Paper to be presented at the DRUID 2011

on

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

Path Dependency and Innovation: Evidence from matched patents and innovation panel data

Stephen Roper
Warwick Business School
Warwick University
stephen.roper@wbs.ac.uk

Dr Nola Hewitt-Dundas
Queen's university Belfast
Management School
nm.hewitt@qub.ac.uk

Abstract

In this paper we explore the role and interaction of firms? pre-existing knowledge stocks, knowledge investments and external knowledge search in shaping innovation success. The paper contributes to our understanding of the role of path dependency on firms? innovation outputs and provides new information on the relationship between knowledge stocks as measured by patents, and innovation output indicators. Our analysis uses innovation panel data relating to business units? investments in knowledge creation, external knowledge search and innovation outputs. Firm-level patent data is matched with this business unit innovation panel to provide a measure of the knowledge stocks. Two substantive conclusions follow. First, patent stocks have negative rather than positive impacts on business unit?s innovation outputs, reflecting potential core-rigidities or negative path dependency rather than cumulative capacity building. Second, business unit?s current knowledge search and investment activities dominate any knowledge legacy effects on innovation performance. Both suggest the primary importance of current strategy choices in influencing innovation and the weakness of any knowledge legacy effects which might shape persistence in innovation outputs. Our results also re-emphasise the potential issues which arise when using patents as a measure of innovation.

Jelcodes:O32,O

Path dependency and innovation: Evidence from matched patents and innovation panel data

Abstract
Successful innovation depends on knowledge – technological, strategic and market related. In this paper we explore the role and interaction of firms' pre-existing knowledge stocks, knowledge investments and external knowledge search in shaping innovation success. The paper contributes to our understanding of the role of path dependency on firms' innovation outputs and provides new information on the relationship between knowledge stocks as measured by patents, and innovation output indicators. Our analysis uses innovation panel data relating to business units' investments in knowledge creation, external knowledge search and innovation outputs. Firm-level patent data is matched with this business unit innovation panel to provide a measure of the knowledge stocks. Two substantive conclusions follow. First, patent stocks have negative rather than positive impacts on business unit's innovation outputs, reflecting potential core-rigidities or negative path dependency rather than cumulative capacity building. Second, business unit's current knowledge search and investment activities dominate any knowledge legacy effects on innovation performance. Both suggest the primary importance of current strategy choices in influencing innovation and the weakness of any knowledge legacy effects which might shape persistence in innovation outputs. Our results also re-emphasise the potential issues which arise when using patents as a measure of innovation.

Keywords: Innovation, path dependency, patents, Ireland

Path dependency and innovation: Evidence from matched patents and innovation panel data

1. Introduction

Successful innovation depends on knowledge – technological, strategic and market related. In this paper we explore the role of pre-existing knowledge stocks, knowledge investments and knowledge search in shaping business units' innovation success. Pre-existing knowledge stocks may, for example, contribute directly to the novelty or complexity of new innovation (Lee 2010). Further, they may also shape business units' investments in internal knowledge creation and their external knowledge search behaviour, emphasising or de-emphasising particular technologies or knowledge-types, with potential implications for innovation outputs (Wu and Shanley 2009). Similarly, internal knowledge investments may have either a complementary or substitute relationship with external knowledge search, again with potential implications for innovation outputs (Arora and Gambardella 1990; Cassiman and Veugelers 2002).

Our analysis is based on information on the innovation outputs, internal knowledge investments and external knowledge activity of individual business units derived from innovation panel data. Matching data on firms' pre-existing knowledge stocks is derived from patent data. Our analysis contributes to the literature on path dependency in innovation, by providing new evidence on the relative impact of pre-existing and 'new' knowledge in shaping innovation trajectories. In particular, our analysis provides a link between the growing literatures on open innovation (Chesborough 2003, 2006) and innovation partnering (Oerlemans, Meeus, and Boekema 1998; Roper 2001; Love and Roper 2004), which emphasise current knowledge inputs to innovation, and other studies which emphasise the path dependency created by knowledge stocks (Brouwer and Kleinknecht 1999; Park and Park 2006). Our analysis also contributes to what Wu and Shanley (2009) call the 'competence-rigidity paradox' reflecting the ambiguity of resource based and more managerial perspectives on the relationship between knowledge and innovation. For example, resource based perspectives on the firm suggest that pre-existing knowledge resources will be positively related to innovation and business performance (Haskel et al. 2009).

Similarly, the literatures on open innovation and innovation partnerships and networks also suggest the positive innovation benefits of external knowledge search (Fleming and Waguespack 2007; West and Gallagher 2006). Managerial perspectives, however, while recognising the potentially positive innovation effects of both pre-existing and current knowledge, also recognise the potential for negative innovation effects through path-dependency (Thrane, Blaabjerg, and Moller 2010), core-rigidities (Leonard-Barton 1992) or search myopia (Levinthal and March 1993). Our analysis encompasses these perspectives, testing inter alia the interactions between knowledge stocks, current investments in knowledge and external knowledge search activity.

Our analysis is based on a matched database which combines firm-level US and European patent data with panel data on business unit innovation activity derived from a series of surveys of Irish manufacturing companies (Hewitt-Dundas and Roper 2008). Our innovation panel data – the Irish Innovation Panel or IIP - also provides a wide range of other variables relating to the characteristics of each business unit, their innovation partnering activities and their internal capabilities and resources (Roper, Du, and Love 2008). The combination of these two data sources enables us to examine the role of knowledge (patent) stocks in shaping innovation activity, directly addressing the gap in our understanding as identified by De Rassenfosse and van Pottlesberghe (2009). Indeed, as far as we can ascertain, this is the first time that a business-unit level analysis of this type, exploring the causal relationship between patent-stocks and survey-based measures of innovation outputs has been possible, although other studies have considered the effect of firms' innovation strategy on patenting behaviour (Peeters and Van Pottelsberghe 2006)[1].

Interest in the importance of patents as a contributor to innovation has been stimulated by the sharp global increase in patent activity over recent years. In Ireland, the number of successful patent applications to the US and European patent offices has also risen sharply over the last two decades (Figure 1) growing faster than that in the large OECD countries and most other small European countries from 1978 to 2009 (Hewitt-Dundas et al. 2010). In the pre-1990 period, patenting activity in Ireland was very limited and was dominated by applications by individual inventors. By 1998,

[1] Brouwer and Kleinknecht (1999) also consider the converse relationship between innovative sales and indicators of patenting activity finding positive linkages.

growth in the foreign-owned sector in Ireland, driven largely by favourable corporation tax rates and relatively low labour costs, meant that foreign owned companies accounted for 47 per cent of the industrial employment, 82 per cent of industrial output and approximately 50 per cent of all patent applications (McCarthy 2001)[2]. Studies have also emphasized the heterogeneity of patenting performance between Irish firms[3], differences in the patenting performance of externally-owned and indigenously-owned firms (O'Sullivan, 2000) as well as the relatively low level of patenting per capita compared to the UK (Mainwaring et al. 2007) and other reference economies (Trajtenberg 2001) [4]. Reflecting the themes highlighted by O'Sullivan (2000) and McCarthy (2001), more recent examinations of the industrial composition of Irish patents also suggests the importance of patenting activity in those high-tech sectors in which inward investment has dominated development, and the relative weakness of citation links between patents held by indigenously and externally-owned firms (Hewitt-Dundas et al. 2010).

The remainder of the paper is organised as follows. Section 2 sets out the conceptual basis for our analysis drawing on the literatures on open innovation and the knowledge or innovation production function. Hypotheses are developed relating to the impact of knowledge (patent) stocks on innovation and the relative importance of both historical and contemporary knowledge investments for innovation. Section 3 describes our data sources and econometric methods and Section 4 summarises the key empirical results. Section 5 identifies the key conclusions and implications. Sections 6 and 7 provide discussion and conclusions.

---

[2] Approximately three quarters of the foreign investments over this period were US owned, concentrated in computer, chemicals, pharmaceuticals and electrical equipment sectors (McCarthy 2001; Barry 2005)).

[3] Ramani et al. (2008) note similar heterogeneity in patenting activity in their study of biotech based foods and that this pattern of heterogeneity changes little from year to year. This reflects other studies which have highlighted the persistence of patenting activity among small numbers of firms. See Roper and Hewitt-Dundas (2008) for a discussion.

[4] On average each patenting firm in Ireland included in the Mainwaring et al (2007) study had an average of 4.28 patents compared to 3.25 in Wales and 4.09 in Scotland and 10.41 in England. Across the whole population of surveyed firms (4149 in Wales and 700 in the other three areas) these translate into average patent numbers per firm of: Ireland, 0.18; Wales, 0.11; Scotland, 0.26 and England, 0.61. Source: Mainwaring et al., 2007, Table 2.

2. Conceptual background

Definitions of innovation vary, but generally stress the commercialisation of new knowledge or technology to generate increased sales or business value. The US Advisory Committee on Measuring Innovation, for example, defines innovation as: 'The design, invention, development and/or implementation of new or altered products, services, processes, systems, organisational structures or business models for the purpose of creating new value for customers and financial returns for the firm' (Advisory Committee on Measuring Innovation in the 21st Century Economy 2008, p. i). Underlying this definition is a process of knowledge transformation or codification in which innovation outputs - the market introduction of new products or process and the generation of business value - are created from diverse knowledge inputs (Hansen and Birkinshaw 2007). For most firms, however, innovation is a common or habitual activity, creating the potential for dynamic economies of scope and enhanced innovation competencies through organisational learning (Nelson and Winter 1982). Recent literature has also emphasised the value of openness in innovation, reflecting the potentially positive role of external knowledge search for innovation (Chesborough 2003, 2006), and its role in complementing the pre-existing knowledge base or intellectual capital (Choo and Bontis 2002) and/or internal knowledge investments (Zenger 2002; Cassiman and Veugelers 2002; Cassiman and Veugelers 2006).

This suggests three potentially inter-related sources from which firms might derive the knowledge inputs for their current innovation (Figure 2). First, pre-existing knowledge stocks might provide proprietary knowledge contributing to the novelty of new innovation. As Tzabbar et al. (2008) suggest, past studies have linked knowledge stocks with technological leadership, enhanced market position and corporate performance. Empirical support for the importance of pre-existing knowledge stocks for innovation is provided both by the widespread importance of incremental innovation (Helfat 1994; Audretsch 2002) as well as evidence on the persistence of patenting and innovation (Cefis and Orsenigo 2001; Roper and Hewitt-Dundas 2008). Secondly, innovation may be influenced by firms' current knowledge investments – such as R&D - which may create new knowledge on which innovation can be based (Jordan and O'Leary 2007; Hewitt-Dundas and Roper 2009). Such activities, and therefore potentially their innovation outcomes, may however be contingent on pre-existing knowledge stocks (Wu and Shanley 2009), which might define the set of innovative opportunities which the company is able, or willing, to address and its capability to develop new technological pathways. Thrane et al. (2010), for example, suggest that such path dependency might work through two main mechanisms. First, 'enactment' in which firms' learning capabilities are influenced by their past focus on specific technologies: 'because learning is cumulative, firms are likely to search for new products and processes in areas related to past R&D. As a result the direction of future learning depends on the nature of the accumulated knowledge base' (Helfat, 1994, p. 174 quoted in Thrane et al. 2010, p.941. Second, 'selection' in which a firm might have a preference for new products or processes more strongly related to their existing knowledge base[5].

Finally, firms might engage in external knowledge search for innovation, what Wu and Shanley (2010) call 'exploration' (Figure 2). Previous studies have emphasised the value for innovation of external knowledge (Oerlemans, Meeus, and Boekema 1998; Love and Roper 2001) as well as the limits of external knowledge search (Laursen and Salter 2006), and the potential importance of different types of knowledge search activity. Knowledge search among customers, for example, might impact most strongly on product innovation (Su, Chen, and Sha 2007), while search with suppliers or external consultants might impact most directly on process change (Horn 2005; Smith and Tranfield 2005). As with firms' knowledge investments, however, the innovation value of external knowledge search is also potentially contingent on firms pre-existing knowledge stock (Wu and Shanley, 2010) and its potential for shaping the focus or intensity of external knowledge search (Wu and Shanley, 2010), or firms' absorptive capacity (Schmidt 2010). Firms' knowledge search may also be influenced by current knowledge investments: substitution effects may be evident where firms consider external knowledge search is an alternative to internal knowledge investments; or more positive relationships may exist where internal knowledge investments have complementary innovation effects to external knowledge search (Veugelers and Cassiman 1999). Griffith et al. (2003), for example, suggest that alongside its contribution to firms' knowledge stocks, R&D investments

[5] For example, Lucas and Goh (2009) document the resistance of Kodak to embracing digital photography despite the firms' understanding of the technologies involved.

may have positive effects on absorptive capacity and therefore the innovation value of external knowledge search.

3. Literature and hypotheses

In competence based-models of innovation, firms' knowledge stocks represent the accumulation of past knowledge investments and knowledge search. Whether represented by codified metrics such as patent stocks, or more intangible knowledge resources, such resources might be expected to make a positive contribution to firms' innovation outputs by accelerating innovation processes or providing the basis for increased novelty and customer satisfaction (Kyriakopoulos and de Ruyter 2004). Wu and Shanley (2009), for example, identify positive innovation output effects from both of the knowledge stock measures they consider. Other studies have suggested that firms with substantial prior knowledge stocks might suffer core-rigidities due to path dependency or an unwillingness to consider alternative technological options. Kyriakopulos and de Ruyter (2004, p. 1470), for example, cite the disk drive sector in particular as having difficulty in trying 'to break away from entrenched routines or obsolete information channels'. On balance, however, the evidence suggests Hypothesis 1 that:

H1: Prior knowledge stocks will have a positive impact on innovation outputs.

There is widespread evidence of the positive role of firms' internal knowledge investments on innovation and business performance with Artz et al. (2010) providing a recent review. At a macro-economic level, studies such as (Guellec and van Pottelsberghe 2004) have identified the positive impact of R&D spending on productivity growth while regional studies have also emphasized the potential value of R&D investments (Rodriguez-Pose 2001). Similarly, sectoral studies have emphasized the positive relationship between R&D intensity and innovation outputs across a range of high-tech (Ulku 2007) and low-tech sectors (Santamaria, Nieto, and Barge-Gil 2009). At a firm or business-unit level, evidence of the positive innovation effect of firms' internal knowledge investments is also widespread. Artz et al (2010), for example, explore the relationship between R&D investment and patenting and R&D investment and product announcements by large North American firms finding a positive relationship in each case. This suggests Hypothesis 2:

H2: Knowledge investments will have a positive impact on innovation outputs

Wu and Shanley (2009) suggest, for example, that such external knowledge search or 'exploration' may contribute to innovation by helping firms to access new knowledge and technology and potentially avoiding core-rigidity or negative path dependency (Leonard-Barton 1992). Negative effects might also be anticipated, however, where external search activity is disproportionate in scale, overly costly, disruptive or where the technologies accessed are more distant from firms' existing knowledge stock (Ahuja and Katila 2001). Laursen and Salter (2006) also consider attention-based theories of the firm and argue that negative knowledge search effects may arise when managerial attention is misallocated or ineffective, both of which are more likely when the number of external search channels is more considerable. The empirical evidence, however, suggests that external knowledge search can have significant positive benefits for innovation outputs (Oerlemans, Meeus, and Boekema 1998; Jordan and O'Leary 2007; Roper, Du, and Love 2008). There is increasing evidence, however, that this effect is non-linear. Wu and Shanley (2009) working with patent citation data, for example, identify an inverted 'U' shape relationship between new patent citations and successful patent applications in the US electromechanical device industry. Laursen and Salter (2006) working with the UK innovation survey also find an inverted 'U' shape relationship between firms' introduction of new products and the number of external search channels they are adopting. As indicated in Figure 2 this suggests Hypothesis 3:

H3: External knowledge search will have a positive but non-linear impact on innovation outputs.

A key theme in the literature on openness in innovation – or external knowledge search – has been the complementarity of internal and external knowledge (e.g. Arora and Gambardella, 1990; Veugelers and Cassiman, 1999; Cassiman and Veugelers, 2006). In general terms this has focused on complementarities between firms' external knowledge search and internal knowledge investments – the make or buy decision (Veugelers and Cassiman 1999), with R&D investment often seen as a key element of absorptive capacity (Cohen and Levinthal 1990; Zahra and George 2002). More specifically, knowledge search may require some internal R&D capability: to permit scanning for the best available external knowledge; to enable the efficient absorption and use of this knowledge; and, to help in the appropriation of the returns from new innovations (Griffith, Redding, and Van Reenan 2003). Internal R&D may, for example, help firms to minimise asymmetric information with technology suppliers and so reduce uncertainty and the transaction costs and other strategic issues associated with external knowledge search (Teece, 1988; Audretsch et al, 1996). This suggests:

> *H4: Knowledge investments and external knowledge search will have complementary impacts on innovation.*

While substantial evidence exists on the complementary relationship between knowledge investments and knowledge search, specific evidence on the role of pre-existing knowledge stocks on the innovation benefits of knowledge investments and search is, to quote Wu and Shanley (2009, p. 481) 'rather limited'. However, their results for the US electro-medical device sector suggest that firms' knowledge stock moderates the benefits of external knowledge search, i.e. 'a continuously increasing effort of exploration is helpful where a firm has a narrow knowledge base; however as the knowledge breadth increases a moderate level of exploration is more productive' (p. 482). This suggests:

> *H5: Prior knowledge stocks will have a negative effect on the innovation value of knowledge investments.*

> *H6: Prior knowledge stocks will have a negative effect on the innovation value of external knowledge search.*

4. Data and methods

Our empirical analysis is based on data from two sources; the Irish Innovation Panel (IIP) which provides information on the innovation activities of Irish businesses and information on Irish firms' patent histories derived from the US and European patent offices. The Irish Innovation Panel provides information on manufacturing business units' technology adoption, networking and performance over the period 1991 to 2008. More specifically, the IIP comprises six surveys or waves conducted using similar survey methodologies and questionnaires with common questions (Roper 1996; Roper and Hewitt-Dundas 1998; Roper and Anderson 2000; Hewitt-Dundas and Roper 2008). Each of the six surveys covers the innovation activities of manufacturing business units with 10 or more employees over a three-year reference period[6]. The resulting panel is highly unbalanced reflecting non-response in individual surveys but also the opening and closure of business units over the 18 year period covered. The panel contains 2,896 observations on 1,596 individual business units and representing an overall response rate of 31.2 per cent.

Business units' innovation activity in the IIP is represented by four variables intended to reflect different aspects of innovation performance. First, a simple binary indicator is used to reflect whether or not a business unit had introduced any new or improved products during the previous three years. At business unit level this indicator provides a baseline measure of engagement with product innovation; at a population level the indicator reflects the extent of product innovation activity (Figure 3, part A). A similar binary indicator is used to reflect the extent of process innovation (Figure 3, part A). The third innovation output measure is the proportion of business units' total sales (at the end of each three-year reference period) derived from products newly introduced during the previous three years. This variable reflects not only units' ability to introduce new products to the market but also their short-term commercial success. Finally, we use a similarly defined but broader innovation measure defined to reflect the contribution to sales of both products newly introduced and improved over the previous three years (Figure 3, part B). Across the IIP, 64.2 per cent of business units were product innovators while 58.0 per cent were process innovators; 14.7 per cent of business units' sales were derived from newly introduced products, with 23.8 per cent of sales coming from either newly introduced or improved products (Table 1). Correlations between the innovation output variables are positive with 70.6 per cent of product innovators also engaged in process innovation activity (Table 2).

[6] The initial IIP survey, undertaken between October 1994 and February 1995, related to business units' innovation activity over the 1991-93 period, and achieved a response rate of 38.2 per cent (Roper et al., 1996; Roper and Hewitt-Dundas, 1998, Table A1.3). The second IIP survey was conducted between November 1996 and March 1997, covered plants' innovation activity during the 1994-96 period, and had a response rate of 32.9 per cent (Roper and Hewitt-Dundas, 1998). The third IIP survey covering the 1997-99, period was undertaken between October 1999 and January 2000 and achieved an overall response rate of 32.8 per cent (Roper and Anderson, 2000). The fourth survey was undertaken between November 2002 and May 2003 and achieved an overall response rate of 34.1 per cent. The fifth wave of the IIP, conducted between January and June 2006, had an overall response rate of 28.7 per cent. The postal element of the sixth wave of the IIP was conducted between April and July 2009 with subsequent telephone follow-up and achieved a response rate of 38 per cent.

The IIP also provides information on a number of other business unit characteristics which previous studies have linked to innovation outputs. For example, whether or not business units are under-taking knowledge investments through in-house R&D or external knowledge search or have innovation partnerships with other organisations may be important in providing the knowledge inputs for innovation (Oerlemans, Meeus, and Boekema 1998; Love and Roper 2001; Jordan and O'Leary 2007), and shaping absorptive capacity (Griffith, Redding, and Van Reenan 2003). Across the panel, knowledge investments in-house R&D were being undertaken by 48.2 per cent of business units (Table 1). External knowledge search we measure using a breadth index similar to that proposed by Lausen and Salter (2006). On average, business units were engaged in external knowledge search with 1.34 partners (Table 1). Correlations between in-house R&D and other innovation partnering relationships are positive (Table 2) suggesting potential complementarity between internal R&D and innovation partnering and between different forms of innovation partnering (Arora and Gambardella 1990; Belderbos, Carree, and Lokshin 2006; Cassiman and Veugelers 2006). Other resource indicators are included to capture the potential impact on innovation of the strength of business units' internal resource base. We include variables which might give a quantitative indication of the scale of units' resources – e.g. size – as well as other factors which might suggest the quality of business units' in-house knowledge base – e.g. multi-nationality and vintage. Multi-nationality is included here to reflect the potential for intra-firm knowledge transfer between national markets and business units (O'Sullivan 2000), while vintage is intended to reflect the potential for cumulative accumulation of knowledge capital by older business units (Klette and Johansen 1998) or life-cycle effects (Atkeson and Kehoe 2005). We also include a variable reflecting the proportion of each business unit's workforces which have a degree level qualification to reflect potential labour quality impacts on innovation (Freel 2005; Leiponen 2005) or absorptive capacity. Finally, studies of the impact of publicly funded R&D have, since Griliches (1995), repeatedly suggested that government support for R&D and innovation can have positive effects on innovation activity both by boosting levels of investment (Hewitt-Dundas and Roper 2009) and through its positive effect on organisational capabilities (Buiseret, Cameron, and Georgiou 1995). Here, we therefore include dummy varibles to indicate a range of public investments in business units' technological and human resources, largely due to the EU Objective 1 status of Ireland through much of the sample period (Meehan 2000; O'Malley, Roper, and Hewitt-Dundas 2008).

Patent data for Ireland was compiled by identifying all patents where an Irish-resident was identified as an inventor, and which were granted between 1976 and 2009 by the US Patent and Trademark Office (USPTO) and the European Patent Office (EPO) (Hewitt-Dundas et al., 2010). Individual assignees were then matched by firm name and where possible location with business units included in the IIP. This allowed us to compile patent application histories for all Irish firms which have any business units within the IIP. These firm-level patent histories were then matched to each business unit within the IIP. Where multiple business units in the IIP were part of the same firm, each business unit was matched with the same, firm level, patent history. The implicit assumption being that at the point a patent application was made the technology involved was available to all business units in the firm.

From the patent history for each business unit we then construct a depreciated patent stock measure defined to reflect the business unit's cumulated prior knowledge base, or at least that element of prior knowledge investments embodied in patents (Ramani, El-Aroui, and Carrere 2008)[7]. As a first step it is useful to consider constructing an aggregate patent stock in period t defined as the cumulative number of successful patent applications from the start of our data collection period (1976) to t-1. For example, for Wave 4 of the IIP which relates to innovation activity over the 2000 to 2002 period the aggregate patent stock would be measured in 1999. As Park and Park (2006) highlight, however, this type of a patent stock definition does not allow for the potential depreciation of patented knowledge which might be expected to be more rapid in high-tech industries. Applying their estimated depreciation rates for each industry, which vary from 17.89 per cent for office machinery and computers to 11.86 per cent for tobacco products, allows us to calculate a depreciated patent stock variable for each business unit observation in the IIP[8]. On average across the IIP, the

[7] In our initial experiments we also considered the un-depreciated patent stock for each business unit, and a patent flow measure intended to represent firms' contemporaneous engagement with patenting. Both generated very similar results to those presented later in the paper.

[8] By industry the patent depreciation rates calculated by Park and Park (2006) are: Food products and beverages, 11.88; Tobacco, 11.86; Textiles, 13.09; Clothing, 13.85; Tanning and leather, 12.69; Wood and products of wood, 12.29; Paper and paper products, 12.02; Printing, 13.97; Coke and refined mineral products, 12.63; Chemicals and chemicals products, 13.11; Rubber and plastics, 12.52; Other

depreciated patent stock has an average of 0.139 (Table 1). As Mainwaring et al. (2007) emphasise, however, the distribution of patent activity is diverse with 'very few firms patent-active and many of these are single-patent firms' (p. 1663). Over the whole IIP an average of 5.0 per cent of firms had made successful patent applications although, reflecting the national trend, this figure rose from 2.1 per cent in the 2001 to 2003 period to 8.2 per cent in the 2006 to 2008 period (Figure 1)[9].

Our empirical approach focuses on the innovation or knowledge production function which represents the process through which pre-existing knowledge stocks and current knowledge inputs are transformed into innovation outputs (Griliches 1995; Love and Roper 2001; Laursen and Salter 2006). In more formal terms, if I_i is an innovation output indicator for business unit i the innovation production function might then be summarised as:

$$I_i = \beta_0 + \beta_1 KS_i + \beta_2 KI_i + \beta_3 KX_i + \beta_4 KS_i \times KI_i + \beta_5 KS_i \times KX_i + \beta_6 KI_i \times KX_i + \beta_7 RI_i + \delta_i$$

Where: KI_i are business units' internal knowledge investments, KX_i are unit i's external knowledge search, KS_i is prior knowledge stock and RI_i is a set of business unit level control variables. Our primary interest here is in the coefficients β_1 to β_6 which relate directly to the hypotheses outlined in the previous section.

Within RI_i we include a range of variables which have been shown to influence innovation outputs in previous studies involving innovation production functions (Crepon et al. 1998; Loof and Heshmati 2001, 2002; Roper, Du, and Love 2008). First, we include a variable to reflect business unit size which we interpret in the Schumpeterian tradition as a resource indicator, and which has been shown in previous studies to have a typically non-linear (inverted-U shape) relationship to innovation outputs (Jordan and O'Leary 2007). Second, we include an indicator of

non-metallic minerals, 12.84; Basic metals, 12.61; Fabricated metal products, 12.52; Machinery and equipment, 12.76; Office accounting and computing, 17.89; Electrical machinery and apparatus, 14.39; Radio tv and comms, 16.08; Medical precision and optical , 13.93; Motor vehicles , 13.72; Other transport equipment , 13.21; Furniture , 12.44; Recycling , 13.35. Source: Park and Park (2006), Table 1.

[9] For individual waves of the IIP the proportion of firms with patents were: Wave 1 (1991-93), 2.1 per cent; Wave 2 (1994-96), 4.4 per cent; Wave 3 (1997-99) 4.9 per cent; Wave 4 (2000-02), 5.5 per cent; Wave 5 (2003-05), 6.4 per cent; Wave 6 (2006-08), 8.2 per cent.

enterprise vintage to capture potential firm life-cycle effects (Atkeson and Kehoe 2005). Third, we include an indicator of whether or not a business unit is externally-owned to reflect the potential for intra-firm knowledge transfer (Jensen 2004). Fourth, we include an indicator of the level of graduate skills in the business unit which we expect to have a positive relationship to innovation outputs (Freel 2005; Arvanitis et al. 2007). Finally, we include an indicator of whether or not the business unit had received public support for its product or process innovation activity. In each case we anticipate this support having positive effects on innovation outputs (Hewitt-Dundas and Roper 2009).

Our estimation approach is dictated largely by the fact that we are using business unit data from a highly unbalanced panel and that our dependent variables are not continuous. We therefore make use of the GEE (population-average) estimator which provides perhaps the best econometric approach[10]. It enables us to specify the binary character of our variables for process and product innovations and the very right skewed (Poisson) distribution of the innovative sales variables. This approach also allows us to estimate standard errors which are heteroscedasticity robust. In addition to the reported variables we also include in each model a set of sector controls at the 2- digit level and a series of time dummies to pick up any secular differences between the waves of the IIP. Business unit observations are also weighted to provide representative results and take account of the structured nature of the IIP surveys.

5. Empirical Results

Estimated innovation production functions for the probability that business units undertook product innovation are included in Table 3. Three models are presented including control variables only (Model 1), control variables and the direct effects of knowledge stocks, knowledge search and knowledge investments on the probability of product innovation (Model 2) and the interaction (moderating) effects (Model 3). Each model includes both (2-digit) industry dummy variables and dummy variables for all except the first wave of the IIP (not reported). In Models 2 and 3 we include both the levels and quadratic of the extent of business units' external knowledge

[10] We use STATA software (xtgee). Stata implementation follows that of Liang and Zeger (1986). For the minimal differences between random effects and population average estimators see Sribney (2007), Neuhaus et al. (1991).

search to reflect the type of limits to search behaviour identified by Laursen and Salter (2006).

In terms of the knowledge inputs to the probability of product innovation: knowledge creation (R&D) has the anticipated significant and positive effect; knowledge search has an inverted 'U' shape effect on the probability of product innovation (Laursen and Salter 2006); but prior knowledge stock has an unanticipated negative and significant effect (Table 3). Introducing the moderating effects has little impact on these direct effects, and only proves significant in terms of the relationship between knowledge search and knowledge investment. The negative coefficient here is unanticipated (Hypothesis 4) suggesting a substitute rather than complementary relationship between knowledge investments and external knowledge search. In terms of the controls, business unit size, vintage, external-ownership, labour quality and government support for innovation all have significant effects (Model 3, Table 3).

Probit models for the probability of process innovation suggest a rather similar picture to that for product innovation (Table 4). Significant negative effects on the probability of undertaking process innovation from business units' pre-existing knowledge stocks again contrast with positive knowledge search and knowledge investment effects (Model 2, Table 4). Prior knowledge stocks have no significant moderating effects on either knowledge search or investment but again we identify a substitute relationship between knowledge investments and external knowledge search. We also find no evidence here of the limits to the innovation benefits of external knowledge search identified by Laursen and Salter (2006). Significant control variables here are also more limited with only size and government support for process change having significant effects (Model 3, Table 4).

Finally, Tobit models of the proportion of sales derived from innovative products are reported in Table 5. These suggest similar positive knowledge search and investment effects to those on the probability of product and process innovation. Prior knowledge stocks have an insignificant effect on innovative sales (Model 2, Table 5). Including the moderating effects highlights a strongly significant, and as anticipated negative, effect from knowledge stocks on the innovation value of firms' knowledge investments (Hypothesis 5), and contrary to expectations (Hypothesis 4) a substitution effect between knowledge investments and knowledge search. Control effects here are similar to those for the probability of undertaking product innovation with business unit size, vintage, external ownership and workforce quality all having statistically significant effects.

6. Discussion

Our results suggest no support for the anticipated positive effect from prior knowledge (patent) stock on innovation outputs envisaged in Hypothesis 1 (Table 6). Indeed, our evidence suggests that business units with higher knowledge (patent) stocks are instead significantly less likely to introduce new product and process innovations. There is no evidence of any statistically robust effect from prior knowledge stocks on innovative sales (Table 5). The lack of any very clear linkage between patent stocks and innovative sales is perhaps not unsurprising given evidence since Mansfield (1986, p. 180) that the effects of the patent system 'are very small in most of the industries we studied … very few additional inventions were commercially introduced because of patent protection, according to the firms themselves'. More recently, Faber and Hensen (2004) examine the relationship between patents granted and sales of innovative products in a group of European economies and are able to find no significant relationship[11]. By way of explanation they conclude that: 'the national institutional and economic infrastructure conditions shape the innovation activities carried out at the level of firms and supersede the effects of these activities on national patent acquisition'(Faber and Hensen 2004, p. 205-06). More surprising is the strong negative relationship between knowledge (patent) stocks and the probability of innovating rather than any more positive resource-based or competence effect (Tzabbar et al. 2008), although Artz et al. (2010) also identify a negative relationship between patents and measures of business performance. One possibility here is a misalignment effect with business units potentially devoting too many resources to the technological investments which may develop, protect or defend patents rather than effective commercialisation. Or, in terms of March (1991) placing too much emphasis on exploration rather than exploitation. Other potential explanations relate to negative path-dependency (Thrane,

[11] Interestingly, in the initial models reported by Faber and Hensen (2004) patents granted has an unexpected negative effect on the relative sales of innovative products at national level.

Blaabjerg, and Moller 2010) or core-rigidities (Leonard-Barton 1992) in which prior patent stocks become a constraint rather than an enabler of business units' innovation activity. For example, in some of the cases discussed by Leonard Barton (1992) managers reacted to internal tensions caused by mismatches between existing and new knowledge by abandoning difficult development projects. In other cases, similar tensions led to isolationist strategies by different groups. Both negatively influenced firms' innovation performance.

Our results suggest, as anticipated from previous studies, positive impacts from business units' knowledge investments on each measure of innovation providing consistent support for Hypothesis 2. That is, business units' engaging in in-house R&D had both a higher probability of making product and process innovations and were also more likely to achieve higher levels of innovative sales. This reflects results from a range of prior studies suggesting a similar positive relationship (Ulku 2007; Santamaria, Nieto, and Barge-Gil 2009; Artz et al. 2010). More interesting perhaps is the pattern of effects we observe for external knowledge search. Search has a positive impact on both the probability of innovating and innovation success, although with evidence of diminishing returns in terms of the probability of undertaking product innovation (Table 6). Unlike Laursen and Salter (2006), however, we do not find any evidence of significant diminishing returns to search breadth for innovative sales. More broadly, therefore our results confirm the importance of external knowledge search for innovation, and the innovation value of openness (Chesborough 2003, 2006).

Taken together these results provide some insight into the relative importance of path dependency and firms' current strategy choices on innovation performance. This helps to address the concerns raised by Hutzschenreuter and Israel (2009) in their review of dynamic strategy, for example, that 'path dependencies are the least studied to date … the empirical studies we have uncovered still fall short in accounting for the performance implications' (p. 448). In particular, our results emphasise the dominance of business units' current knowledge investment and search activities for innovation rather than any cumulative process in which innovation draws strongly on prior knowledge. In strategic terms, alongside the established value of internal knowledge investment, this emphasises the dual importance of openness in innovation strategy – i.e. external knowledge search – and the need to take care to avoid any negative path dependencies arising from business units' knowledge legacy.

Moderating effects, arising from the interaction of business units' knowledge search, investment and stock, also prove interesting. By and large, we find little evidence of any consistent interaction effect between business units' prior knowledge stock and current knowledge search (Table 6). There is evidence, however, that prior knowledge stock has a significant negative moderating effect on the innovation value of knowledge investments where the innovation output variable is innovative sales. This reflects the findings of Wu and Shanley (2010) who also find evidence of negative moderating effects from prior knowledge stocks in the US electro-medical device industry. Perhaps more surprisingly we also find consistent evidence of a negative moderating effect between the innovation value of business units' internal knowledge investment and knowledge search (Table 6). While consistent with a resource-based view in which external knowledge search and knowledge investment might be substitutes, this result contrasts with much of the recent empirical literature which emphasises instead complementarities between firms' internal and external knowledge resources (e.g. Arora and Gambardella, 1990; Veugelers and Cassiman, 1999; Cassiman and Veugelers, 2006).

7. Conclusions

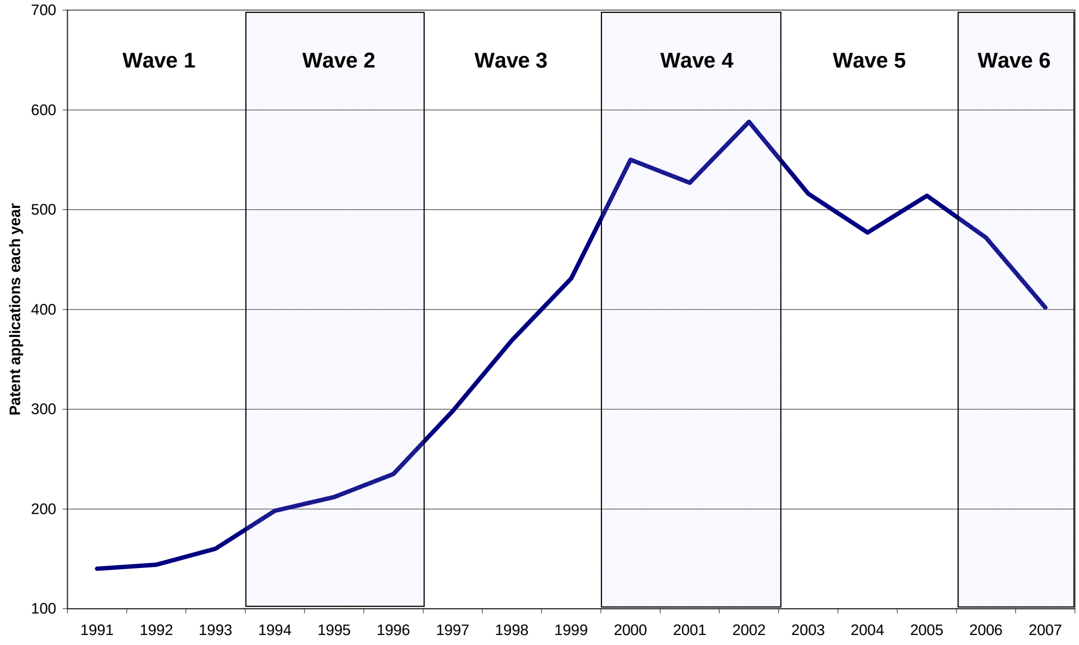
Two substantive conclusions stem from our analysis. First, across manufacturing as a whole, patent stocks have negative rather than positive impacts on business units' innovation outputs, reflecting potential negative path dependency or core-rigidities rather than cumulative capacity building. Second, business units' current knowledge search and investment activities dominate any legacy effects on innovation performance. In strategic terms both suggest the primary importance of current strategy choices in influencing innovation and the weakness of any legacy effects which might shape persistence in innovation outputs (Roper and Hewitt-Dundas 2008). In this sense, the past is likely to be a poor guide to the future in terms of business units' innovation performance; more important is current knowledge search and investment strategy.

In terms of the measurement of innovation, our results reinforce the conclusion of Peeters and van Pottlesberghe (2006) who suggest that 'when using patent-related indicators of innovation, researchers should be aware and explicitly take into account the fact that the empirical results not only refer to a particular type of firms and sectors but also to a specific set of innovation strategies'. Indeed, our results suggest that there may actually be an inverse relationship between patent indicators and innovation output measures reflecting other similar findings in terms of between patents and measures of business performance (Artz et al. 2010). This has clear implications too for debates about the value or otherwise of current IP regulations.

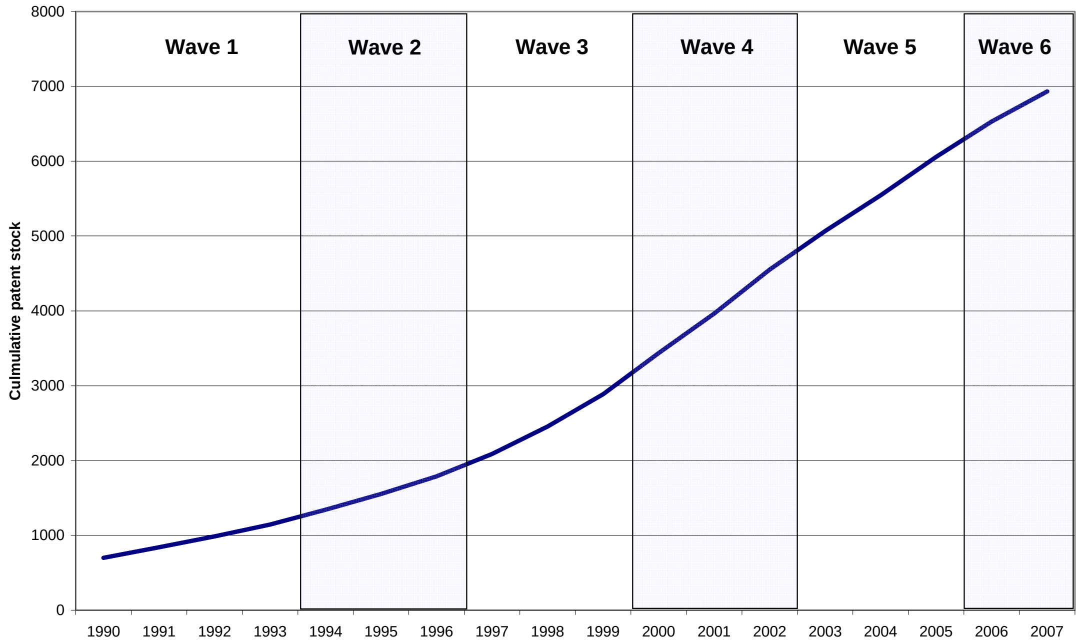
Our study is, of course, not without its limitations. Predominant among these is that it is restricted to manufacturing firms while the majority of economic activity relates to services. However, it is perhaps in manufacturing where the strongest links might be expected between codified knowledge stocks – such as patents – and innovation outputs. For services, future studies might usefully explore tacit knowledge stocks and innovation. A further question relates to the generalisability of our analysis which is based on Irish data. While EU comparisons tend to emphasise the similarity of innovation behaviours in Ireland to those in other EU economies and the US (Roper et al. 2008) national factors cannot, of course, be ruled out and international replication would therefore be valuable. Finally, our measurement of knowledge stocks here using patents data is clearly limited, particularly in more traditional manufacturing sectors. Confirmatory analysis could therefore usefully be developed using other more broadly based knowledge stock indicators reflecting perhaps cumulated investments in R&D and/or other intangibles (Haskel et al. 2009).

Figure 1: Successful patent applications in Ireland: By IIP Survey period

A: Patent Applications



B: Patent Stock



Source: Hewitt-Dundas et al., 2010

Figure 2: Hypotheses

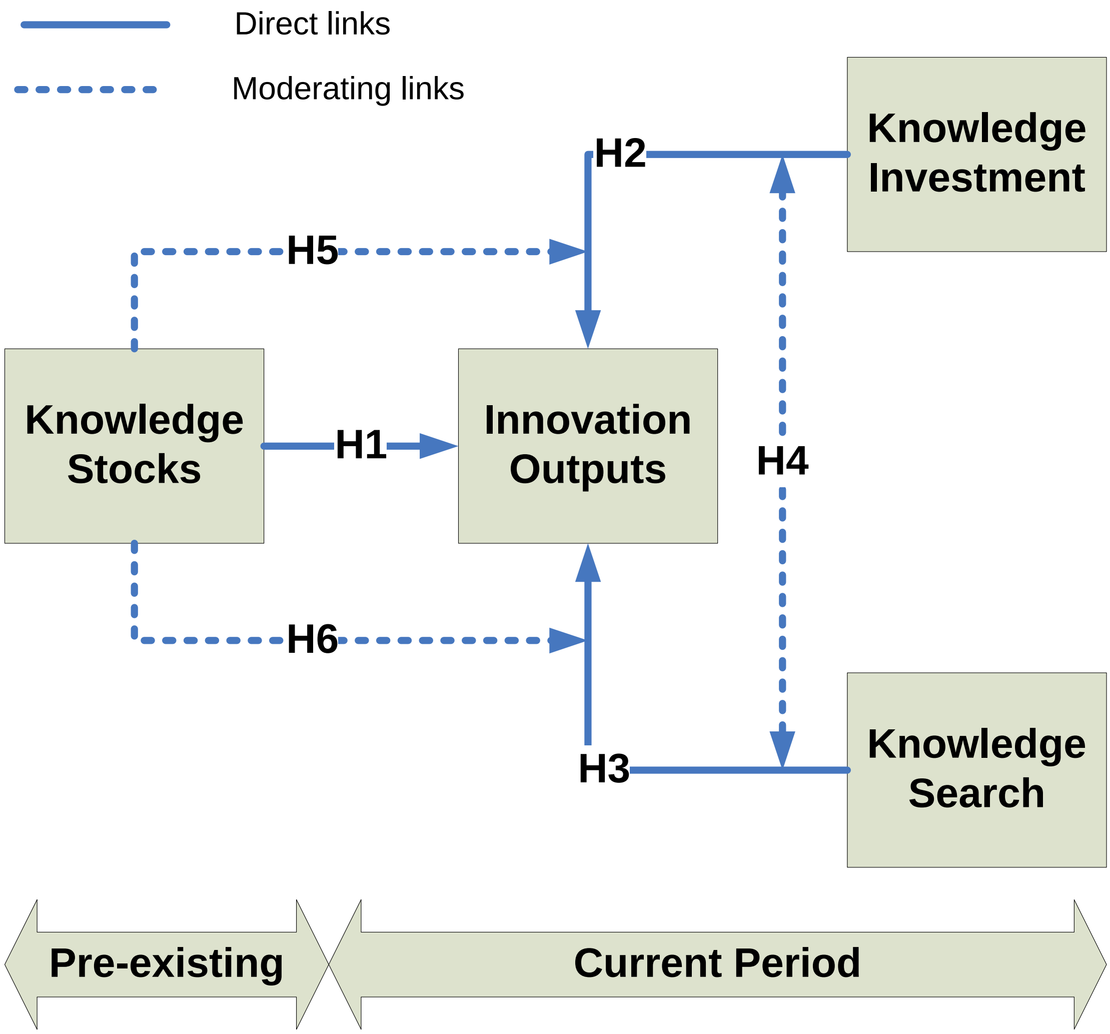
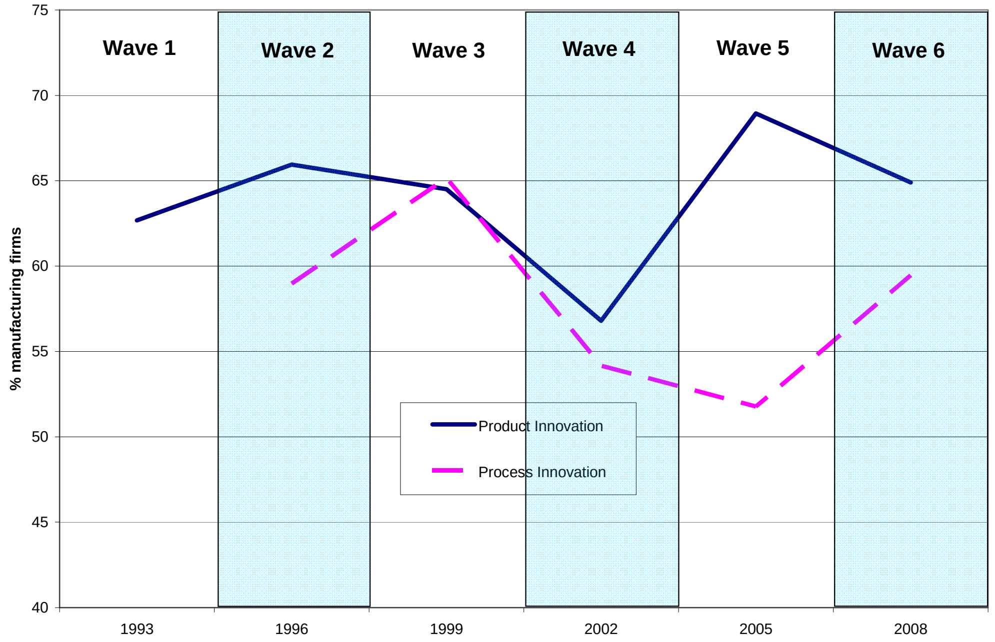
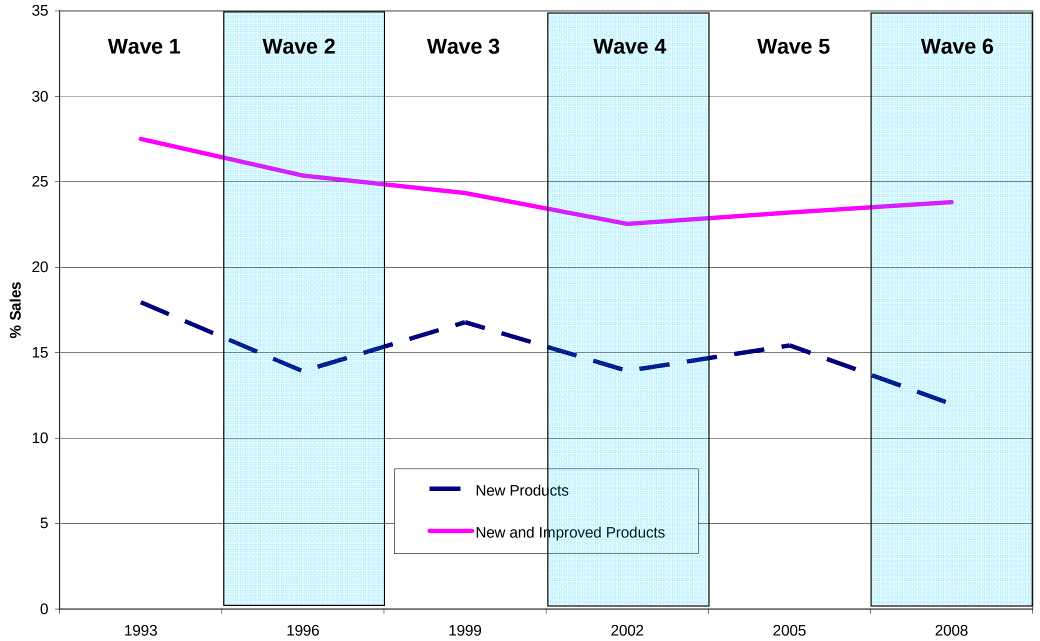


Figure 3: Percentage of innovating business units: By IIP Wave

A. Product and process innovation



B: Percentage of sales from innovative products



Source: Irish Innovation Panel

Table 1: Descriptive Statistics

	Obs	Mean	Std. Dev.
Innovation indicators			
Product innovation (% firms)	2316	0.642	0.479
Process innovation (% firms)	2309	0.580	0.494
Sales of new products (% sales)	2150	14.740	22.570
Sales of new or improved products (% sales)	2145	23.818	29.858
Knowledge stock: Aggregate patent stock (mean per firm)	2368	0.331	4.468
Knowledge stock: Depr. patent stock (mean per firm)	2304	0.139	1.823
Knowledge investment: R&D in-house (% firms)	2368	0.482	0.500
Knowledge search: Innovation partners (avg per firm)	2309	1.343	1.939
Control variables			
Site size (employment)	2327	75.293	164.194
Site age (years)	2327	3.263	35.474
Externally-owned site (% firms)	2342	28.917	29.851
Workforce with degree (% workforce)	2368	0.266	0.442
Govt. support for product development (% firms)	2249	10.790	14.482
Govt. support for process development (% firms)	2327	0.222	0.416

Sources: IIP and Hewitt-Dundas et al., 2010 Observations are weighted to give representative results. Variable definitions in Annex 1.

Table 2: Correlation Matrix

	Prod Innov.	Process Innov	Innovat sales (new)	Depr. Patents Stock	R&D in-house	Innov. Pnering.	Ent. Size	Site age (years)	Ext.-owned	Workers with degree	Govt. support for prod dev	Govt. support for process dev
Product innovation	1.00											
Process innovation	0.27	1.00										
Innovative sales (new)	0.51	0.16	1.00									
Depreciated patent stock	0.05	0.04	0.00	1.00								
R&D in-house (% firms)	0.45	0.28	0.23	0.08	1.00							
Innovation partnering	0.27	0.31	0.21	0.09	0.30	1.00						
Ent size (employment)	0.14	0.15	0.13	0.19	0.11	0.20	1.00					
Site age (years)	0.01	-0.01	-0.14	0.03	-0.01	0.02	0.10	1.00				
Externally-owned site (% firms)	0.12	0.13	0.12	0.12	-0.01	0.17	0.31	-0.02	1.00			
Workforce with degree (% workforce)	0.11	0.01	0.15	0.11	0.12	0.14	0.12	0.00	0.19	1.00		
Govt. support for product development (% firms)	0.29	0.19	0.17	0.08	0.40	0.27	0.06	-0.02	-0.02	0.06	1.00	
Govt. support for process development (% firms)	0.16	0.26	0.10	0.03	0.25	0.29	0.11	0.01	0.02	-0.01	0.48	1.00

Source: IIP and Hewitt-Dundas et al., 2010. Variable definitions in Annex 1.

Table 3: Innovation Production Functions: Probit models of product innovation

	Model 1 dy/dx	Model 2 dy/dx	Model 3 dy/dx
Knowledge inputs to innovation			
Knowledge Stock (log patent stock)		-0.052**	-0.050*
		(0.023)	(0.026)
Knowledge Investment (R&D)		0.326***	0.365***
		(0.024)	(0.029)
Knowledge Search		0.091***	0.101***
		(0.018)	(0.019)
Knowledge Search squared		-0.009***	-0.008***
		(0.003)	(0.003)
Moderating effects			
Investment -Search			-0.033**
			(0.014)
Stock-Investment			-0.095
			(0.088)
Stock-Search			0.022
			(0.019)
Controls			
Business unit size (employment)	0.001***	0	0
	(0.000)	(0.000)	(0.000)
Business unit size squared (employment)	-0.002***	0.004	0.004
	(0.000)	(0.002)	(0.002)
Business unit age (years)	0	0.001	0.001
	(0.000)	(0.001)	(0.001)
Externally-owned site (% units)	0.077***	0.084***	0.084***
	(0.027)	(0.031)	(0.031)
Workforce with degree (% workforce)	0.004***	0.002	0.002
	(0.001)	(0.001)	(0.001)
Govt. support for product development (% units)	0.247***	0.131***	0.134***
	(0.021)	(0.030)	(0.030)
N	2516	2008	2008
Chi^2	232.354	356.796	394.215

Source: IIP and Hewitt-Dundas et al., 2010. Observations are weighted to give representative results. Variable definitions in Annex 1. Models contained industry dummy variables and constant term. Coefficients reported are marginal effects. * denotes significance at the 10 per cent level; ** at 5 per cent and *** at the 1 per cent level.

Table 4: Innovation Production Functions: Probit models of process innovation

	Model 1 dy/dx	Model 2 dy/dx	Model 3 dy/dx
Knowledge inputs to innovation			
Knowledge Stock (log patent stock)		-0.104***	-0.114***
		(0.021)	(0.024)
Knowledge Investment (R&D)		0.165***	0.197***
		(0.027)	(0.034)
Knowledge Search		0.062***	0.076***
		(0.021)	(0.022)
Knowledge Search squared		0.001	0.003
		(0.004)	(0.004)
Moderating effects			
Investment -Search			-0.039**
			(0.017)
Stock-Investment			0.048
			(0.076)
Stock-Search			0.011
			(0.021)
Controls			
Business unit size (employment)	0.001***	0	0
	(0.000)	(0.000)	(0.000)
Business unit size squared (employment)	-0.003***	0.001	0.001
	(0.001)	(0.001)	(0.001)
Business unit age (years)	0	0	0
	(0.001)	(0.001)	(0.001)
Externally-owned site (% units)	0.039	0.009	0.004
	(0.030)	(0.033)	(0.033)
Workforce with degree (% workforce)	0	-0.002*	-0.002**
	(0.001)	(0.001)	(0.001)
Govt. support for product development (%	0.340***	0.271***	0.274***
	(0.025)	(0.031)	(0.031)
N	2105	2005	2005
Chi^2	166.918	283.573	307.708

Source: IIP and Hewitt-Dundas et al., 2010. Observations are weighted to give representative results. Variable definitions in Annex 1. Models contained industry dummy variables and constant term. Coefficients reported are marginal effects. * denotes significance at the 10 per cent level; ** at 5 per cent and *** at the 1 per cent level.

Table 5: Innovation Production Functions: innovative sales

	Model 1 dy/dx	Model 2 dy/dx	Model 3 dy/dx
Knowledge inputs to innovation			
Knowledge Stock (log patent stock)		-0.709	0.046
		(0.666)	(0.777)
Knowledge Investment (R&D)		6.994***	8.696***
		(1.276)	(1.532)
Knowledge Search		1.865***	2.375***
		(0.555)	(0.622)
Knowledge Search squared		-0.151*	-0.136*
		(0.078)	(0.077)
Moderating effects			
Investment -Search			-0.840**
			(0.403)
Stock-Investment			-5.408***
			(2.053)
Stock-Search			0.284
			(0.466)
Controls			
Business unit size (employment)	0.007**	-0.005	0.001
	(0.004)	(0.005)	(0.005)
Business unit size squared (employment)	-0.014	0.024**	0.01
	(0.013)	(0.012)	(0.013)
Business unit age (years)	-0.105***	-0.086**	-0.081**
	(0.035)	(0.035)	(0.034)
Externally-owned site (% units)	2.421**	2.535**	2.762**
	(1.156)	(1.221)	(1.256)
Workforce with degree (% workforce)	0.125***	0.085***	0.088***
	(0.028)	(0.028)	(0.028)
Govt. support for product development (%	4.908***	1.880*	2.090**
	(1.011)	(1.028)	(1.011)
N	2363	1875	1875
Chi^2	176.289	290.188	284.914

Source: IIP and Hewitt-Dundas et al., 2010. Observations are weighted to give representative results. Variable definitions in Annex 1. Models contained industry dummy variables and constant term. Coefficients reported are marginal effects. * denotes significance at the 10 per cent level; ** at 5 per cent and *** at the 1 per cent level.

Table 6: Symbolic Summary of Results

	Anticipated Effects	Product Innovation	Process Innovation	Innovative Sales
Knowledge inputs to innovation				
H1: Knowledge stock (log)	+	-	-	(+)
H2: Knowledge investment	+	+	+	+
H3: Knowledge Search	+	+	+	+
H3: Knowledge Search squared	-	-	(+)	-
Moderating effects				
H4: Investment-Search	+	-	-	-
H5: Stock-Investment	-	(-)	(+)	-
H6: Stock-Search	-	(+)	(+)	(+)

Notes: '-' denotes a negative and significant marginal effect (at the 10 per cent level or above); '+' denotes a positive and significant marginal effect; (+)' is an insignificant positive effect and (-) denotes an insignificant negative effect.

Annex 1: Variable Definitions

Innovation	
Product innovation (0/1)	A binary variable taking value 1 if the firm introduced any new or improved product during the previous three years.
Process innovation (0/1)	A binary variable taking value 1 if the firm introduced any new or improved process during the previous three years.
Innovative sales (new) (% sales)	An indicator representing the percentage of firms' sales at the time of the survey accounted for by products which had been newly introduced over the previous three years.
Knowledge indicators	
Depreciated patent stock (number)	The cumulative number of patent applications made by the firm in the period prior to the survey reference period depreciated using the estimated depreciation rates from Park and Park (2006).
In plant R&D	A binary indictor taking value one if the firm has an in-house R&D capacity
Innovation Partnering	An indicator of the number of the breadth of innovation partnering conducted by the firm. Takes values 0 to 10 depending on how many different types of partner firm is working with: group company, supplier, consultant, client, competitor, joint venture, government laboratory, university, private laboratory, industry research centre.
Control variables	
Plant vintage	The age of the site (in years) at the time of the survey.
Externally owned	A binary indicator taking value one if the firm was owned outside Ireland at the time of the survey.
Employment	Employment at the time of the survey.
Percentage with degree	Percentage of the workforce with a degree or equivalent qualification
Govt support for product innovation	A binary indicator taking value one if the firm had received government support for product innovation over the previous three years.
Govt support for process innovation	A binary indicator taking value one if the firm had received government support for process innovation over the previous three years.

References

Advisory Committee on Measuring Innovation in the 21st Century Economy. 2008. Innovation Measurement - Tracking the state of innovation in the US economy *A report to the Secretary of Commerce*.

Ahuja, G, and R Katila. 2001. Technological Acquisitions and the Innovation Performance of Acquiring Firms: A Longitudinal Study. *Strategic Management Journal* 22 (3):197-220.

Arora, A, and A Gambardella. 1990. Complementarity and external linkages: the strategies of the large firms in biotechnology. *Journal of Industrial Economics* 38:361-79.

Artz, K. W., P. M. Norman, D. E. Hatfield, and L. B. Cardinal. 2010. A Longitudinal Study of the Impact of R&D, Patents, and Product Innovation on Firm Performance. *Journal of Product Innovation Management* 27 (5):725-740.

Arvanitis, S, H Hollenstein, U Kubli, N Sydow, and M Wörter. 2007. Innovationstätigkeit in der Schweizer Wirtschaft. *Strukturberichterstattung Nr. 24, Staatssekretariat für Wirtschaft (seco) (ed.). Bern.*

Atkeson, and Kehoe. 2005. Modelling and Measuring Organization Capital. *Journal of Political Economy* 113:1026-1053.

Audretsch, D B. 2002. The Dynamic Role of Small Firms: Evidence from the U.S. *Small Business Economics* 18 (1-3):13-40.

Barry, F. 2005. FDI, Transfer Pricing and the Measurement of R&D-Intensity. *Research Policy* 34 (5):673-681.

Belderbos, R., M. Carree, and B. Lokshin. 2006. Complementarity in R&D cooperation strategies. *Review of Industrial Organization* 28 (4):401-426.

Brouwer, E, and A Kleinknecht. 1999. Innovative output, and a firm's propensity to patent. An application of CIS micro data. *Research Policy* 28:615-624.

Buiseret, T, H M Cameron, and L Georgiou. 1995. What differences does it make? Additionality in the public support of R&D in large firms. *International Journal Of Technology Management* 10 (4-6):587-600.

Cassiman, B , and R Veugelers. 2002. Complementarity in the Innovation strategy: Internal R&D, External technology acquisition and co-operation in R&D. In *EARIE Annual Conference*. Madrid.

Cassiman, B, and R Veugelers. 2006. In Search of Complementarity in Innovation Strategy:Cooperation in R&D Internal R&D and External Technology Acquisition *Management Science & Public Policy* 52 (1):68-82.

Cefis, E, and L Orsenigo. 2001. The Persistence of Innovative Activities; A Cross Country and Cross-Sectors Comparative Analysis. *Research Policy,* 30:1139-1158.

Chesborough, H W. 2003. *Open Innovation*: Harvard University Press.

———. 2006. *Open Innovation: a new paradign for understanding industrial innovation*. Edited by H. W. Chesbrough, W. Vanhaverbeke and J. West, *Open Innovation: researching a new paradigm*. Oxford: Oxford University Press.

Choo, C W, and N Bontis. 2002. *The Strategic Management of Intellectual Capital and Organizational Knowledge*. Oxford: Oxford University Press.

Cohen, W M, and D A Levinthal. 1990. Absorptive capacity: a new perspective on learning and innovation. *Administrative Science Quarterly* 35:128-152.
Crepon, AD , A Hughes, P Lee, and J Mairesse. 1998. Research, Innovation and Productivity: An econometric analysis at the firm level. *Economics of Innovation and New Technology* 7:115-158.
de Rassenfoss, G, and B van Pottelsberghe. 2009. A policy insight into the R&D-patent relationship. *Research Policy* 38:779-792.
Faber, J, and A B Hensen. 2004. Innovation capabilities of European nations - Cross-national analysis of patents and sales of product innovations. *Research Policy* 33:193-207.
Fleming, L., and D. M. Waguespack. 2007. Brokerage, boundary spanning, and leadership in open innovation communities. *Organization Science* 18 (2):165-180.
Freel, M S. 2005. Patterns of innovation and skills in small firms. *Technovation* 25 (2):123-134.
Griffith, R, S Redding, and J Van Reenan. 2003. R&D and Absorptive Capacity: Theory and Empirical Evidence. *Scandinavian Journal of Economics* 105 (1):99-118.
Griliches, Z. 1995. *R&D and Productivity: Econometric Results and Measurement Issues*. Edited by P. Stoneman, *Handbook of the Economics of Innovation and Technological Change*. Oxford: Blackwell.
Guellec, D, and B van Pottelsberghe. 2004. From R&D to productivity growth: do the institutional settings and the source of funds matter? *Oxford Bulletin of Economics and Statistics* 66:353-378.
Hansen, M T, and J Birkinshaw. 2007. The Innovation Value Chain. *Harvard Business Review* June 121-130.
Haskel, J, T Clayton, P Goodridge, A Pesole, D Barnett, G Chamberlin, R Jones, K Khan, and A Turvey. 2009. Innovation, knowledge spending and productivity growth in the UK Interim report for NESTA Innovation Index project: NESTA
Helfat, C. 1994. Firm-specificity in corporate applied R&D. *Organisation science* 5 (2):173-184.
Hewitt-Dundas, N , and S Roper. 2009. Output Additionality of Public Support for Innovation: Evidence for Irish Manufacturing Plants. *European Planning Studies* forthcoming.
Hewitt-Dundas, N, and S Roper. 2008. Ireland's Innovation Performance: 1991-2005. *Quarterly Economic Commentary, ESRI, Dublin.* (Summer 2008):46-68
Hewitt-Dundas, N, A Singh, Y P Ho, and P K Wong. 2010. Knowledge Flows Of Innovation In Small Open Economies – Comparative Analysis Of Ireland And Singapore. In *Institute of Small Business and Entrepreneurship* London
Horn, Paul M. 2005. The Changing Nature of Innovation. *Research Technology Management* 48 (6):28-33.
Hutzschenreuter, T., and S. Israel. 2009. A review of empirical research on dynamic competitive strategy. *International Journal of Management Reviews* 11 (4):421-461.
Jensen, C. 2004. Localized spillovers in the Polish food industry: The role of FDI in the development process? *Regional Studies* 38 (5):535-550.
Jordan, D , and E O'Leary. 2007. Sources of innovation in Irish SMEs: Evidence from two Irish regions. Paper read at British-Irish Regional Science Association Annual Conference, at Bangor.

Klette, T. J, and F Johansen. 1998. Accumulation of R&D Capital and Dynamic Firm Performance: a not-so-Fixed Effect Model. *Annales de Economie et de Statistique* 49-50:389-419.
Kyriakopoulos, K, and K de Ruyter. 2004. Knowledge Stocks and Information Flows in New Product Development. *Journal of Management Studies* 41 (8):1469-1498.
Laursen, K, and A Salter. 2006. Open for Innovation: The role of openness in explaining innovation performance among UK manufacturing firms. *Strategic Management Journal* 27:131-150.
Lee, C. Y. 2010. A theory of firm growth: Learning capability, knowledge threshold, and patterns of growth. *Research Policy* 39 (2):278-289.
Leiponen, Aija. 2005. Skills and innovation. *International Journal of Industrial Organization* 23 (5-6):303-323.
Leonard-Barton, D. 1992. Core capabiliteis and core rigidities: a paradox in managing new product development. *Strategic Management Journal* 13:111-25.
Levinthal, DA, and JG March. 1993. The myopia of learning. *Strategic Management Journal* (14):95-112.
Liang, K Y, and S L Zeger. 1986. Longitudinal data analysis using generalized linear models. *Biometrica* 73:13-22.
Loof, H, and A Heshmati. 2001. On the Relationship between Innovation and Performance: A Sensitivity Analysis. Stockholm School of Economics.
———. 2002. Knowledge capital and performance heterogeneity: A firm level innovation study. *International Journal of Production Economics* 76:61-85.
Love, J H, and S Roper. 2001. Networking and Innovation Success: A Comparison of UK, German and Irish Companies. *Research Policy* 30:643-661.
———. 2004. The Organisation of Innovation: Collaboration, Co-operation and Multifunctional Groups in UK and German Manufacturing. *Cambridge Journal Of Economics* 28:379-395.
Lucas, H. C., and J. M. Goh. 2009. Disruptive technology: How Kodak missed the digital photography revolution. *Journal of Strategic Information Systems* 18 (1):46-55.
Mainwaring, L, N Moore, and P D Murphy. 2007. A regional comparison of enterprise patent holdings: A study of British and Irish data. *Research Policy* 36:1655-1665.
Mansfield, E. 1986. Patents and innovation: an empirical study. *Management Science* 32 (2):173-181.
March, J G. 1991. Exploration and Exploitation in Organisational Learning. *Organisation science* 2 (71-115).
McCarthy, F D. 2001. Social Policy and macroeconomics: The Irish experience, . In *Policy Research Working Paper Series No. 2736*: The World Bank.
Meehan, E. 2000. Britain's Irish Question: Britain's European Question?: British-Irish relations in the context of the European Union and the Belfast Agreement. *Review of International Studies* 26 (1):83-97.
Nelson, R R, and S G Winter. 1982. *An Evolutionary Theory of Economic Change'*. Cambridge, Mass. : Harvard University Press.
Neuhaus, J M, J D Kalbfleisch, and W W Hauck. 1991. A comparison of cluster-specific and population-averaged approaches for analyzing correlated binary data. *International Statistical Review* 59:25-35.
O'Malley, E, S Roper, and N Hewitt-Dundas. 2008. High growth and innovation with low R&D: The case of Ireland. In *Small Economy Innovation System;*

Comparing Globalization, Change and Policy in Asia and Europe, edited by C. Edquist and L. Hommen: Elgar.
O'Sullivan, M. 2000. The sustainability of industrial development in Ireland. *Regional Studies* 34 (3):277-290.
Oerlemans, L, M Meeus, and F Boekema. 1998. Do networks matter for innovation? The usefulness of the economic network approach in analysing innovation. *Tijdschrift voor Economische en Sociale Gcografie* 89:298-309.
Park, G, and Y Park. 2006. On the measurement of patent stock as knowledge indicators. *Technological Forecasting And Social Change* 73:793-812.
Peeters, C, and B Van Pottelsberghe. 2006. Innovation strategy and the patenting behaviour of firms *Journal Of Evolutionary Economics* 16:109-135.
Ramani, S V, M-A El-Aroui, and M Carrere. 2008. On estimating a knowledge production funtion at the firm and sector level using patent statistics. *Research Policy* 37:1568-1578.
Rodriguez-Pose, A. 2001. Is R&D investment in leading areas of Europe worthwhile? Theory and empirical evidence. *Papers in Regional Science* 80:275-295.
Roper, S. 2001. Innovation, Networks and Plant Location; Evidence for Ireland. *Regional Studies* 35 (3):215-228.
Roper, S , and N Hewitt-Dundas. 2008. Innovation Persistence: Survey and Case-Study Evidence. *Research Policy* 37 (1):149-162.
Roper, S , J Youtie, P Shapira, and A Fernandez-Ribas. 2008. Knowledge, Capabilities and Manufacturing Innovation: A US-Europe Comparison'. *Regional Studies* Forthcoming.
Roper, S, and J Anderson. 2000. Innovation and E-Commerce - A Cross-Border Comparison of Irish Manufacturing Plants. Belfast.
Roper, S, J Du, and J H Love. 2008. Modelling the Innovation Value Chain. *Research Policy* 37 (6-7):961-977.
Roper, S, and N Hewitt-Dundas. 1998. Innovation, Networks and the Diffusion of Manufacturing Best Practice: A Comparison of Northern Ireland and the Republic of Ireland. Belfast: NIERC.
Roper, S. Ashcroft, B., Love, J H., Dunlop, S., Hofmann, H. Vogler-Ludwig, K. 1996. Product Innovation and Development in UK, German and Irish Manufacturing: Queen's University of Belfast/University of Strathclyde/info Institut.
Santamaria, L., M. J. Nieto, and A. Barge-Gil. 2009. Beyond formal R&D: Taking advantage of other sources of innovation in low- and medium-technology industries. *Research Policy* 38 (3):507-517.
Schmidt, T. 2010. Absorptive Capacity - One Size Fits All? A Firm-Level Analysis of Absorptive Capacity for Different Kinds of Knowledge. *Managerial and Decision Economics* 31 (1):1-18.
Smith, D J, and D Tranfield. 2005. Talented suppliers? Strategic change and innovation in the UK aerospace industry. *R&D Management* 35 (1):37-49.
Sribney, W. 2007. Comparing RE and PA models. *Stata Data Analysis and Statistical Software*.
Su, C. T., Y. H. Chen, and D. Y. J. Sha. 2007. Managing product and customer knowledge in innovative new product development. *International Journal Of Technology Management* 39 (1-2):105-130.
Thrane, S., S. Blaabjerg, and R. H. Moller. 2010. Innovative path dependence: Making sense of product and service innovation in path dependent innovation processes. *Research Policy* 39:932-944.

Trajtenberg, M. 2001. Innovation in Israel 1968-1997: a comparative analysis using patent data. *Research Policy* 30 (3):363-389.
Tzabbar, D., B. S. Aharonson, T. L. Amburgey, and A. Al-Laham. 2008. When is the whole bigger than the sum of its parts? Bundling knowledge stocks for innovative success. *Strategic Organization* 6 (4):375-406.
Ulku, H. 2007. R&D, innovation, and growth: evidence from four manufacturing sectors in OECD countries. *Oxford Economic Papers-New Series* 59 (3):513-535.
Veugelers, R, and B Cassiman. 1999. Make and Buy in Innovation Strategies: Evidence from Belgian manufacturing firms. *Research Policy* 28 (1):63-80.
West, J., and S. Gallagher. 2006. Challenges of open innovation: the paradox of firm investment in open-source software. *R & D Management* 36 (3):319-331.
Wu, J. F., and M. T. Shanley. 2009. Knowledge stock, exploration, and innovation: Research on the United States electromedical device industry. *Journal of business research* 62 (4):474-483.
Zahra, S A, and G George. 2002. Absorptive capacity: a review, re-conceptualization, and extension. *Academy of management review* 27:185-203.
Zenger, T. 2002. Crafting internal hybrids: complementarities, common change initiatives and the team-based organisation. *International Journal of the Economics of Business* 9:79-95.