between innovation and productivity?	Which enterprises are more likely to invest in R&D/ innovation?	Which enterprises have higher innovation expenditure per employee ?	Which enterprises are more likely to innovate successfully?
Lööf, Heshmati, Asplund and Nåås (2001) Finland, Norway, Sweden CIS 1994-96 in Finland and Sweden CIS 1995-97 in Norway Manufacturing	<i>Sales per employee:</i> Positive link with innovative sales per employee in Norway and Sweden Negative link with process innovation in Sweden	Larger enterprises (Finland and Sweden) With greater export intensity (Finland and Sweden) With patent application history With less non-R&D engineers (Finland) With more administrators (Norway)	Larger enterprises (Norway) Smaller enterprises (Finland) With higher export intensity (Finland and Norway) In knowledge- and capital – intensive industries (Sweden) With more administrators (Norway) With patent application history Engaged in innovation co-operation with domestic customers Engaged in innovation co-operation with universities and competitors (Finland) Engaged in co-operation with foreign suppliers (Finland and Norway)	<i>Innovative sales per employee:</i> With higher innovation investment intensity (Sweden) In knowledge-intensive industries (Sweden) In capital-intensive industries (Finland and Sweden)
Polder, van Leewen, Mohnen, Raymon (2010) The Netherlands CIS 2002-2008 (panel data) Manufacturing (mfg.) and services (serv.)	<i>Value added per employee:</i> Positive link with organisational innovation; with process innovation when combined with organisational innovation; with product and process innovation when performed together with an organisational innovation. Effects are stronger in services than in manufacturing firms	Larger enterprises With group involvement With international markets	Smaller enterprises With group involvement (mfg.) With international markets Engaged in co-operation With support from national public funds With support from EU funds	<i>Product, process, organisational innovation:</i> Larger enterprises With greater R&D intensity (product innovation, mfg. only) With greater ICT investment intensity (serv.; in mfg. only for organisational innovation) With higher broadband intensity (serv.; in mfg. only for product and for organisational innovation) With higher e-purchases (serv.; in mfg. only for process innovation) With higher e-sales (serv. only for product innovation; in mfg. only process innovation)

Authors Country and data	Is there a link between innovation and productivity?	Which enterprises are more likely to invest in R&D/ innovation?	Which enterprises have higher innovation expenditure per employee ?	Which enterprises are more likely to innovate successfully?
OECD (2010) Selected OECD countries CIS 2002-2004 (Austria, Belgium, Switzerland, Italy) CIS 2004-2006 (Denmark, Finland, Ireland, Luxembourg, the Netherlands, the UK) Manufacturing and services	<i>Sales per employee:</i> Positive link with sales from innovative products per employee (BE, CH, DK, IE, LU, UK) No significant link with process innovation	Larger enterprises With group involvement (BE, CH, DK, IT, NL) With higher innovation capability (FI, IT, NL)	With group involvement (BE, DK, IT, LU) With higher innovation capability (AT, BE, FI, IE, IT, NL) With export markets (AT, DK, IE, IT, NL, UK) Engaged in co-operation (AT, CH, DK, FI, IE, IT, NL, UK) With financial support from public funds (AT, BE, FI, IT, NL, UK)	<i>Innovative sales per employee:</i> Larger firms (IE only) With higher innovation expenditure per employee (no effect for AT, CH, LU) With higher innovation capabilities (excluding AT) With higher skills (UK) Engaged in process innovation (BE, FI, IT, NL)
Siedschlag, Zhang, Cahill (2010) Ireland CIS 2004-2008 (panel data) Manufacturing and services	<i>Sales per employee:</i> Positive link with product, with process and with organisational innovation – highest effect for organisational innovation Positive link with innovative sales share	Larger enterprises With foreign ownership With export markets With higher innovation capability	Smaller enterprises With foreign ownership  With higher innovation capability	<i>Product, process, organisational innovation;</i> <i>innovative sales share:</i> Larger enterprises With foreign ownership With export markets With higher innovation expenditure (only for organisational innovation) Engaged in co-operation with suppliers; with consultants; with universities; other enterprises (no link in the case of organisational innovation); with customers (product innovation)
Doran and O'Leary (2011) Ireland CIS 2004-2006 Manufacturing and services	<i>Sales per employee:</i> Positive link with innovative sales per employee <i>Gross value added per worker:</i> Positive link only with innovative sales from new-to- market products per employee	Not estimated	Not estimated	<i>Innovative sales per employee:</i> Smaller enterprises With higher R&D expenditure (only for new- to-firm product innovations) With foreign ownership With higher productivity

Notes: AT = Austria; BE = Belgium; CH = Switzerland; DK = Denmark; ES = Spain; FI = Finland; IE = Ireland; IT = Italy; LU = Luxembourg; NL = the Netherlands; NO = Norway; UK = United Kingdom



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