The Innovation Decision: an Economic Analysis

Abstract
Studies of the determinants and effects of innovation commonly make an assumption about the way in which firms make the decision to innovate, but rarely test this assumption. Using a panel of Irish manufacturing firms we test the performance of two alternative models of the innovation decision, and find that a two-stage model (the firm decides whether to innovate, then whether to perform product-only, process-only or both) outperforms a one-stage, simultaneous model. We also find that external knowledge sourcing affects the innovation decision and the type of innovation undertaken in a way not previously recognised in the literature.

Keywords: Innovation, decision-making

JEL Codes: O31, O32, O33

1. Introduction

How do firms make the decision to innovate and how do they choose between product and process innovation, or doing both? Are these decisions sequential or simultaneous? Despite the substantial body of research on the determinants and effects of innovation, surprisingly little is known about the decision-making process of the innovation decision. Since the early observations by Abernathy and Utterback (1982) that the distribution of firms' resources between product and process innovation depends on the market phase of the relevant technology, there has been an advance in the theoretical literature which examines the product/process mix (Klepper, 1996; Yin and Zuscovitch, 1998; Rosencranz, 2003). But this has not been reflected in the empirical work on the microeconomics of innovation, where it is still common to proceed as if firms concentrate wholly on product innovation. This is most evident in the recent empirical literature examining the 'knowledge production function', which invariably either ignores process innovation or treats it as a subsidiary issue with no explicit consideration of how firms make the relevant decisions (e.g. Crépon et al, 1998; Lööf and Heshmati 2001, 2002; Klomp and Van Leeuwen, 2001).

Virtually the only empirical study which explicitly deals with the choice between product, process or both is Cabagnols and Le Bas (2002), which examines the determinants of 12,779 French innovating firms' product innovation and process innovation during 1987-1992. Cabagnols and Le Bas (2002) analyze how French innovating firms' choices among product innovation, process innovation and both are determined. However, they investigate innovating firms only, which excludes a crucial part of the innovation decision: whether the firm decides to innovate at all. This begs the question of whether the innovation decision is a one-off or a two-stage process. The answer to this question is important both conceptually and econometically: if it is a two-stage decision we need a better understanding of the process in order to distinguish and differentiate the determinants of firms' innovation strategies in each stage. On the other hand, if it is a one-off decision, excluding non-innovating as one potential choice unquestionably violates the exhaustiveness assumption of multiple-choice model, such as the multinomial logit model used by Cabagnols and Le Bas (2002), suggesting that more caution should be exercised in future research.

This paper directly addresses the issue of the nature of the innovation decision from an economic perspective. More specifically, we consider two competing models of firms' innovation decision process involving the choice of undertaking: 1) no innovation; 2) product innovation; 3) process innovation; and 4) both product and process innovation, and test which is statistically more reliable. The purpose of the analysis is therefore to examine the economics behind the innovation decisions actually made by firms, rather than to offer advice to management on how the innovation process should be structured. Throughout the analysis we use a panel dataset of Irish manufacturing firms spanning the period 1994-2002, which allows us to capture the information on firms' business environment, knowledge sourcing activities, absorptive capacities, and other firm characteristics.

2. Two Models

To model the firm's decision-making on innovation, we consider two alternative modelling pathways. Described in Figure 1-A, the one-stage model assumes that the firm faces four choices: not to innovate at all, to innovate on product only, to innovate on process only, or to innovate both on product and process. This model therefore involves a one-off choice between four discrete alternatives. By contrast, the two-stage model as depicted in Figure 1-B assumes that the firm first decides whether or not to engage in any innovation activity, then considers what category of innovation activities it would participate in. By evaluating and comparing the accuracy of the predicting power of these two models, we seek a (more) reliable way to model firms' innovation behaviour.

One-stage model. For a multiple discrete choices setting, we adopt the multinomial probit model (MNP) for its obvious advantage of being able to relax the Independence for Irrelevant Alternatives (IIA) restriction[1]. For individual firm *i* (*i*=1,2,…n), maximizing the utility of choosing the j^{th} innovating behaviour can be expressed in Model I as:

$$U_{ij} = X_{ij}^{'}\beta_{ij} + \varepsilon_{ij},\ j = 0,1,2,3;\ [\varepsilon_0, \varepsilon_1, \varepsilon_2, \varepsilon_3] \sim [0, \Sigma]. \qquad (1)$$

where the choice set j=0, 1, 2, 3 when the firm chooses not to innovate, to innovate in process only, to innovate in product only, and to innovate both in process and product innovation respectively. The random errors $\varepsilon_0, \varepsilon_1, \ldots, \varepsilon_3$ follow multivariate normal distributions. The

[1] For details see Greene (2005) chapter 21.

dataset has been organized in such a way that four choices are exclusive to each other. The implied probability that observed alternative i occurs is:

$$\begin{aligned} &prob[Y_i = j] = \Pr ob[U_{ij} > U_{ik}, j,k = 1,2,3,4, j \neq k] \\ &= prob[\varepsilon_{i1} - \varepsilon_{ij} > (X_{ij} - X_{i1})' \beta, \ldots\ldots, \varepsilon_{i4} - \varepsilon_{ij} > (X_{i4} - X_{ij})' \beta] \end{aligned} . \quad (2)$$

The coefficients are estimated by using method of maximum likelihood:

$$\log L = \sum_{i=1}^{n} \sum_{j=1}^{4} d_{ij} \log prob(Y_i = j) . \quad (3)$$

Two-stage model. A binary choice model is considered at the first stage as below:

$$prob(Y_i = 1 | X_i) = \int_{-\infty}^{X'\beta} \phi(t) dt = \Phi(X_i' \beta) \quad (4)$$

where the firm is either a non-innovator ($Y_i = 1$) or an innovator ($Y_i = 0$), and the choice depends on vector X. $\Phi(.)$ notates the standard normal distribution. The coefficients are estimated using the method of maximum likelihood:

$$\log L = \Pi_{i,Y_i=0} prob[Y_i = 0] \Pi_{i,Y_i=1} prob[Y_i = 1] . \quad (5)$$

Having decided to innovate, at the second stage the firm chooses which type of innovation activity it wants to engage in. This is modelled again by MNP as in equation (1) ~ (3) with three choices, i.e. j=1, 2, 3.

3. Data and Method

Our empirical analysis is based on data from the Irish Innovation Panel (IIP), which provides information on knowledge sourcing, innovation and the performance of manufacturing establishments throughout Ireland and Northern Ireland over the period 1994-2002 (see Annex).

Each wave of the IIP relates to plants' innovation activity over a three-year period, with individual responses weighted to give representative results. A firm is defined as a product/process innovator if it introduced any new or improved products/production processes during the previous three years. Across the IIP panel, half of the firms undertook both product and process innovation, 14.3 per cent of firms undertook process innovation only, another 17.8 per cent of firms undertook product innovation only, and the remaining 17.8 per cent were non-innovators.

The vector X in equations (1) and (4) comprises variables which have previously been shown to be relevant determinants of innovative activity at the plant level (Love and Roper, 1999, 2001). These include measures of the plant's R&D and knowledge sourcing activities, the plant's absorptive capacity and other internal resources, identified constraints on innovation, and regional and industry dummies to account for differences in levels of demand and sectoral differences in technological opportunity. Descriptive statistics for each variable are shown in Table A1 in the Annex.

Our knowledge sourcing activities are measured through both internal and external knowledge sources. Internal knowledge sourcing is represented by in-house R&D intensity (measured by employment) and a dichotomous indicator of R&D being undertaken in plant[2]. We also allow

[2] The presence of in-plant R&D need not indicate that the decision to innovate has already been taken, nor does its absence indicate the reverse. Conceptually, having an R&D department or investing in R&D is clearly no guarantee of successful innovation in a given time period. And empirically this is the case for our sample: from a total of 2,629 observations, there are 884 which either innovate in the absence of R&D or which fail to innovate in a given period despite the presence of R&D. Other work reinforces this point. In a sample of German manufacturing firms, Hofmann and Orr (2005) find that even establishing a specialist project team related to a specific investment was not significantly associated with a greater likelihood of successful process innovation.

for the possibility that intra-group knowledge flows may enhance the plants' own in-house capacity (Buckley and Clarke, 1999; Love and Roper, 2001), and therefore include a dummy variable indicating the presence of relevant group R&D. External knowledge sourcing is represented by a series of dummy variables, one for each potential knowledge source. In each case respondents were asked whether they had links with any other company or organisation as part of their product or process development activities. Backwards linkages to suppliers or consultants were most common (32.5 per cent) followed by forwards linkages to customers (26.5 per cent). Horizontal linkages (12.1 per cent) and links to public knowledge sources (19.3 per cent), were less common but still formed part of the knowledge sourcing strategies of a significant proportion of enterprises.

There is some evidence that external knowledge sources may not only encourage firms to become innovative, but may affect the choice between product and process innovation. The literature indicates that links to suppliers mainly promote process innovation (Pavitt, 1984; Levin et al, 1987; Kleinknecht and Reijnen, 1992; Cabagnols and Le Bas, 2002), while links to customers or users mainly promote product innovation (Von Hippel, 1982; Lundvall, 1988; Cabagnols and Le Bas, 2002). *A priori*, intra-industry or horizontal links might be considered an important source for product innovation but not significantly for process innovation, but there is little empirical evidence on the topic[3].

[3] One exception to this is Cabagnols and Le Bas (2002) who find that horizontal links are positively linked to product innovation.

Absorptive capacity may reflect both the quality of plants' human resource (Freel, 2005) as well as the organisational characteristics of the enterprise (Finegold and Wagner, 1998). In the models we therefore include indicators designed to reflect firms' skills base – the proportion of employees with graduate level qualifications – and whether the plant has a formal R&D department. The latter variable reflects the second of Cohen and Levinthal's (1989) two faces of R&D; its ability to increase a plant's capacity for absorbing knowledge generated elsewhere.

The resource indicators are intended to give an indication of the strength of the plants' in-house resource-base and its impact on innovation strategy. We therefore include variables which give a quantitative indication of the scale of plant resources; plant size, measured by total employment; plant vintage, intended to reflect the potential for cumulative accumulation of knowledge capital by older establishments (Klette and Johansen, 1998) and plant life-cycle effects (Atkeson and Kehoe, 2005); and production type – one-off production or large batch production type. We also allow for perceived constraints on innovation using a number of Likert-type constraint variables. These were obtained by asking respondents the extent to which a range of factors had hindered product or process development in the plant over the previous three years. Finally, to reflect potential differences in the operating environment and level of economic activity between Ireland and Northern Ireland we include a locational dummy, and industry dummies to allow for variations in technological opportunity and other sector-specific effects.

4. Empirical Results

Tables 1 and 2 report the marginal results of two models discussed above. Generally, the results are consistent, with significant variables always having the same sign, nearly always the same level of significance, and often very similar coefficients.

In terms of knowledge inputs, in-plant R&D makes it much more likely that plants will innovate and does something to distinguish between types of innovators: it helps a plant perform product innovation and both types, and makes it less likely that a plant will perform process innovation only. By contrast, having access to group R&D boosts the likelihood of being an innovator and of doing both types rather than product innovation alone. R&D intensity has no effect; this is not entirely surprising, as it probably affects the extent of innovation rather than its probability. External knowledge sourcing matters a great deal, except public knowledge sources, where there is no evidence of any effect. Backward and forward linkages show the pattern suggested by the earlier literature (i.e. supplier links promote process innovation and customer links promote product innovation), but do so in an interesting fashion not picked up by the previous literature. Both forms of knowledge sourcing encourage plants to perform product and process innovation jointly, and each acts to *discourage* the use of product or process innovation alone respectively. Horizontal knowledge sourcing has a similar effect to backward knowledge linkages; this effect is clearest in Model II (Table 2). These results therefore show both similarities and differences with respect to Cabagnols and Le Bas (2002), where horizontal links were found to be associated with the enhancement of product innovation.

Neither of the absorptive capacity measures affects the probability of a plant innovating, but both have a marked effect on the pattern of innovative activity. Having an R&D department increases the chance of its performing both types of innovation, rather than process alone, while a high proportion of graduates both increase the probability that a plant will be a product innovator only and decreases the probability of being a process innovator only. Thus labour skills alter the choice between innovation types, while having a formal R&D department in-plant makes it more likely that both types will be performed concurrently rather than singly.

In terms of the internal resource factors, size has a positive effect on the possibility of innovating, but at a decreasing rate, one of the most established findings in the innovation literature. Size has no effect on distinguishing between types of innovators. Age has some power in discriminating between types of innovation, with older plants more likely to perform only product innovation. There is evidence that plants which principally employ one-off production processes are more likely to perform process innovation alone, and are less likely to perform product and process innovation together, while large-batch firms are predisposed towards being innovative. Constraints do little to distinguish between types of innovators, but do have a systematic effect on probability of innovating. Lack of market opportunities makes it less likely that a plant will innovate, but a perceived financial constraint makes innovation more likely. This latter finding has been noted elsewhere (Iammarino et al 2005), and appears to suggest that innovating firms are more likely both to experience a financial constraint, and to be able to overcome this constraint, whereas a perceived lack of market opportunities prevents plants from becoming innovative. By contrast, a perceived lack of technological information hinders product innovation but has no effect on process innovation, suggesting that this issue is more related to product than process development.

Given the systematic findings of the determinants of innovation, the next stage is to test whether one of the models is statistically superior to the other. Table 3 offers a comparison of the prediction statistics from both models. The first panel shows the number of actual plants in each innovation category. The second panel first presents the predicted number and proportion of innovators from Model I, followed by the correctly predicted probabilities and their proportions, i.e. the proportion of correctly predicted plants for each category. The third panel does the same for Model II, the two-stage model. The last column reports a simple significance test of the difference of the correctly predicted probabilities of the two models. From the results, we see Model II has an unambiguous advantage over Model I. Model II has a statistically significant advantage in prediction in three of the four categories[4], and in predicting overall. Both models are very good at distinguishing between innovators and non-innovators, but have less success in distinguishing between those plants which perform only one type of innovation and both. Looking back at Tables 1 and 2, it is clear that while several variables have a discriminating effect between product-only and process-only innovation, most of them also influence the probability of performing both jointly. Only two variables – the extent of degree-level skills and plant vintage – have a discriminatory effect *only* between product-only and process-only innovation. These are not 'innovation-specific' variables, and clearly they lack the power by themselves to discriminate clearly between what are otherwise very similar groups of firms; firms which employ either product or process innovation are simply difficult to distinguish

[4] The exception is product innovation only, where neither model is superior.

statistically from those that do both, but this does not weaken the conclusion that Model II outperforms Model I as a means of modelling the innovation decision.

5. Conclusions

Studies of the determinants and effects of innovation commonly make an assumption about the way in which firms make the decision to innovate, but rarely test this assumption. Using a panel of Irish manufacturing firms we test the performance of two alternative models of the innovation decision, and find that a two-stage model (firm decides whether to innovate, then whether to perform product-only, process-only or both) outperforms a one-stage, simultaneous model. This has both conceptual and econometric dimensions: as we point out in the introduction, omitting the non-innovate choice in a one-stage model (e.g. Cabagnols and Le Bas, 2002) violates the exhaustiveness assumption of multiple-choice models. We also find that external knowledge sourcing affects the innovation decision and the type of innovation undertaken, but in subtle ways not previously recognised in the literature, and that absorptive capacity and resource considerations have a systematic impact.

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The finding that the two-stage model is statistically more reliable is clearly specific to the sample studied. However, since other empirical evidence on the subject is lacking, this has implications for the way in which studies of innovation are set up, and suggests that a two-stage model should be considered in economic research on the determinants and effects of innovation.

Consider, for example, the increasingly large body of research relating internal and external knowledge sourcing to the innovation performance of firms, and relating this in turn to the productivity and growth of enterprises (e.g. Crépon et al, 1998; Lööf and Heshmati 2001, 2002; Klomp and Van Leeuwen, 2001). Although such research is increasingly sophisticated in terms of econometrics, there is rarely any explicit consideration given to the nature of the innovation decision itself. The results discussed above suggest that a more detailed consideration of this part of the 'knowledge production function' would be worthwhile. For example, a clearer understanding of how the innovation decision evolves might lead to further insights into issues such nature of the interaction between internal and external sources of knowledge: does the impact of different knowledge sources occur at the same stage of the innovation decision process, as is often assumed, or might some knowledge sources affect principally the innovate/not innovate decision while others influence the type of innovation undertaken? Further research of this type would not only further understanding about the early stages of the knowledge production function, but might help provide policymakers with better information on which to base policy interventions designed to enhance innovation and competitiveness.

Table 1: Marginal Effects of Multinomial Probit Model for Innovation Choice (Model I)

Variables	Non-innovator		Process innovator only		Product innovator only		Process and product innovator	
	dy/dx	Std. Err.	dy/dx	Std. Err.	dy/dx	Std. Err.	dy/dx	Std. Err.
Internal Knowledge Sourcing								
R&D Labour Intensity	0.0027	0.0020	-0.0045	0.0046	0.0033	0.0027	-0.0015	0.0039
R&D in Plant*	-0.1794	0.0260 ***	-0.0935	0.0271 ***	0.0483	0.0277 *	0.2246	0.0350 ***
R&D in Group*	-0.0560	0.0154 ***	-0.0298	0.0243	-0.0844	0.0278 ***	0.1703	0.0350 ***
External Knowledge Sourcing								
Forward knowledge sourcing*	-0.0935	0.0189 ***	-0.0493	0.0278 *	0.0393	0.0365	0.1035	0.0414 ***
Backward knowledge sourcing*	-0.0455	0.0203 **	-0.0172	0.0281	-0.0828	0.0316 ***	0.1455	0.0393 ***
Horizontal knowledge sourcing*	-0.0476	0.0215 **	-0.0270	0.0319	-0.0481	0.0360	0.1227	0.0447 ***
Public knowledge sourcing*	-0.0299	0.0263	0.0583	0.0375	-0.0320	0.0358	0.0036	0.0454
Absorptive Capacity								
R&D Department *	0.0134	0.0295	-0.0767	0.0284 ***	-0.0445	0.0321	0.1078	0.0419 ***
Staff with Degree	-0.0004	0.0007	-0.0033	0.0013 **	0.0034	0.0010 ***	0.0002	0.0014
Resources								
Size (employment)	-0.0004	0.0001 ***	0.0000	0.0002	-0.0001	0.0001	0.0004	0.0002 ***
Size-squared	0.0007	0.0004 *	-0.0006	0.0017	0.0003	0.0006	-0.0003	0.0010
Plant vintage (years)	0.0001	0.0003	-0.0003	0.0004	0.0009	0.0004 **	-0.0007	0.0005
One-off Production*	0.0338	0.0213	0.0490	0.0305	0.0379	0.0345	-0.1206	0.0417 ***
Large Batch Production *	-0.0352	0.0143 **	0.0067	0.0221	-0.0074	0.0256	0.0359	0.0314
Innovation Constraints								
Lack of Necessary Finance	-0.0126	0.0052 **	-0.0059	0.0077	0.0130	0.0089	0.0055	0.0111
Riskness of Innovation	-0.0081	0.0060	-0.0027	0.0088	-0.0044	0.0103	0.0152	0.0127
Few Market Opportunity	0.0180	0.0058 ***	0.0092	0.0083	0.0003	0.0099	-0.0275	0.0122 **
Lack of Technological Information	-0.0022	0.0066	0.0005	0.0097	-0.0234	0.0117 **	0.0252	0.0141 *
Market condition								
Northern Ireland Plant	0.0166	0.0145	-0.0078	0.0212	0.0009	0.0248	-0.0097	0.0308
Industrial characteristics								
Food, drink and tobacco	0.0133	0.0235	-0.0249	0.0310	-0.0325	0.0363	0.0441	0.0465
Textiles and clothing	0.0416	0.0346	-0.0831	0.0300 ***	0.0489	0.0495	-0.0074	0.0582
Wood and wood products	-0.0369	0.0201 *	-0.0072	0.0459	0.0241	0.0591	0.0200	0.0713
Paper and printing	0.0703	0.0410 *	0.1914	0.0622 ***	-0.0985	0.0437	-0.1632	0.0707 **
Chemicals	-0.0584	0.0190 ***	0.0794	0.0569	0.0358	0.0554	-0.0568	0.0657
Metals and metal fabrication	0.0116	0.0254	0.0126	0.0379	-0.0179	0.0429	-0.0062	0.0553
Mechanical engineering	-0.0061	0.0275	-0.0080	0.0416	-0.0145	0.0482	0.0286	0.0603
Electrical and optical equipment	-0.0239	0.0233	0.0210	0.0393	-0.0011	0.0430	0.0039	0.0528
Transport equipment	0.0402	0.0507	-0.0145	0.0576	-0.0642	0.0604	0.0385	0.0851

Number of observations: 1500; Log likelihood = -1491.1578.

Note 1: (*) dy/dx is for discrete change of dummy variable from 0 to 1;

Note 2: All the estimations include industry dummies.

Table 2: Marginal Effects of Multinomial Probit Model for Innovation Choice (Model II)

Variable	Probit of Innovator		Multinomial Probit Model					
			Process innovator only		Product innovator only		Process and product innovator	
	dy/dx	Std. Err.	dy/dx	Std. Err.	dy/dx	Std. Err.	dy/dx	Std. Err.
Internal Knowledge Sourcing								
R&D Labour Intensity	-0.0019	0.0017	-0.0040	0.0043	0.0039	0.0028	0.0002	0.0039
R&D in Plant*	0.1608	0.0238 ***	-0.1345	0.0300 ***	0.0022	0.0303	0.1323	0.0366 ***
R&D in Group*	0.0484	0.0144 ***	-0.0393	0.0228 *	-0.1030	0.0284 ***	0.1424	0.0335 ***
External Knowledge Sourcing								
Forward knowledge sourcing*	0.0838	0.0175 ***	-0.0617	0.0268 **	0.0152	0.0366	0.0464	0.0407
Backward knowledge sourcing*	0.0399	0.0188 **	-0.0305	0.0271	-0.1005	0.0332 ***	0.1310	0.0384 ***
Horizontal knowledge sourcing*	0.0425	0.0200 **	-0.0380	0.0287	-0.0619	0.0355 *	0.0999	0.0415 **
Public knowledge sourcing*	0.0292	0.0240	0.0535	0.0355	-0.0385	0.0363	-0.0150	0.0438
Absorptive Capacity								
R&D Department *	-0.0090	0.0269	-0.0675	0.0276 **	-0.0463	0.0328	0.1138	0.0383 ***
Staff with Degree	0.0005	0.0006	-0.0038	0.0013 ***	0.0036	0.0011 ***	0.0001	0.0014
Resources								
Size (employment)	0.0003	0.0001 ***	-0.0001	0.0002	-0.0002	0.0001	0.0002	0.0001
Size-squared	-0.0005	0.0003 *	-0.0003	0.0014	0.0004	0.0005	0.0000	0.0010
Plant vintage (years)	0.0000	0.0002	-0.0002	0.0004	0.0009	0.0004 **	-0.0007	0.0005
One-off Production*	-0.0235	0.0186	0.0567	0.0328 *	0.0514	0.0382	-0.1081	0.0441 **
Large Batch Production *	0.0322	0.0132 **	-0.0012	0.0215	-0.0164	0.0267	0.0176	0.0310
Innovation Constraints								
Lack of Necessary Finance	0.0112	0.0047 **	-0.0064	0.0077	0.0089	0.0095	-0.0025	0.0111
Risk of Innovation	0.0070	0.0055	-0.0049	0.0088	-0.0080	0.0109	0.0129	0.0127
Few Market Opportunity	-0.0157	0.0053 ***	0.0133	0.0084	0.0045	0.0105	-0.0178	0.0122
Lack of Technological Information	0.0013	0.0060	-0.0010	0.0097	-0.0228	0.0124 *	0.0238	0.0142 *
Market condition								
Northern Ireland Plant	-0.0153	0.0133	-0.0027	0.0213	0.0052	0.0266	-0.0025	0.0311
Industrial characteristics								
Food, drink and tabacco	-0.0146	0.0220	-0.0197	0.0312	-0.0328	0.0388	0.0525	0.0459
Textiles and clothing	-0.0412	0.0327	-0.0756	0.0295 **	0.0568	0.0539	0.0188	0.0583
Wood and wood products	0.0337	0.0184 *	-0.0136	0.0445	0.0139	0.0621	-0.0002	0.0722
Paper and printing	-0.0415	0.0329	0.2285	0.0734 ***	-0.0889	0.0504 *	-0.1396	0.0786 *
Chemicals	0.0548	0.0169 ***	0.0626	0.0538	0.0229	0.0555	-0.0855	0.0658
Metals and metal fabrication	-0.0089	0.0231	0.0105	0.0384	-0.0193	0.0463	0.0088	0.0558

Mechanical engineering	0.0038	0.0258	-0.0085	0.0411	-0.0124	0.0512	0.0209	0.0600
Electrical and optical equipment	0.0230	0.0212	0.0158	0.0378	-0.0073	0.0444	-0.0085	0.0522
Transport equipment	-0.0416	0.0483	-0.0139	0.0584	-0.0619	0.0654	0.0758	0.0816
Log likelihood	-492.9573				-999.2285			
Number of observations	1500				1223			

Note 1: (*) dy/dx is for discrete change of dummy variable from 0 to 1;

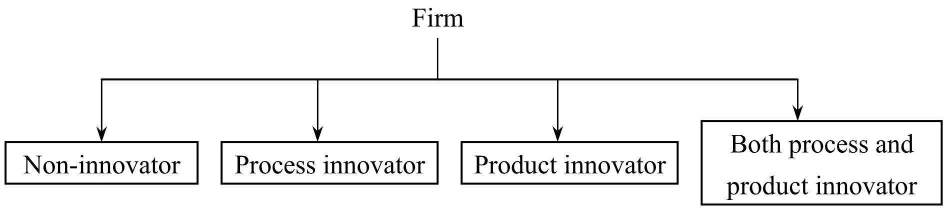
Note 2: All the estimations include industry dummies.

Table 3: Prediction Statistics

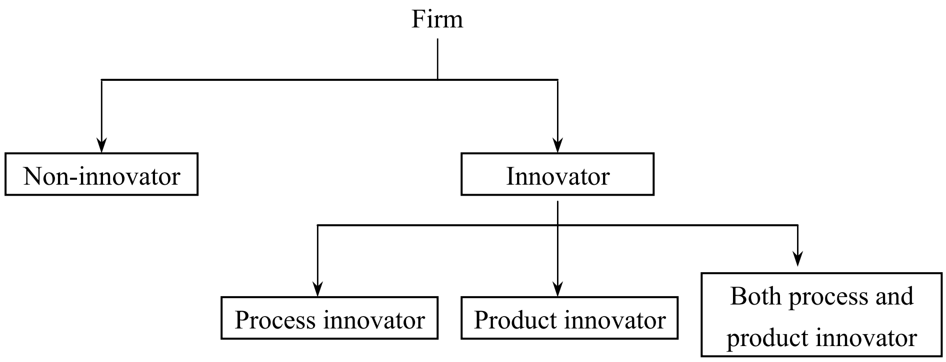
		One-stage Model				Two-stage Model				
	Actual Probability	Predicted Probability	%	Correctly Predicted Probability	% (p1)	Predicted Probability	%	Correctly Predicted Probability	% (p2)	z-stat
0: Non-innovator	268	400	149.3%	193	72.0%	466	173.9%	210	78.4%	-1.70462
1: Process only	214	37	17.3%	12	5.6%	127	59.3%	62	29.0%	-6.71977
2: Product only	267	44	16.5%	25	9.4%	58	21.7%	32	12.0%	-0.98189
3: Process plus product	751	1,019	135.7%	664	88.4%	1047	139.4%	702	93.5%	-3.43019
sum of innovators, 1-3	1,232					1223	100%	796	64.6%	
sum, 0-3	1500	1500	100%	894	59.6%	1689	113.2%	1006	67.1%	-4.25611

Note 1: The selection threshold value for the Probit model predicting non-innovator is tuned to 0.25.

Figure 1: Firms' decision tree of innovation activity



[1-A: One-stage Model]



[1-B: Two-stage model]

Annex: The Irish Innovation Panel (IIP)

Data used in this paper is drawn from the Irish Innovation Panel (IIP), which provides information on knowledge use, innovation and the performance of manufacturing plants with 10 or more employees in Ireland and Northern Ireland over the period 1991-2002. The IIP comprsies four linked surveys conducted using similar survey methodologies and questionnaires with common questions.

Each survey covers the innovation activities of manufacturing plants over a three-year period and was undertaken by post using a sampling frame perovided by the economic development agencies in Ireland and Northern Irland. The initial survey, undertakend between October 1994 and Feburary 1995, related to plants's inovation acticity over the 1991-1993 period, and achieved a response rate of 38.2 per cent (Roper et al., 1996). The second survey was conducted between November 1996 and March 1997, covered plants' innovation activities during the 1994-1996 period, and had a response rate of 32.9 percent (Roper and Hewitt-Dundas, 1998). The third survey covering the 1997-1999 period, was undertaken between October 1999 and January 2000, with a repsonse rate of 32.8 per cent (Roper and Anderson, 2000). The fourth survey was undertaken betweeen November 2002 and May 2003 and achieved an overall response rate of 34.1 per cent (Roper et al., 2004). The analysis in this paper uses data from the second to fourth waves of the panel.

Table A1: Descriptive Statistics

Variable Description	Mean	Std. Dev.
Innovation choice (0: non-innovation; 1: product innovation; 2: process innovation; 3: both product and process innovation)	1.872	1.216
Knowledge Sourcing Activities		
R&D labour intensity	2.128	8.957
R&D being undertaken in the plant (0/1)	0.482	0.500
Relevant R&D being conducted in the group (0/1)	0.192	0.394
Forward knowledge linkages to clients or customers (0/1)	0.265	0.442
Backwards knowledge linkages to suppliers or consultants (0/1)	0.325	0.468
Horizontal knowledge linkages to competitors or joint ventures (0/1)	0.121	0.326
Public knowledge linkages to universities, industry operated labs or public labs (0/1)	0.193	0.395
Absorptive Capacity		
Formal R&D Department in plant (0/1)	0.213	0.409
Percentage of workforce with degree (%)	9.064	12.294
Resources		
Employment (number)	114.48	315.685
Plant vintage (years)	32.528	30.123
Type of production in plant - mainly one-offs (0/1)	0.192	0.394
Type of production in plant - mainly large batches (0/1)	0.294	0.456
Innovation Constraints		
Shortages of finance (score)	2.812	1.452
Risk of innovation (score)	2.626	1.310
Few market opportunities (score)	2.690	1.314
Lack of technological information (score)	2.215	1.159
Market Condition		
Northern Ireland Plant (0/1)	0.424	0.494

Source: Irish Innovation Panel.

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