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The value of design strategies for new product development: Some econometric evidence

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Abstract

Investments in design play a potentially significant role in new product development (NPD) although there is little unanimity on the most appropriate or effective design strategy. Previous case-study based studies have identified three alternative design strategies for NPD: design used as a functional specialism, design used as part of a multi-functional team and designer-led NPD. Using data on a large sample (c. 1300) of Irish manufacturing plants we are able to examine the effectiveness of each of these three design strategies for NPD novelty and success. Our analysis suggests that design is closely associated with success in NPD performance regardless of the type of strategy pursued. Adopting designer-led NPD, however, results in a much greater design effect on NPD performance than more functionally-oriented strategies. The impacts of design on NPD outcomes are also strongly moderated by other plant characteristics. For example, the beneficial effects of design on NPD outputs are only evident for plants which also engage in R&D. Also, while both small and larger plants do gain from using design as a functional specialism and as part of multi-functional teams, the additional benefits of design-leadership in the NPD process are only evident in larger plants.

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The value of design strategies for new product development success: Some econometric evidence

1. Introduction

Moves towards knowledge-based competition, and market-leadership based on innovation and product quality have emphasised the challenge of lean innovation, as plants seek to maximise the innovation value of investments in R&D, human and knowledge capital (Choo and Bontis, 2002). Investments in design play a potentially significant role in innovation, although there is little unanimity on the most appropriate or effective implementation of design in new product development (Perks et al., 2005). This is reflected in widely differing operationalizations of 'design' in the new product development (NPD) research literature[1][2]. In a recent review, for example, Candi and Gemser (2010), contrast four main operationalizations of industrial design in research on NPD reflecting: (i) industrial design emphasis and the priority attached to design in plants' NPD strategy; (ii) industrial design capabilities measured, for example, by design investments or human resource inputs; (iii) industrial design outcomes evaluated by, say, customers; and, (iv) the management and organisation of industrial design as part of the NPD process. As Candi and Gemser (2010) also argue there has been very little research linking these different dimensions of industrial design and, in particular, little quantitative evidence on issues relating to industrial design management (Chiva and Alegre, 2009). Here, we use data taken from a large plant-level database to examine econometrically how alternative design strategies – distinguished by different patterns of engagement of design staff in plants' NPD processes - influence NPD outcomes. This addresses one of the key agenda items identified by Candi and Gemser (2010, p.72), i.e. 'the need to conduct systematic quantitative research to test the theories and

[1] Design is the activity which supports 'the application of human creativity to a purpose – to create products, services, buildings, organisations and environments which meet people's needs. It is the systematic transformation of ideas into reality…' (Bessant (2002) quoted in Chiva and Alegre (2009)).
[2] Plants' view of the potential contribution of 'design' to NPD has also changed significantly through time. Perks et al (2005) review this historical development stressing the movement from design as a purely aesthetic discipline, through more functional interpretations towards today's more systemic perspective.

intuitive findings of existing in-depth research about the integration of designers in the NPD process'[3].

Our analysis builds on main two literatures: the primarily case-study based literature profiling the engagement of design staff with the NPD process (Perks et al., 2005, Goffin and Micheli, 2010), and the econometric literature on the innovation production function which relates inputs to the NPD process to NPD outputs (Griliches, 1995, Roper et al., 2008). In terms of the case-study based literature on the use of design staff within the NPD process, we build particularly on the work of Perks et al. (2005) who suggest a typology of three contrasting modes of engagement of design staff within the NPD process: design staff used as functional specialists; the engagement of design staff as members of multi-functional teams; and, the engagement of design staff as NPD process leaders. Because we have detailed data on the way in which a large group of plants engage design staff in the NPD process, or plants' 'design strategies', we are able to estimate econometrically the impact on NPD outcomes of adopting each of the strategies identified by Perks et al. (2005). This enables us to answer questions such as: What is the contribution of design to NPD outcomes when design staff are employed as functional specialists? Is the contribution larger where design staff are involved as members of multi-functional teams or where they are NPD process leaders?

The second literature on which we draw relates to the innovation production function. This provides an empirical framework within which we can model the relationship between the engagement of design staff in the NPD process and NPD outputs (Tether, 2005, Marsili and Salter, 2006, Talke et al., 2009, Czarnitzki and Thorwarth, 2011). Adopting the innovation production function approach also allows us to take into account plant characteristics and other elements of plants' NPD strategies – such as 'openness' or 'multifunctional working' – and so generate more robust estimates of the contribution of alternative design strategies to NPD outputs (Chesbrough, 2004, Chesbrough and Appleyard, 2007, Minguela-Rata and Arias-Aranda, 2009). It also allows us to identify any contingent factors which might be associated with aspects of plants' operating environment (e.g. sector) or other dimensions of plants' NPD activity (e.g. R&D strategy, skills availability etc.). Prior studies in the

[3] This is reflected in their Research Opportunity 5: 'Quantitative research is needed to compare the effectiveness of industrial design in the different phases of the NPD processes in terms of contributing to performance…' (Candi and Gemser, 2010, p. 75).

innovation production function literature provide evidence that, even after accounting for other control factors, design resources tends to be associated with higher innovation outputs and enhanced plant performance (Czarnitzki and Thorwarth, 2011, Marsili and Salter, 2006, Love et al., 2011). Other papers, however, emphasise the heterogeneity of effects of different types of design activities (Czarnitzki and Thorwarth, 2011), a key theme of our investigation here, and the complementarity of design activities with R&D and other investments (Tether 2005).

The main contribution of our study is to our understanding of the value of alternative design strategies for NPD outcomes. More specifically, we are able to quantify the value of extending the role of designers beyond that of functional specialists to having a wider role either as part of multifunctional NPD teams or as NPD process leaders. The results suggest some clear strategic recommendations for the most effective design strategies in NPD in different sectoral and market contexts. In particular, we find that plants with designer-led NPD strategies significantly outperform those employing design staff either in a purely functional capacity, or as members of multi-functional teams. The proportion of plants with designer-led NPD strategies remains small, however, suggesting the potential for substantial population gains in NPD performance from the wider adoption of designer-led NPD.

2. Conceptual foundations and hypotheses

Our focus here is the new product development or NPD process which describes the way in which manufacturing plants envisage, develop and market new products. This process is the subject of a diverse literature which suggests the variety of NPD structures and processes between sectors and markets (Varela and Benito, 2005, Harmancioglu et al., 2007). Four key themes emerge from the NPD literature, however, which provide the context for our more specific discussion of the role of design in NPD. First, the technology management literature emphasises the value of structured NPD processes, with the best performing plants using organising mechanisms such as stage-gate processes involving multi-functional development teams (Griffin, 1997). More recent contributions seek to integrate the stage-gate model with the requirements of open innovation in order to reduce development risk and ensure the full exploitation of ideas developed within the plant (Gronlund et al., 2010). Non-linear models of innovation, however, stress that such processes need to be flexible, allowing for feedbacks and loopbacks between the different activities which comprise an NPD process (Rosenberg, 1982), and linking marketing to R&D (Atuahene-Gima and Evangelista, 2000, Cordon-Pozo et al., 2006, Ernst et al., Olson et al., 2001, Song et al., 1996), design (Lawrence and McAllister, 2005) and manufacturing (Calantone et al., 2002). Secondly, NPD processes are generally said to start from either a market finding, i.e. the identification of a new or improved product which would satisfy an unfulfilled market need, or a new technological discovery (Myers and Marquis, 1969). Third, structured NPD processes involve a range of different activities, each of which are different in nature and may involve both internal and external actors[4]. Historically, design has been seen as one of these stages focussed on the aesthetic or functional aspects of product development but making little contribution to other activities within the NPD process (Perks et al., 2005). Finally, the evidence suggests that the development of an effective new product marketing strategy can significantly influence new product success both in isolation and in combination with R&D (Ernst et al., 2010). Taken together these themes suggest a view of the NPD process which comprises a number of diverse activities, which may or may not be structured or sequential and which reflects both the technical and more market-related aspects of any product development. NPD activities are also often ‘open’ reflecting plants’ engagement in development partnerships or networks (Chesborough, 2003, Chesborough, 2006).

The importance of design as a potentially important contributor to NPD success has been emphasised due to the increasing ‘design intensity’ of a wide range of products (Gemser and Leenders, 2001), and the ability of designers to enhance products’ functional, emotional and symbolic value (Verganti, 2009). Design-driven or design-led NPD processes may also contribute to the development of more radical innovations (Verganti, 2008). The difficulties of effectively integrating design staff into the NPD process have been emphasised repeatedly, however. Case studies undertaken by Goffin and Micheli (2010), for example, emphasise issues relating to the involvement of designers in the NPD process: ‘cultural barriers’, related to language and designers’ self-image, and work process barriers, related different work processes of designers and others involved in the NPD processes. ‘The goal of good industrial design was perceived by designers to be the creation of an ‘iconic’ product – one that would become famous and instantly recognizable. By contrast, managers perceived design as a means to build brand and achieve the right price’ (Goffin and Micheli, 2010,

[4] Schulze and Hoegl (2008) suggest, however, that socialisation and internalisation processes – reflecting in-house knowledge creation and combination – are more positive for novelty than externalisation.

p.32). Similar tensions have also been observed between designers and marketing staff involved in NPD activities. As Perks et al. (2005) observed in their case studies: 'This frequently led to design-marketing conflict. Designers were compelled to express performance parameters in marketing terms, of which they had no experience and were unable to understand' (p. 119-120)[5]. Song et al. (1997) also emphasise goal incongruity between marketing staff and others involved in NPD as an antecedent of conflicts in plants attempting to integrate design into their NPD activities.

Notwithstanding these difficulties, there is increasing empirical evidence positively relating various dimensions of plants' design activity to NPD outcomes. Marsili and Salter (2006) , for example, base their analysis on Dutch Community Innovation Survey data and consider the relationship between design expenditure (expressed as a proportion of sales) and various NPD output indicators[6]. In their sample, 21.9 per cent of plants had positive design spending which was found to have a positive link to new product sales although no significant link to sales of improved products. Using a similar design expenditure variable Cereda et al. (2005) find essentially similar results for the UK, again identifying a positive link between design spending and product innovation but no significant link between design spending and process change[7]. More recently, Czarnitzki and Thorwarth (2011) also demonstrate the positive relationship of design spending with NPD outputs in a group of Flemish plants as well as suggesting that both in-house and external design resources have positive impacts on incremental innovation. This generally positive evidence suggests our first hypothesis which relates to the positive contribution of design resources to NPD outcomes:

Hypothesis 1: The contribution of design resources

Design resources make a positive contribution to NPD outcomes.

[5] Goffin and Micheli (2010), for example, suggest that designers talk about 'form and function', 'aesthetics', consumer experience' while managers emphasise 'price', 'brand' and exclusivity' etc. (Table 3, p. 33).
[6] Marsili and Salter (2006) note that the definition of 'design' in the Dutch Community Innovation Survey is 'The preparations aimed at taking into actual production new or improved products and/or services'. This they argue accords to definitions of 'normal engineering design', equivalent to an indication of design resources in terms of Candi and Gemser (2010).
[7] In the UK survey 'design expenditure' is said to cover 'all design functions, including industrial, product, process and service design and specifications for production or delivery' (Cereda et al., 2005, p.7).

In general terms, econometric studies of the value of design resources in NPD, such as those reviewed above typically focus on one-dimensional measures of design resources - such as plants' overall spend – and do not consider the different ways in which design resources can be incorporated into the NPD process[8]. Case-study based evidence, however, suggests that the utilisation of design resources – or the management and organisation of design - as part of the NPD process vary widely between plants. In a series of case studies with UK manufacturing plants, Perks et al. (2005), for example, develop a three-fold taxonomy of design strategies for NPD, with each strategy differentiated by the extent of the engagement of design staff in the NPD process. The first, design strategy identified by Perks et al. (2005) involves Design as a Functional Specialism. Here, the NPD process is seen as functionally structured, with designers engaged only in specific NPD activities such as product design and development, and excluded from other activities such as marketing and design engineering. Such an approach may enable design staff to contribute to the functional and/or aesthetic aspects of new products, but may risk losing any benefits which may arise from complementarities between design staff and other staff (Lehoux et al., 2011, p. 313) and design leadership of the NPD process and the potential for more radical innovation (Verganti, 2008).

The second design strategy identified by Perks et al. (2005) involves design staff working as part of multi-functional teams. Here, the NPD process is seen as being organised to be multi-functional rather than functionally demarcated, and design staff are engaged in NPD activities outside their specialist areas. Engaging design staff as part of multifunctional teams may allow plants to exploit complementarities of knowledge and/or perspective between design staff and other staff. This recognises of nature of design as an essentially social process in which different individuals bring to design teams different skills and functional perspectives which may 'create opportunities and set constraints which influence the design process' (Lehoux et al., 2011, p. 313). Based on three case studies of medical device design projects Lehoux and Hivon (2011) argue that each NPD team member generally starts to envision an innovation from their own 'world' or perspective: 'In all of the cases, the object to be designed takes shape because knowledge circulates from one domain to another and is adapted or transformed along the way' (p. 328). Marion and Meyer (2011), for example, identify positive complementarities between cost engineering and industrial design in NPD in early stage plants, while Tether (2005) emphasises complementarities between design and

[8] Although Czarnitzki and Thorwarth (2011) do compare the innovation impact of in-house and external design.

R&D and Acha (2005) stresses the interaction between in-house design and boundary spanning linkages. Adopting a multi-functional approach to the engagement of design staff in NPD may therefore allow plants to benefit from complementarities reflected in increased knowledge sharing (Lawrence and McAllister, 2005, Hsu, 2011), the development of trust and mutual learning (Creed and Miles, 1996), and an ability to overcome any hierarchical and spatial barriers to project success (Zeller, 2002). The potential for these complementarities between design staff and other functions in the NPD process suggests our second hypothesis:

Hypothesis 2: Multifunctional role of design

Design resources employed in multifunctional teams will make a greater contribution to NPD outcomes than design resources used as a functional specialism.

The engagement of design staff in multi-functional teams may be positive for NPD but the evidence suggests that this type of engagement may vary substantially between elements of the NPD process. Love and Roper (2004, Table 8), for example, show that 40.7 per cent of UK manufacturing plants were involving designers in identifying new products compared to only 19.0 per cent of plants in which designers were involved in market research or the development of marketing strategies. Essentially similar variation is also evident for German companies. It has been suggested by Verganti (2009), however, that the implied lack of consistency in the engagement of design staff in the NPD process may lead to the type of inter-disciplinary conflicts identified by Goffin and Micheli (2010). Potentially one way of avoiding these issues is the adoption of the third design strategy suggested by Perks et al. (1995) - designer-led NPD - in which 'designers drive and support actions throughout the entire development process and across a broad scope of functional activities' (p. 121). Consistency in NPD leadership has also been positively linked to NPD outcomes (Rosing et al., 2011), however, Oke et al. (2009) also argue that innovation leadership may have other organisational advantages such as helping to maintain focus within a development team and help to protect development teams from diversion from other pressures within the organisation. Whether any leadership advantages are internal to the NPD team or more organisational we would anticipate that:

Hypothesis 3: Designer-led innovation and NPD outcomes

Design resources employed as a process leader will make a greater contribution to NPD outcomes than design resources used as part of multifunctional groups.

While a designer-led NPD process may enable a plant to effectively coordinate resource inputs to NPD, Verganti (2009) also argues that adopting a designer-led NPD strategy may also help plants to achieve radical product changes, perhaps involving user interaction (Harty, 2010)[9]. In empirical terms, Perks et al. (1995) also find that plants adopting a strategy employing design staff as functional specialists tend to be focussed on more incremental product changes than plants engaging design staff in the NPD process in either multi-functional groups or a leadership role. This suggests our fourth hypothesis:.

> **Hypothesis 4: Designer-led innovation and innovation quality**
>
> Design resources employed as a process leader will allow plants to make more radical innovations than situations where design resources are used either as part of multifunctional groups or as functional specialists.

Hypotheses 1 to 4 relate to the direct impact of plants' design strategy choices on NPD outcomes. Design is, however, only one of a number of factors which contribute to the success of NPD processes (Love et al., 2011), suggesting the potential for other NPD inputs to moderate the impact of design resources on NPD outcomes. For example, a number of studies have emphasised the potential value of complementarity between plants' design resources and R&D: 'the design elements of a product are usually more sensational and visible to the consumer than the R&D elements; both are essential for the functioning of the product but design is the element that allows consumers to distinguish between similar products' (Rusten and Bryson, 2007, p. 76). Empirical evidence also suggests the potential for synergies between R&D and design activities in the NPD process (Tether, 2005), although exploiting such synergies is not always easy due to the distinctive cultures of R&D staff and design staff and potential differences in physical settings and motivations (Lilleoere and Hansen, 2011). More generally, we might anticipate that the contribution of design resources to NPD outputs will be constrained where other resource inputs to the NPD process are more limited. In smaller plants, for example, it has been argued that internal resource constraints may limit the scale and quality of NPD outputs (Vossen, 1998, Hewitt-Dundas, 2006). This suggests:

[9] Other writers have equated the distinction between radical and incremental product changes with the extent of the changing 'meanings' of products linked to technological developments – consumers' functional and psychological and cultural utility from products (Verganti, 2011 1735).

H5: Design and R&D

Design effects on NPD outcomes will be enhanced by the presence of R&D within the plant.

H6: Design effects and plant size

Design effects on NPD outcomes will be proportionately greater in larger plants.

3. Data and Methods

Data for our study are taken from three plant-level surveys of manufacturing in Ireland and Northern Ireland covering plants' NPD activity in the periods 1991-93, 2000-02 and 2006-08. Each of the three surveys comprises one 'wave' of the Irish Innovation Panel (IIP) dataset and was carried out by post with telephone follow-up to boost response rates. Sampling frames were either obtained from private sector providers (1991-93 and 2006-8) or government agencies (2000-02) and were intended to be representative of the target population of manufacturing plants with more than 10 employees. Samples were structured by sizeband with different sampling fractions for plants of different sizes[10]. The initial survey, covering plants' NPD activity from 1991 to 1993 was undertaken between October 1994 and February 1995 and achieved a response rate of 38.2 per cent (Roper et al., 1996; Roper and Hewitt-Dundas, 1998, Table A1.3). The 2000 to 2002 survey was undertaken between November 2002 and May 2003 and achieved an overall response rate of 34.1 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 resulting panel is unbalanced, reflecting non-response in individual surveys but also the opening and closure of individual plants: on average there are 1.7 observations per plant in the dataset. Non–response checks on survey responses suggest little significant difference in terms of innovation behaviour between respondent and non-respondent plants. In each case, surveys were targeted at either company Managing Directors, CEOs or senior managers with a responsibility for R&D or new product development.

[10] Sampling fractions were: 50 per cent for plants with 10-19 employees, 75 per cent for plants with 20-99 employees and 100 per cent for plants with 100 plus employees.

Our analysis is based on answers to three questions asked in each of these surveys. First, plants were asked whether they had introduced any new or improved products over the previous three years. Plants answering in the affirmative were then asked what proportion of their current sales was derived from products newly introduced in the previous three years, and whether these new products were either 'new to the market for the first time' or simply 'new to the plant but had previously been made elsewhere'. This data was used for our two dependent variables. First, the overall level of sales derived from newly introduced products has been widely used in the NPD and innovation studies literatures (Leiponen 2005; Laursen and Salter 2010; Roper et al 2008; Love and Roper 2009; Leiponen and Helfat 2010; Love et al 2011) and reflects both plants' ability to bring new products to market and the short-term success of those products. It therefore provides an indication of short-term NPD success. On average, for the sample as a whole, plants derived 20.6 per cent of sales from newly introduced products (Table 1)[11]. Our second dependent variable is an ordinal variable reflecting the radicalness of plants' innovation and taking value 3 if the plant introduced 'new to the market products', 2 if the plant had introduced products new to the plant and value 1 where plants had introduced no new products in the previous three years.

Plants indicating that they had undertaken some NPD activity in the previous three years were also then asked to indicate whether design staff had been involved in seven specific elements of the NPD process: Identifying New Products, Prototype Development, Final Product Design, Product Testing, Production Engineering, Market Research, and Developing Marketing Strategy. Across the sample of manufacturing plants in the IIP around 44 per cent of plants were involving design staff in the Final Product Design element of the NPD process, with a slightly smaller proportion of plants (41 per cent) of plants involving design staff in prototype development (Figure 1, Table 1). By contrast, only about 10-15 per cent of plants were engaging design staff in either market research or the development of marketing strategy (Table 1) [12]. While these differences between the involvements of design staff in the different elements of the NPD process are substantial we see surprisingly little change in this pattern through time (Figure 1, top panel). Pooling data from the three waves of the IIP also

[11] See Hewitt-Dundas and Roper (2008) for a discussion of the development of this variable as an indication of Irish innovation performance since the early-1990s.

[12] An essentially similar profile of design engagement with NPD is evident in the case studies conducted by Perks et al. (2005), with significant design engagement in 'Concept Development ' and 'Design' in their study and significantly less design involvement in 'Production' or 'Launch'.

suggests little systematic difference in the pattern of design engagement in the NPD process between small, medium and large plants (Figure 1, central panel). More difference is evident, however, between plants engaging and not engaging in R&D, with the former being more likely to engage design staff in all stages of the NPD process (Figure 1, lower panel).

From these data on the engagement of design staff in individual elements of the NPD process we derive three variables intended to capture the three design strategies identified by Perks et al. (2005). First, to reflect the functional specialist strategy we define a variable which takes value 1 if a plant involves design staff in the Identification, Prototyping, or Final Product Design elements of the NPD process but in no other elements of the NPD process. Secondly, to reflect the multi-functional team strategy we define a dummy variable which takes value 1 if a plant involves design staff in any of the three functional specialist elements of the NPD process (i.e. Product Identification, Prototyping, or Final Product Design) *and* in any other single element of the process. Finally, to reflect the consistent engagement of design staff in the NPD process implied by the designer-led NPD strategy we define a dummy variable which takes value 1 where a plant involves design staff in all stages of the NPD process. Of the plants surveyed, 17 per cent employed a functional specialism strategy, 29 per cent employed design staff in multi-functional teams and 4 per cent of plants were adopting a designer-led NPD strategy. These data accord with patterns noted in Figure 1, with design staff routinely engaged in the prototyping and final product stages of the NPD process, but more rarely involved in the production or marketing elements of the NPD process.

To test our hypotheses we make use of the concept of the innovation production function which relates plants' NPD outputs to the knowledge inputs to the NPD process (Griliches, 1995, Love and Roper, 2001, Laursen and Salter, 2006). In more formal terms, if I_{it} is an NPD output indicator for plant *i* in period *t* the innovation production function might then be summarised as:

$$I_{it} = \beta_0 + \beta_1 DFS_{it} + \beta_2 DMT_{it} + \beta_3 DPL_{it} + \beta_4 RI_{it} + \lambda_j + \tau_t + \delta_i \qquad (1)$$

where DFS_{it} denotes a dummy variable relating to plants' use of a design as a functional specialism, DMT_{it} is a dummy variable relating to plants' use of design staff as part of multi-functional teams and DPL_{it} is a similar variable relating to the adoption of designer-led NPD strategy. For Hypothesis 1 to Hypothesis 4 our primary interest is in the coefficients β_1 to β_3 which relate to the direct effects of design strategy on innovation outputs. For Hypotheses 5 and 6 we undertake sub-sample estimation for R&D performers and non-performers and for smaller and larger plants and test the similarity of β_1 to β_3 between sub-samples.

In the innovation production function we also include a set of plant-level control variables (RI_i) which have been shown to influence innovation outputs in previous studies involving innovation production functions. These are necessary to ensure that the estimated effects of the design strategy coefficients are not systematically biased upwards or downwards. First, we include a variable to reflect the engagement of the plant in R&D which is generally associated positively with new product development (Crepon et al., 1998, Loof and Heshmati, 2001, Loof and Heshmati, 2002, Roper et al., 2008) and may also influence plants' ability to absorb external knowledge for NPD (Cohen and Levinthal, 1990, Griffith et al., 2003). Second, we include a variable to control for plants' use of multi-functional working in the NPD process as previous studies have suggested that the use of multi-functional teams are strongly linked to innovation success (Minguela-Rata and Arias-Aranda, 2009). This variable is defined in a similar way to our design strategy variables reflecting plants' use of multi-functional teams across the seven identified elements of the NPD process[13]. Third, we include a dummy variable to indicate whether or not plants' had any external linkages as part of their NPD activities. Previous studies provide strong evidence of the positive effects of such linkages on NPD outputs (Roper at al 2008; Love and Mansury 2007). Fourth, we include a plant size indicator (employment) which we interpret in the Schumpeterian tradition as a resource indicator, and which has been shown in previous studies to have a strong relationship to innovation outputs (Jordan and O'Leary, 2007). Fifth, we include an indicator of enterprise vintage to capture potential plant life-cycle effects (Atkeson and Kehoe 2005). Sixth, we include an indicator of whether or not a plant is externally-owned to reflect the potential for intra-firm knowledge transfer within a multinational enterprise (Jensen, 2004). Seventh, 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.,

[13] Specifically , this variable takes values from 0 to 28 depending on the engagement of four skill groups (engineers, scientists and technicians, skilled production staff, marketing staff) in the seven elements of the NPD process. For example, a plant involving all skill groups in all elements of the NPD process would score 28 on this variable.

2007). As standard we also include sectoral dummies λ_j, period dummies τ_t and a regional dummy relating to Northern Ireland in each model (not reported).

Our estimation approaches are dictated largely by the fact that we are using plant level data from three waves of a highly unbalanced panel and the nature of our dependent variables. As Figure 1 suggests design engagement within the NPD process has remained relatively stable over the three survey waves and we therefore pool observations across the three waves of the survey and include time dummies to isolate any temporal fixed effects. Our first dependent variable – the share of new products in sales - is expressed as a percentage of plants' sales and is therefore bounded at zero and one hundred. For these models we therefore use an upper and lower censored tobit estimator. Our second dependent variable – an ordinal indicator of innovation quality – requires an ordered probit. All models include sectoral dummies at the 2-digit level, time dummies for each wave of the survey and a Northern Ireland dummy to control for any regional effects.

Finally, before turning to our empirical results it is important to acknowledge the potential for survey-based studies such as ours to suffer from common method variance or bias (CMB). CMB is the variance due to the general measurement methods rather than due to the measured key explanatory variables themselves (Podsakoff et al., 2003, Sharma et al., 2010) and may lead to biased estimates of the effects of key variables of interest in survey-based studies. Three aspects of our analysis reduce the potential for CMB: first, our analysis is based on three separate surveys rather than a single survey; second, we estimate a relatively complicated innovation production function with the dependent variable measured at the end of the period and key explanatory variables reflecting plants' NPD activities during the previous three years; third, the answer scales of our dependent variable and key explanatory variables are very different. Formally, we have checked for CMB using the Harmon's one factor test which suggests that in our data the most important single factor explains only about 27 per cent of the total variation of the main variables in our model, well below the norm of 50 per cent (Podsakoff and Organ, 1986). Using the alternative marker variable technique with a range of different marker variables suggests a similar pattern with no evidence that CMB is likely to be an issue in our study (Malhotra et al., 2006).

4. Empirical Results

The results of our econometric estimation with the percentage of innovative sales as the dependent variable are shown in Table 2. Hypothesis 1, 2 and 3 are tested for the whole sample in Model 1. In each case the size of the coefficients on the three design strategy variables reflect the impact of employing each design strategy relative to plants which were engaging in NPD activity but had no design engagement in their NPD activity. Thus, at the most basic level, plants employing design staff as functional specialists had, on average, a level of innovative sales around 9 percentage points higher than plants with no design engagement in their NPD activity, even after allowing for the effects of R&D, size, ownership etc. (Table 2, Model 1). This initial result provides strong support for Hypothesis 1 and the value of the engagement of design staff in NPD even where their role is limited to that of a functional specialist. It also provides support for other studies which have emphasised the value of design resources as part of plants' NPD process irrespective of how these resources are used (Marsili and Salter, 2006, Cereda et al., 2005, Czarnitzki and Thorwarth, 2011).

Extending the engagement of design staff to be part of multi-functional NPD teams should allow the plant to exploit potential complementarities between designers and other staff. The plants adopting this type of strategy considered by Perks et al. (2005) 'made considerable effort to generate on-going interaction between designers and relevant stakeholders … The designer's role was dominated by communication and interfacing activities' (p. 120). In our analysis, however, the impact on NPD outputs of engaging design staff in multi-functional teams was only marginally greater than that of engaging design staff as functional specialists (Table 2, Model 1). Indeed, a χ^2 test of the equality of the estimated coefficients relating to design as a functional specialism and design as part of a multi-functional team proves insignificant (Table 2, Model 1). This therefore provides little support for the contention of Hypothesis 2 that engaging design staff in multi-functional teams generates significant complementarities. Various explanations for this rather negative result are possible. First, it is possible that the synergies between design staff and other staff involved in NPD are simply not empirically significant. Perhaps a more likely scenario, however, is that such synergies are possible but are being undermined or offset by skill limitations or other contextual factors. As Perks et al. (2005) comment: 'Designers need the interfacing skills to interact and to communicate with other functions … For some designers, acquiring the skills to implement team-based NPD can be a long and problematic learning process' (p. 121). Similarly, (Dackert et al., 2004) for example, emphasise the importance of team climate and leadership in maximising team innovation, while Perks et al. (2005) emphasise longevity as a facilitator of team interaction. Either, or both, factors might be undermining synergies between design staff and other team members.

The final design strategy we consider involves designer-led NPD, which embeds design staff throughout the NPD process. In our sample, plants adopting this design strategy have, on average, a level of innovative sales around 20 percentage points (pp) higher than plants not engaging design staff in their NPD activity, and 9 pp higher than plants adopting a multi-functional team design strategy (Table 2, Model 1). Both differences are statistically significant as suggested by the reported χ^2 tests, providing strong support for Hypothesis 3 and the contention that innovation outputs benefit significantly in plants adopting a designer-led NPD strategy.

The second potential impact of design we investigate is the impact on the novelty of the outcomes of NPD. Table 3 reports ordered probit models with Model 1 relating to the whole sample. Positive coefficients in the table suggest that an increase in an independent variable is associated with an increase in the novelty of NPD outcomes. Here, unlike the situation with innovation success discussed earlier, plants engaging design staff purely as functional specialists achieved no significant increase in the novelty of their NPD outputs (Table 3, Model 1). Where design staff were engaged either as part of a multifunctional team or as an NPD process leader, however, significant effects on the novelty of NPD outputs were evident (Table 3, Model 1). The implication is that both of these design strategies increase the novelty of NPD outcomes relative to a no-design strategy. Interestingly, however, as the χ^2 tests reported in Table 3 suggest, neither of these effects on NPD novelty were significantly greater than that for design used as a functional specialism. In other words, in terms of the novelty of NPD outcomes it is the presence of design staff in either multifunctional teams or as process leaders which is the crucial factor rather than the specific design strategy chosen. In terms of the discussion in Candi and Gemser (2010) the suggestion is that the management and organisation of industrial design is more important in ensuring NPD success rather than the novelty of NPD outcomes.

Overall, then estimation for our whole sample suggests that all three design strategies have positive and significant relationship with NPD outcomes: design as a functional specialism is associated with an increase in new product sales; design as part of multi-functional teams contributes positively to both NPD novelty and new product sales but its effect is similar in scale to that of design used as a functional specialism. A design-led NPD process is also associated with higher levels of new product sales and NPD novelty, with the effect on new product sales significantly larger than that where design is used as a functional specialism. Investing in design resources – however they are engaged with the NPD process – therefore increases plant' ability to develop novel and/or successful new products. Our results do also emphasise, however, the importance of the choice of design strategy, or the management and organisation of industrial design (Candi and Gemser, 2010). More specifically, for our whole sample of respondents, while engaging design staff in the innovation process as functional specialists or in teams is associated with increase in new product sales by around 9 pp, a design strategy involving designer-led NPD more than doubles the design effect on NPD outputs. In other words, having design resources is only half of the issue; the other half is their effective utilisation.

Our analysis so far deals with the effect of design strategies on the sample of plants as a whole. We now extend the analysis to examine the impact of R&D and plant size as potential moderators of the design strategy – NPD outcomes relationship. In particular, we consider the effects of the alternative design strategies separately for plants that do and do not conduct in-house R&D and for small and larger plants. The potential importance of R&D as a moderator of the impact of design on NPD outcomes is suggested by the bottom panel of Figure 1, where design engagement is shown to be consistently higher among R&D-performing establishments, while previous studies have also emphasised potential complementarities between R&D and design in NPD (Tether, 2005). The question therefore is whether the relationship of of alternative design strategies with NPD outputs is conditional on plants' in-house R&D. Models 2 and 3 in Tables 2 and 3 report the relevant estimation results. For NPD success we find a clear result: only where plants have in-house R&D is design and the choice of design strategy significantly correlated with NPD outcomes (Table

2, Model 2); where plants have no in-house R&D neither the presence or the choice of design strategy influence NPD outcomes (Table 2, Model 3). In terms of the novelty of NPD outcomes our results are less clear, although again the strongest role of design is evident when R&D is being undertaken in a plant (Table 3, Models 2 and 3). Taken together we interpret these results as providing strong support for Hypothesis 5, i.e. suggesting strong complementarities between the presence of R&D in a plant and design-strategy choice in NPD activity. Note, however, that our data relates purely to manufacturing plants. This is important as previous studies have suggested that in the service sector innovation activity may depend much less strongly on R&D than in manufacturing (Leiponen, 2005).

Now, we turn to the role of plant size as a potential moderator of design effects on NPD. Here, we anticipate that design effects on NPD will be proportionately stronger where other resources are less constrained, i.e. in larger plants. Our results suggest that engaging design staff either as functional specialists or as members of multi-functional teams enhances NPD success and novelty in both small and larger plants (Models 4 and 5, Tables 2 and 3). This suggests the generality of results relating to Hypothesis 1 and Hypothesis 2. However, only in larger plants (with more than 50 employees) does a design-led NPD strategy add greater value, suggesting more conditional support for Hypothesis 3. In this sense our results reflect those of Khan et al. (2009) who identify a similar moderating effect between organisational size and transformational leadership in the innovation activities of plants in Pakistan. Perhaps the key point here is the greater need for coordination in the NPD process in larger plants where NPD teams are likely to be larger and operating within a more complex organisational environment.

5. Conclusions and managerial implications

Our aim in this study was to combine the insights of previous qualitative, case-study based analyses on design in NPD with a systematic quantitative analysis. The main contribution is to our understanding of the value of alternative design strategies for NPD outcomes. More specifically, we are able to quantify the value of extending the role of designers beyond their functional specialisms either as part of multifunctional teams or as NPD process leaders as suggested by Perks et al. (2005). Using detailed data on design involvement in the NPD process from three waves of the Irish Innovation Panel we are able to test econometrically a number of hypotheses on the strategic use of design in new product development. In more conceptual terms our analysis examines the relative value for NPD of design complementarities within multifunctional teams and the co-ordination benefits of designer-led NPD.

The empirical results suggest a number of key findings. First, our evidence suggests that design is closely associated with success in NPD performance. Regardless of the type of strategy pursued, design has a statistically significant and substantial association with new product development performance. Second, adopting a strategy of design as a process leader, in which design is used throughout all elements of the NPD process, results in a much greater effect of design on NPD performance than more functionally-oriented strategies. Third, extending the use of designers beyond the functional specialism roles of prototyping, final product development etc. has no discernable impact on NPD performance *unless* the strategy is extended to the full design as a process leader strategy. Fourth, the impacts of design on NPD outcomes are strongly moderated by other plant characteristics. For example, the beneficial effects of design on NPD outputs are only evident for plants which also engage in R&D. Also, while both small and larger plants do gain the benefits of design as a functional specialism and as part of multi-functional teams, the additional benefits of design-leadership in the NPD process are only evident in larger plants.

In general terms our results re-emphasise the importance of design resources to plants' NPD activities supporting other evidence of a strong positive relationship between design inputs and NPD outcomes (Marsili and Salter, 2006, Cereda et al., 2005, Czarnitzki and Thorwarth, 2011). Our results also suggest, however, that the choice of design strategy for NPD is as important as the decision to engage design staff in the NPD process (Candi and Gemser, 2010). For small plants, our evidence suggests that the most effective design strategy is to engage design staff in NPD purely as functional specialists. For these plants our evidence suggests that there is little gain in terms of either the success or novelty of NPD outcomes in extending the role of designers into other elements of the NPD process. This type of design strategy for NPD may also help to minimise costs and potential conflicts between design staff and other skill groups involved in NPD activity (Perks et al., 2005, Goffin and Micheli, 2010). For larger plants (with more than 50 employees) our results also suggest that there are significant gains from engaging design staff in NPD as functional specialists. However, for these plants adopting a designer-led NPD strategy can also lead to significantly more successful and novel NPD outputs. More specifically, larger plants adopting a designer-led NPD strategy had a share of new products in sales 23 pp higher than plants not engaging design staff in the NPD process and 16 pp higher than plants adopting a design as a functional specialism strategy (Table 2, Model 5). Achieving these NPD gains, however, is likely to pose significant challenges for larger plants in terms of the skill needs of those design staff acting as NPD process leaders. Rosing et al. (2011) for example, emphasise the importance of ambidextrous leadership in the innovation process, i.e. matching leadership styles to different elements of the NPD process. Alongside this ambidexterity Perks et al. (2005) also suggest that 'as designers begin to lead the NPD effort, a new set of process management skills are generated. These encompass skills to negotiate, to motivate and persuade… it is unlikely that all existing designers are able or willing to make this transition' (p. 122-3).

Our results also suggest one other important pre-condition for maximising the value of design inputs to NPD – the need for complementary R&D. In managerial terms this suggests the need to consider design and R&D investment decisions together, or at least to make decisions about design strategy in the light of decisions about R&D. Our survey data provides little clear evidence, however, on either the precise structure of the relationship between R&D and design inputs to the NPD process or how this complementary relationship actually works. One attractive possibility is that our results suggest the complementarity of technological and aesthetic inputs to the NPD process, or more generally that plants' R&D competence or skills allows the more effective implementation or adoption of new design ideas. Further research is necessary to understand the interrelation between R&D and design inputs to the NPD process and also to clarify whether the complementary relationship we identify for manufacturing is also evident in other sectors. Such research may also inform recent calls for more strongly developed design policy as a support for developing successful innovation activity (Hobday et al., 2012)

Our results also suggest two potentially valuable directions for future research. First, our results provide support for the argument put forward by Candi and Gemser (2010) of the need for a better understanding of the consequences of the management and organisation of plants' design resources. However, our results also suggest the importance of contextual factors – e.g. R&D, plant size – in influencing the success of different design strategies. Taken together, these arguments suggest the need for a context specific or at least strongly contextualised approach to developing an understanding the management and organisation of design. Second, our results emphasise the potential value at least in larger plants of a designer-led NPD strategy. In our dataset, however, only a small percentage of plants were adopting this type of approach. Why is this? What are the barriers to implementing a designer-led NPD strategy? Both questions require further investigation using a more in-depth approach than that adopted here.

Figure 1: Design engagement with the NPD process: by date, plant size and R&D

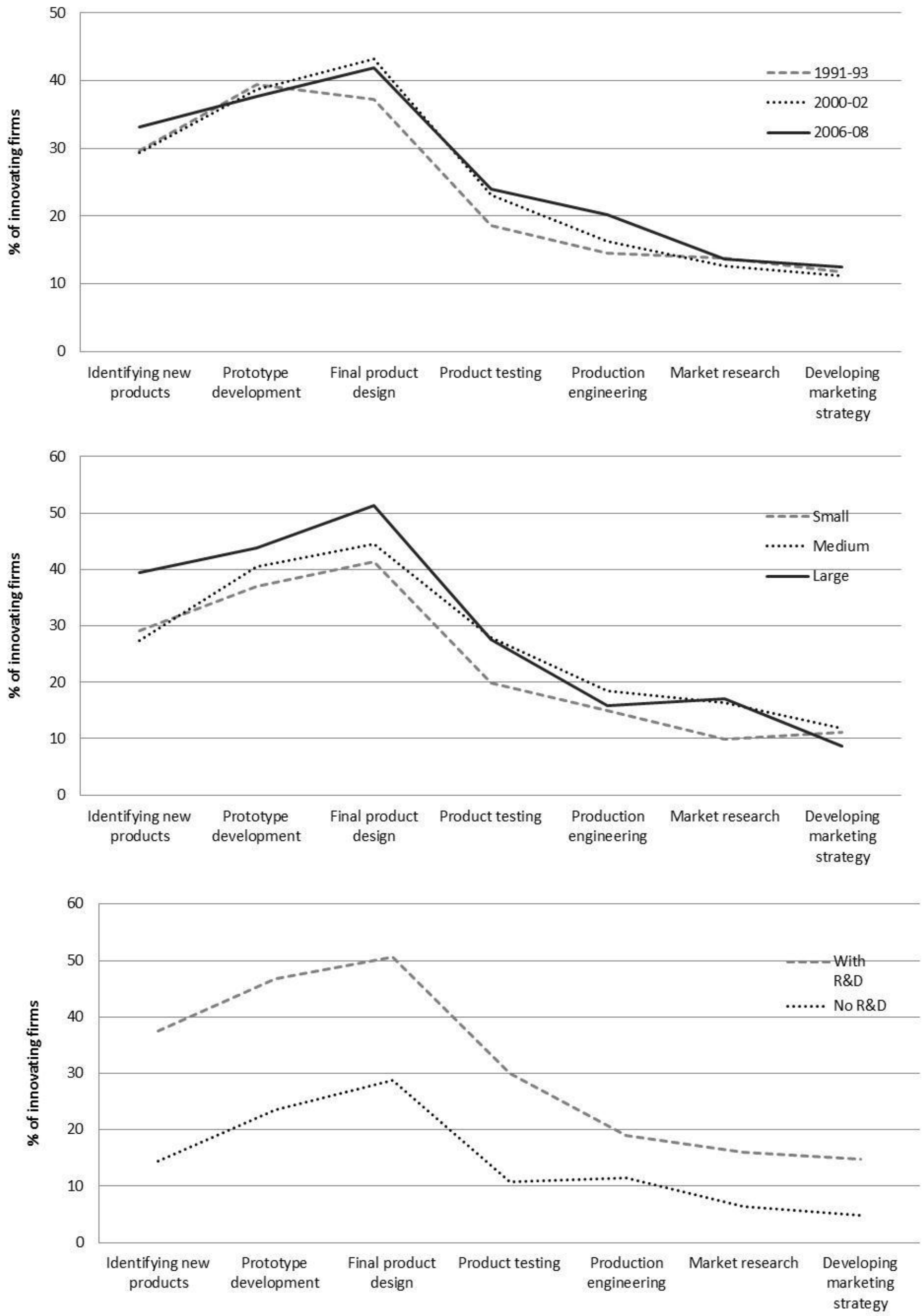

Table 1: Descriptive statistics

Variable	Obs.	Mean	Std. Dev.
New product development outputs			
Share of new products in sales (%)	1269	20.60	23.80
Design engagement in individual NPD elements (share of innovative plants)			
Identifying new or improved products	1317	0.32	0.47
Prototype development	1317	0.41	0.49
Final product design/development	1317	0.44	0.50
Product testing	1317	0.24	0.42
Production engineering	1316	0.18	0.38
Market research	1317	0.14	0.35
Developing marketing strategy	1317	0.13	0.34
Design strategies (share of innovative plants)			
Design as a functional specialism	1363	0.17	0.38
Design as part of multifunctional team	1363	0.29	0.45
Design as process leader	1363	0.04	0.18
Innovation but no design involvement	1363	0.50	0.50
Control variables			
R&D engagement (share of innovative plants)	1357	0.69	0.46
Multi-functionality indicator (0-28)	1363	9.17	4.95
External NPD linkages (share plants)	1356	0.58	0.49
Number of employees (mean)	1288	125.19	323.46
Age (mean years)	1097	28.62	36.71
External ownership (share of innovative plants)	1363	0.16	0.37
Share of employees with degrees (mean %)	1300	11.36	14.04

Notes: Figures relate to pooled data from three waves of the IIP relating to the periods 1991-1993, 2000-2002, 2006-2008 and only to innovating plants. Variable definitions in Data Annex.

Table 2: Tobit models of the share of new products in sales (per cent)

	(1)	(2)	(3)	(4)	(5)
	Whole Sample	R&D Performers	Plants with no R&D	Small plants	Larger plants
Design strategies					
Design as a functional specialism	9.179***	11.917***	3.341	12.851***	7.100**
	(2.405)	*(2.824)*	*(4.384)*	*(3.465)*	*(3.418)*
Design as part of multifunctional team	9.604***	12.248***	3.489	10.050***	8.165**
	(2.117)	(2.389)	(4.184)	(2.986)	(3.001)
Design as process leader	20.023***	22.965***	12.012	11.593	22.732***
	(4.802)	(5.178)	(11.267)	(8.067)	(6.056)
Control variables					
R&D done in-plant	5.291***			5.191*	5.993**
	(1.995)			(2.700)	(2.946)
Multi-functional teams indicator	-0.457**	-0.419*	-0.478	0.189	-0.839***
	(0.205)	(0.236)	(0.368)	(0.320)	(0.272)
External NPD linkages	2.871*	1.960	2.976	-0.731	5.383*
	(1.743)	(2.009)	(3.283)	(2.379)	(2.546)
Number of employees	-0.001	-0.006	0.021	-0.110	-0.002
	(0.004)	(0.005)	(0.011)	(0.109)	(0.005)
Age	-0.081**	-0.056	-0.112**	-0.072	-0.089*
	(0.032)	(0.038)	(0.057)	(0.042)	(0.045)
External ownership	-3.212	0.351	-11.916***	-0.531	-5.264
	(2.476)	(2.934)	(4.167)	(4.383)	(3.082)
Share of employees with degree	0.092	0.113	0.119	0.028	0.192*
	(0.063)	(0.074)	(0.125)	(0.082)	(0.097)
Constant	16.014***	20.860***	9.113	14.606**	19.101***
	(4.060)	(4.830)	(7.111)	(6.026)	(5.870)
Observations	917	635	282	451	466
Log-likelihood	-3646.8	-2586.8	-1041.1	-1737.3	-1895.0
χ^2 Des. as functional specialism = Des. in multifunctional team	0.03 (0.87)	0.01 (0.909)	0.00 (0.978)	0.55 (0.46)	0.09 (0.763)
χ^2 Des. as functional specialism = Des. in process leadership	4.75 (0.029	4.22 (0.04)	0.57 (0.449)	0.02 (0.881)	6.27 (0.012)

Notes: Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Models are based on pooled data for 1991-1993, 2000-2002, 2006-2008. All estimated models include also sector dummies (10 sectors), period dummies and Northern Ireland dummy. Variable definitions in Data Annex.

Table 3: Ordered probit models of the novelty of plants' innovative products

	(1)	(2)	(3)	(4)	(5)
	Whole Sample	R&D Performers	Plants with no R&D	Small plants	Larger plants
Design strategies					
Design as a functional specialism	0.195	0.124	0.439	0.037	0.366
	(0.133)	(0.159)	(0.260)*	(-0.176)	(0.216)*
Design as part of multifunctional team	0.396	0.435	0.256	0.551	0.196
	(0.124)***	(0.148)***	(0.246)	(0.185)***	(0.179)
Design as process leader	0.565	0.604	0.533	0.075	0.846
	(0.333)*	(0.413)	(0.596)	(0.464)	(0.508)*
Control variables					
R&D done in-plant	0.111			0.057	0.187
	(-0.106)			(0.142)	(0.168)
Multi-functional teams indicator	0.022	0.024	0.008	0.060	-0.008
	(0.011)*	(0.014)*	(0.020)	(0.018)***	(0.015)
External NPD linkages	0.137	0.027	0.377	0.135	0.086
	(0.097)	(0.123)	(0.172)**	(0.131)	(0.152)
Number of employees	0.000	0.000	0.001	0.003	0.000
	(0.000)	(0.000)	(0.000)	(0.006)	(0.000)
Age	-0.003	0.000	-0.008	-0.002	-0.003
	(0.001)**	(0.002)	(0.003)***	(0.002)	(0.002)*
External ownership	-0.137	0.062	-0.423	-0.080	-0.256
	(-0.136)	(0.182)	(0.228)*	(0.232)	(0.184)
Share of employees with degree	-0.006	-0.006	-0.008	-0.006	-0.003
	(0.003)**	(0.003)	(0.006)	(0.004)	(0.006)
Observations	975	675	300	489	486
Log-likelihood	-581.91	-362.58	-207.00	-309.36	-255.51
Equation Chi-2	77.2	51.1	39.79	57.61	38.22
Pseudo R-2	0.062	0.066		0.085	0.070
χ^2 Des. as functional specialism = Des. in multifunctional team	2.16 (0.14)	3.18 (0.07)	0.33 (0.56)	5.73 (0.02)	0.55 (0.46)
χ^2 Des. as functional specialism = Des. in process leadership	1.78 (0.18)	1.30 (0.25)	0.02 (0.88)	0.01 (0.94)	0.84 (0.36)

Notes: Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Models are based on pooled data for 1991-1993, 2000-2002, 2006-2008. All estimated models include also sector dummies (10 sectors), period dummies and Northern Ireland dummy. Variable definitions in Data Annex.

Annex: Variable Definitions

NPD Outcomes

New Product sales (% sales)	An indicator representing the percentage of plants' sales at the time of the survey accounted for by products which had been newly introduced over the previous three years.
NPD Novelty	An ordinal indicator taking value 3 if the product was new to the market, 2 if the product was new to the plant and 1 if the plant had undertaken no NPD activity over the previous three years.

Design strategies

Design as a functional specialism	A dummy variable taking value 1 if design staff were engaged in the Identification, Prototyping, or Final Product Design elements of the NPD process but no other element of the process. 0 otherwise
Design as part of a multifunctional team	A dummy variable taking value 1 if design staff were engaged in the Identification, Prototyping, or Final Product Design elements of the NPD process and one other element of the NPD process. 0 otherwise
Design as a process leader	A dummy variable taking value 1 if design staff were engaged in all elements of the NPD process. 0 otherwise

Control variables

In plant R&D	A binary indictor taking value one if the plant has an in-house R&D capacity
Multi-functionality indicator	An indicator of the breadth of multifunctional working across the NPD process. Four skill groups (engineers, scientific and technical staff, marketing and sales staff, production staff) by seven elements of the NPD process. Index takes maximum value of 28 where all skill groups were involved in each stage of the NPD process.
External NPD linkages	A binary indicator taking value 1 where a plant had external NPD linkages (e.g. suppliers, customers etc.) and 0 otherwise.
Employment	Employment at the time of the survey.

Plant age	The age of the site (in years) at the time of the survey.
Externally owned	A binary indicator taking value one if the plant was owned outside Ireland at the time of the survey.
Share of employees with a degree (%)	Percentage of the workforce with a degree or equivalent qualification

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