Market *Versus* Corporate Structure in Plant-Level Innovation Performance

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ABSTRACT. This paper examines the effect which market and corporate structure have on the extent of innovation for a sample of circa 300 manufacturing plants located in Scotland. Innovation is defined as the introduction of a commercially significant new product at the establishment level. The theoretical model of Geroski (1990) is extended to incorporate plant-level variables such as size, multiplant operation, the presence of R&D facilities and external/indigenous ownership. A distinction is made between the direct and indirect effects of these variables. Negative binomial estimations indicate that corporate structure influences are more important in determining the number of innovations than market structure and barrier to entry variables. Plant size, foreign ownership and the presence of R&D are all positively associated with innovation. Direct effects greatly outweigh indirect effects. Tobit estimations on the number of innovations per employee support the findings of Acs and Audretsch (1988) that smaller enterprises are more innovation intensive than larger enterprises, at least up to a limit of around 1200 employees. The positive effect of R&D arises principally from increasing the probability of a plant becoming an innovator, rather than from making a plant more innovation intensive. By contrast, the importance of size lies principally in encouraging further innovations among plants which are already innovators, but less than proportionately with the increase in employment size.

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1. Introduction

There is now a substantial economics literature which examines the factors determining innovation, with particular emphasis being placed on the role of market power (e.g. Kamien and Schwartz, 1982; Levin et al., 1985), and on establishment size (Acs and Audretsch, 1988; Brouwer and Kleinknecht, 1996). A second strand of literature examines the link between corporate ownership structure and innovation, but with little attempt to model formally the relationship, or to see these factors in the context of more general economic determinants of innovation (e.g. Oakey et al., 1980; Goddard et al., 1986). This paper attempts to bring together these two elements, and to add to them in three distinct ways. First, instead of the industry analysis often employed in the industrial organisation literature, we employ establishment-level data within a clear theoretical framework. This allows a closer analysis of how elements of corporate structure affect innovation than is permitted by industry-level analysis. Secondly, instead of regarding innovation in simple dichotomous terms (i.e. whether or not firms innovate), this paper examines the determinants of the *extent* of innovation, thus allowing for the fact that while many firms do not innovate, some innovate a great deal. Finally, we explicitly distinguish between the direct and indirect effects of the explanatory variables on innovation; that is between the effect which is not mediated through post-innovation profits, but arises for any given level of post-innovation profitability (the direct effect) and that effect which occurs via the impact which the explanatory variables have on the size of post-innovation returns (the indirect effect). This distinction has rarely been made in the literature on innovation.[1]

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Using data from a representative survey of manufacturing plants in Scotland, we conclude that establishment size and corporate structure influences are more important in determining the extent of innovation than are market structure and monopoly power effects. There is also evidence that the direct effects of the explanatory variables greatly outweigh the indirect effects, and are frequently of the opposite sign to these effects.

2. A model of innovation

While various aspects of the link between size, corporate ownership structure and innovation have been investigated, until recently there has been little attempt to model formally the relationship, or to see these factors in the context of more general economic determinants of innovation. A suitable model for consideration is contained in Geroski (1990) which examines the effect of monopoly power, market structure and rivalry on innovation in the context of an "innovation production function". Although designed to test aspects of the Schumpeterian hypothesis of a positive relationship between market power and innovation, Geroski's empirical work (and that of the industrial organisation literature generally) is at the *industry* level, obscuring potentially important firm-level influences.

Two recent papers extend and adapt Geroski's theoretical model to consider establishment-level innovation in a regional context (Harris and Trainor, 1995; Love et al., 1996), but do so in the context of a dichotomous logit analysis of innovation. In the analysis below, such a model is employed to assess the determinants of the *extent* of innovation at the plant level. The model begins with the assumption that research activity will only take place when expected post-innovation returns are greater than zero, and so:

$$R_i = \phi\pi^e_i + \phi Y_i \tag{1}$$

where R_i is research expenditure relative to sales, π^e_i is the expected profit from innovating, and Y_i is a vector of other factors influencing research activity. This vector in turn has determinants as follows:

$$Y_i = \lambda_0 + \lambda_2 M_i + \lambda_3 S_j + \lambda_4 Z_i \tag{2}$$

where M_i is the degree of monopoly power of the establishment, S_j is a vector of market structure variables, and Z_i is a vector of corporate structure factors influencing the plant's R&D capacity and thus its potential for innovation. Substituting gives:

$$R_i = \tau_0 + \tau_1\pi^e_i + \tau_2 M_i + \tau_3 S_j + \tau_4 Z_i + e \tag{3}$$

Clearly research intensiveness is an imprecise proxy for innovation, and may be complemented in multi-plant enterprises by intra-firm technology transfer (T_i). It is therefore plausible to postulate a production function relating R&D and technology transfer to innovation of the form:

$$\text{INNOV}_i = \gamma R_i + \gamma T_i + \omega \tag{4}$$

where INNOV_i is the number of innovations by plant i. Substituting (3) into (4) yields:[2]

$$\text{INNOV}_i = \alpha_0 + \alpha_1\pi^e_i + \alpha_2 M_i + \alpha_3 S_j + \alpha_4 Z_i + \alpha_5 T_i + \mu \tag{5}$$

Geroski points out that monopoly power may have both a direct and an indirect effect on innovation: the former arises for any given level of post-innovation profitability, while the latter occurs via the effect which market power has on the size of post-innovation profits. In the formulation above these are α_2 and $\alpha_1(\partial\pi^e/\partial M)$ respectively. There are *a priori* reasons for believing that the direct and indirect effects of market power on innovation may run in opposite directions. While the indirect effect is likely to be positive (because of the ability of a plant with market power to build barriers to entry), the direct effect may well be negative. This would arise if, for example, the positive effect of economies of scale in research was more than offset by X-inefficiency and the natural desire of the establishment with market power to avoid introducing technologies or products which compete with those it already possessed. Clearly the direction and scale of the direct effect of monopoly power on innovation is an empirical issue.

This analysis of direct and indirect effects can be extended to wider issues of market structure, external control and corporate ownership. One advantage of the formulation of Equation (5) is that α_3, α_4 and α_5 provide estimates of the *direct* effects of these variables; that is, those effects which are not mediated through post-innovation profits but which affect the probability and/or scale and intensity of innovation at given level of profitability. Later we provide comparisons of the size and magnitude of these direct effects with their indirect counterparts.

3. Establishment structure, ownership and innovation

There are several specific firm and plant-level characteristics repeatedly identified in the literature as being important for innovation. These include establishment size, multiplant operation, the nature of the ownership and control of local establishments, and, relatedly, the presence or absence of key functions such as R&D. The direct and indirect effects of these variables are generally implicitly conflated in the regional economics literature. For example, Oakey et al. (1988) suggest several Schumpeterian reasons why large firms may be more innovative than small firms. Large firms will probably experience scale-sensitive advantages in R&D itself and will also benefit from non-technological, scale-intensive activities which support innovation, such as production, marketing and finance: such firms will also be better able to finance a range of innovative projects, allowing them to spread risk. These may be characterised as indirect effects of scale, which act to raise the post-innovation price-cost margins of larger firms. But Oakey et al. also note more direct advantages of scale, such as greater division of labour permitting the maintenance of specialised departments such as patenting and specialist libraries. The ability to maintain contacts with external organisations will also increase with size if pressure on management time in smaller firms leaves little room for this This is supported by Freeman (1982), who notes that one of the factors which discriminated between success and failure was the ability to maintain contact with specialised centres of excellence.

The effects of multiplant operation and external control are highly interlinked, and there is no attempt in the literature to distinguish between direct and indirect effects. For example, Thwaites (1978) suggests some grounds for belief in a positive association between external control and innovation, particularly in the context of "mobile plants", i.e. those which were encouraged to move to the peripheral areas (of the U.K.) because *in situ* growth was constrained by legislation prohibiting expansion in the South East. In the first instance, such plants will have been part of a growing firm and probably a growing industry, with the possibility that the propulsive force behind growth was innovation. Secondly, externally-owned plants are, in the majority of cases, part of larger commercial organisations, and they may therefore gain by access to the parent's resources. Such resources may be technological, for example, access to larger scale R&D facilities operated by the parent, or to proprietary knowledge developed by the parent (Oakey, 1979; Brugger and Stuckey, 1987). Branch plants may also benefit from contacts with external research establishments maintained by the parent, or they may be the direct recipients of innovations developed elsewhere in the group. Alternatively, access may be available to a wide range of non-scientific resources such as finance, a national or international marketing organisation through which new products can be diffused, patenting and other support functions. Finally, branch plants may be of a sufficient size to support innovation because of the market area served and, in particular, may be larger than indigenous counterparts.

However, external ownership is most commonly viewed as having a detrimental effect on innovation in the region, with the majority of reasons for this supposition concerning the type of facility which may exist in the region as part of a larger enterprise. The key factor here is hypothesised to be the presence of an R&D function. The importance of on-site technological activity is strongly suggested by the SBRC (1992) study of small firms, which found that 55.5% of companies cited their in-house technological expertise as a very important support for innovation, a proportion which rose to 60% in firms which had exhibited fast growth. In addition, 43.7% of firms performed systematic on-site R&D in support of new product development. The analyses by Malecki (1980) and by Howells (1984) suggest that the location of R&D is likely to be heavily influenced by corporate decisions. In addition, it is also argued that factors affecting R&D location will vary according to the type of research under consideration, with basic scientific research, for example, typically assumed to be the most scale-intensive activity and therefore more likely to be centralised than applied research and development work. Two studies, both using data on manufacturing firms in Northern Ireland, provide contradictory evidence on the effect of external ownership on the probability of innovation (Harris, 1991; Harris and Trainor, 1995): both studies also shed light on the link between the presence of R&D and innovation at the plant level. In the first of these, Harris concludes that, although there is no direct evidence that externally-owned establishments are less likely to innovate than indigenous plants, external control is nevertheless inimical to innovation because externally-owned plants are less likely to have an *in situ* R&D function. By contrast, the latter study concludes that externally owned plants are more likely to innovate, at least in part because they devote more resources to R&D. This is supported by Love et al. (1996), who find evidence that foreign-owned manufacturing plants (but not other U.K.-owned plants) in Scotland are more likely to innovate than their indigenous counterparts. One possible reason for this is suggested by Love and Roper (1999), who find evidence of intra-firm technology transfer acting as a substitute for establishment-level R&D, thus helping to enhance the innovativeness of branch plants.

Teasing out the possible direct and indirect effects of the various factors discussed above leads to the following schema (Table I). As discussed earlier, size is hypothesised to have positive direct and indirect effects. Most of the hypothesised advantages of multiplant operation relate to the ability of branch plants to tap into internal or quasi-internal information networks which may reveal an enhanced range of innovation opportunities at any given level of profitability, and the possibility of transfers of innovations within the intrafirm network. This suggests a positive direct effect of multiplant structure on innovation at the regional level, but with little suggestion of any indirect effect. The same conclusion can be reached with respect to the presence of R&D facilities, especially in the case of *allocated* research and development in externally-owned enterprises.[3] Given both the tendency for non-scale- dependent development work to be allocated to regional branch plants, and the general finding of the empirical work that on-site research activity directly stimulates innovation, a positive direct effect of R&D presence is a reasonable hypothesis. By contrast, the mere *presence* of such facilities (unlike economies of scale effects in research) is unlikely to promote any indirect effect on innovation.

This leaves the effect of external control. When examined closely, hypotheses of a negative influence of external control actually reduce to arguments on the absence of key functions such as R&D. Once the R&D effect is allowed for directly, it is difficult to determine the likely direction of any remaining external control influence. A positive effect may be expected from the potential for technology transfer to local branch plants from externally-controlled owners. Equally, however, an externally-owned plant active in R&D may find the results of its research allocated as "new products" among sister plants, therefore depressing its R&D-innovation relationship. Thus the direct effect of external control and technology transfer on any individual plant is ambiguous.

TABLE I
Hypothesised direct and indirect effects on innovation

	Direct	Indirect
Size	+	+
Multiplant operation	+	?
In-plant R&D	+	?
External control	?	?

Note: + indicates a positive hypothesised effect; ? indicates an uncertain effect.

4. Definitions and data

This section considers suitable measures for the dependent and independent variables in Equation (5), and describes the dataset used in the empirical analysis.

Measuring innovation

For the dependent variable $INNOV_i$ some measure is required of the number of innovations at the establishment level. Studies of innovation generally approach the issue either from the input side (number of R&D employees, R&D expenditure etc.), or from the output side, using data on, for example, the number of patents granted, process technologies implemented or new products generated. Davelaar (1991) notes that in practice the majority of empirical studies have used input measures due to the limited availability of output data. The obvious drawback of an input measure is that much R&D input produces no tangible innovation output (Mansfield, 1984), and tends to underestimate the innovative activity of small firms by concentrating on the work of formal R&D laboratories (Kleinknecht, 1987). Patent counts appear to offer a more accurate measure of actual innovation, but as Audretsch (1995) points out, ". . . patents are more a type of intermediate than innovative output measure. A patent reflects new technical knowledge, but it does not indicate whether this knowledge has a positive economic value." (p. 28). In addition, patent counts assume a linear view of the process of innovation in which the development of new products and processes is driven by the science and technology which underlies them (Ashcroft et al., 1995).

By contrast, the present research regards the innovation as a *business* activity which is stimulated by and affects a firm's competitive position; innovation may or may not be linked to significant technological advance. This is in line with the view of the U.K. government, which views innovation as:

> "the commercial application of knowledge or techniques in new ways or for new purposes . . ." so that
>
> "(i)t is not necessarily about thinking up new things in the first place but about exploiting opportunities profitably and ahead of competitors." (Department of Trade and Industry, 1992).

It is the notion of innovation as the initiation and management of commercially significant change that goes to the heart of the concept, and it is in this sense that innovation is crucial to national and regional economic development. "Blue skies" research followed by the introduction of unique products and processes may be a key ingredient in the success of several economies. However, successful economies will often rely on adaptation, improvement and rapid imitation to provide the bedrock of their success. Any study which ignored these aspects of innovation would paint a distorted picture of the dynamics of change in the chosen economy. This is supported by a comprehensive study of innovation in U.S. manufacturing, which found that 87% of commercially significant innovations are "modest improvements designed to update existing products" (Audretsch, 1995, p. 31). A similar view underlies R&D. Research and development is a heterogeneous activity, a significant proportion of which is likely to be geared towards adaptation and imitation, and this should be reflected in the measure of innovation.

The present study therefore chose to define innovation broadly. Establishments were asked to identify all new or improved products of commercial significance introduced in the five years preceding the study. Note also that the respondents were given the task of judging the commercial significance of their "innovations". This would appear wholly appropriate in view of the definition of innovation employed. Some innovation studies enlist outside experts to identify and/or assess the innovations. This procedure offers the possibility of an assessment in terms of technical or commercial originality. It is, however, of little help in gauging the commercial significance to the companies concerned and therefore to the development of the local and regional economies of which they are part. For that, information must be sought from the companies themselves.

Independent variables

The expected post-innovation price-cost margin, π^e_i, is by definition not directly observable. In the estimating equation below, this is proxied by actual industry price-cost margins for the period directly following that to which the dataset relates, derived from the U.K.'s Annual Census of Production (PA1002). This effectively assumes that establishments base the expected profit from innovating on the weighted average profitability of innovators and non-innovators in their industry, which is a less than perfect proxy indicator. However, the absence of plant-level profitability in the dataset, or of any ready measure of industry-level *innovator* profit data, renders inevitable the use of an imperfect proxy.[4]

We now turn to suitable proxies for the vectors M_i, S_j, Z_i and T_i. M_i is a measure of establishment i's share of its market. Since turnover data were not available from the survey described below, this is proxied by each plant's share of its (U.K.) industry employment and denoted by the variable

MSHR. Simple Schumpeterian analysis predicts that market power will have a positive effect on innovation, the usual argument being that the deadweight loss of monopoly is the price to be paid for the stimulation which market power gives to innovation. While empirical studies at the industry level frequently do find a positive relationship (e.g. Kamien and Schwartz, 1982), this is often between concentration and R&D activity rather than innovation *per se*. However, as the earlier discussion of the likely effects of monopoly power indicates, it is impossible to predict the direct effect of the market power variable *a priori*.

S_j contains two elements, both of which serve as proxies for different barriers to entry and barriers to innovation in the firm's industry. The first is CR5, the five-firm concentration ratio for each 2-digit SIC, obtained from the Annual Census of Production. Because firms with market power have the ability to build barriers to entry, it follows that the innovative behaviour of individual firms should also be affected by the degree of concentration in the sector of which it is part. Note that the CR5 measure takes account of concentration at the level of the U.K. market only, and does not take account of the impact of international competition or of the importance of international markets.

An obvious barrier to entry is economies of scale, as indicated by minimum efficient scale, the smallest level of production (and hence of plant) at which least-cost production techniques are feasible: to the extent that minimum efficient scale proxies sunk costs, this is also an indicator of barriers to exit. This second element of S_j is proxied by the variable MES, a version of the Comanor-Wilson measure of minimum efficient scale, defined as the average size of the largest plants accounting for half the output in each two-digit SIC expressed as a percentage of industry output (Davies and Lyons, 1991). This was again obtained from the Annual Census of Production.

As indicated above, Geroski's view is that barriers to entry have a positive indirect effect on innovation because of the protection which they afford to firms already in the industry, allowing higher post-innovation rewards than would otherwise be the case and helping to permit the preemption of rivals. But the direct effects are more ambiguous. The very fact that barriers can inhibit entry by innovative firms may also provide a shield behind which incumbent companies have no direct desire to be as innovative as would otherwise be the case, especially if the presence of X-inefficiency dulls the profit-maximising motive. On the other hand, the same entry barriers may provide the security which firms require to carry out precisely the form of speculative R&D from which innovations may flow. As with MSHR, the likely direct effect of CR5 and MES cannot be unambiguously assigned *a priori*.

The various corporate structure and ownership factors discussed earlier are as follows. Z_i are proxied by PLANTEMP, the number of people employed in the plant, and by RANDD, a dummy variable taking the value 1 if the plant carries out some R&D function and 0 otherwise. The technology transfer influences (T_i) are proxied by MULTI, a dummy variable taking the value 1 for a firm with multiplant operations and 0 otherwise, and EXTERNAL, a dummy variable taking the value 1 if the plant is externally controlled and 0 otherwise.

The equation to be estimated is therefore as follows:

$$\begin{aligned} \mathrm{INNOV}_i = {} & \beta_0 + \beta_1\pi^e_i + \beta_2\mathrm{EXTERNAL}_i \\ & + \beta_3\mathrm{RANDD}_i + \beta_4\mathrm{PLANTEMP}_i \\ & + \beta_5\mathrm{MULTI}_i + \beta_6\mathrm{MSHR}_i \\ & + \beta_7\mathrm{CR5}_j + \beta_8\mathrm{MESj} + \theta \end{aligned} \tag{6}$$

where subscript j refers to the industry to which firm i belongs. The anticipated sign pattern is β_1, β_3, β_4, $\beta_5 > 0$. The signs on the other coefficients cannot be assigned *ex ante*: as the previous section indicated, there is ambiguous theoretical and empirical guidance on the likely signs of the market power/barriers to entry coefficients β_6, β_7 and β_8, and on the external control coefficient β_2.

Dataset

The principal data source for the selection of manufacturing establishments was the Scottish Chambers Business Survey (SCBS) database. This is maintained by the Fraser of Allander Institute at the University of Strathclyde, and uses establishment data supplied from the membership lists of the Scottish Chambers of Commerce which take part in the quarterly SCBS. The database contains relevant information on over 4,000 establishments in Scotland, of which almost half are in manufacturing. The Chambers of Commerce membership is known to be biased towards smaller, indigenously-controlled enterprises. Since the research was particularly interested in the effect of size and of external ownership on the innovation process, the sample was supplemented by the inclusion of the fifty largest manufacturing establishment in Scotland which were not already included in the SCBS, and a sample of overseas-owned manufacturing plants operating in Scotland. The final sample size was 1,200.

The postal questionnaire was administered during March and April 1992. A total of 417 usable responses were received; of these, 304 respondents answered all questions, representing a response rate of 25%. The dataset is representative of Scottish manufacturing as discussed in Love et al. (1996), and descriptive statistics are contained in Table IIa. Of the 304 respondents, 185 (60.9%) had produced at least one product innovation, and they produced a total of 721 innovations (Table IIb). The proportion of innovating plants is in line with recent research on other European countries such as the U.K., Germany, Ireland and Belgium (Roper et al., 1996; Veugelers and Cassiman, 1999). The average number of innovations per respondent was 2.37, and of innovations per innovator 3.90.

TABLE IIA
Descriptive statistics

	Mean	s.d.
INNOV	2.372	4.815
INNEMP	0.048	0.105
π	0.210	0.054
EXTERNAL	0.382	0.487
UK	0.168	0.374
FOREIGN	0.214	0.411
RANDD	0.572	0.496
PLANTEMP	180.25	348.03
MULTI	0.549	0.498
CR5	15.937	10.006
MES	0.828	2.188
MSHR	9.020	81.937

TABLE IIB
Innovations by observation

Number of innovations	Number of observations
0	119
1	38
2	47
3	43
4	17
5	13
6	11
7	2
8	1
9	2
10	5
12	1
19	1
20	2
50	2
Total observations	304
Total innovations	721

5. Econometric analysis

As indicated in Table IIB, INNOV_i is a limited dependent count variable with numerous zero observations. The classical regression model is unsuitable for such a variable, and so linear exponential models are employed (Hausman et al., 1984; Cameron and Trivedi, 1986). The simplest formulation is the Poisson model; for any discrete random variable Y with observed frequencies $y_i \geq 0$, the conditional probability density function is:

$$\text{prob}(Y = y_i) = \frac{e^{-\lambda_i}\lambda_i^{y_i}}{y_i!}$$

where λ_i is both the mean and variance of y_i. In practice, the restriction that $\text{var}[y_i] = E[y_i]$ is rarely valid in count data, leading to a problem of overdispersion. Under these circumstances, a more suitable model is the negative binomial, an extension of the Poisson model which does not depend on the mean-variance equality restriction. The negative binomial model has an additional parameter α, so that $\text{var}[y_i] = E[y_i]\ \{1 + \alpha E[y_i]\}$.

Cameron and Trivedi (1990) propose a simple regression-based test for the existence of overdispersion, which is based on testing the null hypothesis of mean-variance equality (i.e. $\text{var}[y_i] = E[y_i]$) against the alternative hypothesis $\text{var}[y_i] = E[y_i] + \alpha E[y_i]$. In the estimations which follow, the Cameron-Trivedi test in both its linear and quadratic forms consistently suggested rejection of the null hypothesis of mean-variance equality, and so the negative binomial model is used.

Results are given in Table III. Because the negative binomial model is non-linear, the estimated coefficients are not equal to the marginal effects of the independent variables. These are calculated as $(\partial Ey/\partial x_i) = \lambda_i\beta$, and are shown separately. As indicated earlier, theory gives ambiguous predictions on the sign on the coefficients of MSHR, CR5 and MES. Recent empirical evidence (Blundell et al., 1995; Baptista and Swann, 1995), suggests that while firm-level market power has a positive influence on innovation, market concentration may have the reverse effect, leading to the conclusion that competition authorities ought to look sceptically on the argument that market power is necessary for dynamic efficiency. The results of the present estimation do not support this view: the coefficients on MSHR and CR5 are highly insignificant. However, the coefficient on MES is positive and significant, suggesting that the ability of high minimum efficient scale to stimulate innovation outweighs any depressing X-inefficiency effect.

TABLE III
Negative binomial regression: INNOV

	Estimate	Marginal effect
π	3.1527	5.8721
	(2.2796)	(4.1963)
EXTERNAL	0.3681	0.6857
	(0.2470)	(0.4614)
RANDD	0.9610***	1.7899***
	(0.1628)	(0.3499)
PLANTEMP	0.5926E-03**	0.1104E-02**
	(0.2514E-03)	(0.4674E-03)
MULTI	0.2262	0.4214
	(0.2351)	(0.4401)
CR5	0.1454E-01	0.2709E-01
	(0.1309E-01)	(0.2429E-01)
MES	0.9488**	0.1767**
	(0.3907)	(0.0723)
MSHR	−0.6437E-03	−0.1199E-02
	(0.5980E-02)	(0.1111E-02)
Constant	−1.2651**	−2.3563**
	(0.6468)	(1.1718)
α	1.1316	
	(0.1547)	

Log-likelihood = −573.21.
Number of observations = 304.
α is an estimate of the overdispersion parameter discussed in the text.
Standard errors in brackets. Significant at ** 5%, *** 1% on a two-tailed test.

Several of the corporate structure and ownership variables have a highly significant effect on innovation. PLANTEMP is significant at the 5% level, supporting the Schumpeterian view that size can, through the ability of larger organisations to manage research programmes more effectively, have a positive effect on innovation. However, once the size effect is allowed for, there is no evidence that multiplant structure increases the extent of innovation: although the coefficient on MULTI is positive it is insignificantly different from zero. The presence of R&D facilities has a very strong effect in the hypothesised direction.[5]

The external ownership variable has an insignificant coefficient, appearing to suggest that external control has no direct effect *per se* on innovation. This may, however, be a premature conclusion. The dataset permits us to split the external control dummy variable into two dummies, thus separately identifying (non-Scottish) British-owned plants (labelled UK), and foreign-controlled plants (labelled FOREIGN). When this is done (Table IV) the coefficient on UK is positive but insignificant, indicating that Scottish plants owned by firms from other parts of the UK are no more or less innovative than indigenous Scottish firms. However, the coefficient on FOREIGN is significant and positive, indicating that foreign-owned subsidiaries produce more innovations than their Scottish counterparts, even after allowing for the effects of size and the presence of R&D facilities.

It is unclear from the results of Table IV whether the effect of the significant variables comes principally from increasing the *probability* of being an innovator, or from increasing the *number* of innovations among innovators. Some indication of this can be found by carrying out a truncated negative binomial regression only on the innovating respondents.[6] The results (not shown) indicate that only PLANTEMP has a statistically significant coefficient, of very similar magnitude to that displayed in Table IV; the significance of RANDD and FOREIGN disappears. This suggests that the importance of the latter two variables lies in increasing the probability of becoming an innovator, but that foreign ownership and the presence of R&D activities do little to increase the

TABLE IV
Negative binomial regression: INNOV (extended model)

	Estimate	Marginal effect
π	3.1567 (2.2819)	5.8502 (4.1792)
UK	0.1902 (0.2759)	0.3526 (0.5104)
FOREIGN	0.4983* (0.2737)	0.9235* (0.5112)
RANDD	0.9782*** (0.1641)	1.8129*** (0.3499)
PLANTEMP	0.6198E-03** (0.2586E-03)	0.1149E-02** (0.4803E-03)
MULTI	0.2264 (0.2363)	0.4196 (0.4398)
CR5	0.1635E-01 (0.1322E-01)	0.3031E-01 (0.2437E-01)
MES	0.8056E-01* (0.4348E-01)	0.1493* (0.8028E-01)
MSHR	−0.7211E-03 (0.5525E-02)	−0.13364E-02 (0.98391E-02)
Constant	−1.3001** (0.6456)	−2.4094** (1.1617)
α	1.1237 (0.1548)	

Log-likelihood = −572.40.
Number of observations = 304.
α is an estimate of the overdispersion parameter discussed in the text.
Standard errors in brackets. Significant at * 10%; ** 5%; *** 1% on a two-tailed test.

number of innovations once innovation has occurred. By contrast, the stability of the coefficient on PLANTEMP between the two estimations suggests that the importance of size lies principally in increasing the number of innovations among plants which are already innovators:[7] indeed, in this estimation, the only discernible difference between plants which produce many innovations and those which produce only one or a few is employment size.

Yet to conclude that large innovating plants produce more innovations than small innovating plants seems rather trivial. Are large plants actually more *innovation-intensive* than other plants? The evidence reviewed earlier suggests that the reverse may be the case, where innovation intensity is measured as the number of innovations per employee. At first sight the present dataset gives only limited support for this view: the correlation coefficient between innovations per employee (INNEMP) and PLANTEMP is −0.17. A more detailed examination requires that further multivariate analysis is carried out, and so Equation (6) was re-estimated with INNEMP_i as the dependent variable. INNEMP is continuous but censored at zero, and so the appropriate estimation technique here is tobit (Amemiya, 1973). Previous work in industrial organization strongly suggests that there is a distinct tendency for smaller firms to be more innovation intensive than their larger counterparts. For example, Acs and Audretsch (1988) and Audretsch (1995) show that this is the case for firms below 500 employees, suggesting further exploration is warranted at the plant level. But rather than attributing the possible effect to some arbitrary cut-off point between "large" and "small" plants, Equation (6) was estimated with employment expressed in quadratic form. The results show clear evidence of a U-shaped relationship between employment size and INNEMP, with a turning point occurring at 1245 employees (Table V). The positive and significant coefficient on R&D remains, and while the coefficient on FOREIGN is positive, it is statistically insignificant.

As with the negative binomial model, tobit coefficients are not marginal effects. To obtain estimates of the marginal effects for all observations (i.e. innovators and non-innovators) the estimated coefficients are multiplied by $F(z)$, the cumulative normal distribution function for $z = X\beta/\sigma$, where X is the vector of means of the explanatory variables and β is the vector of estimated coefficients. Marginal effects are shown separately, with a calculated value for $F(z)$ of 0.496. Conveniently, McDonald and Moffitt (1980) show that the marginal effects can be decomposed into two parts: that which is due to the response above the (zero) limit on the dependent variable, and that which is the change in probability of being above the limit, i.e.

$$\frac{\partial Ey}{\partial x_i} = \text{Prob}[y > 0] \cdot \frac{\partial Ey_{y>0}}{\partial x} + \frac{Ey_{y>0} \cdot \partial \text{Prob}[y > 0]}{\partial x}$$

Intuitively, these two elements are the change in the conditional mean arising from changed inno-

TABLE V
Tobit regression: INNEMP

	Estimate	Marginal effect
π	0.3619	0.1794
	(0.2525)	(0.1251)
UK	–0.1548E-01	–0.7672E-02
	(0.3002E-01)	(0.1487E-01)
FOREIGN	0.2960E-01	0.1467E-01
	(0.2892E-01)	(0.1433E-01)
RANDD	0.1097***	0.5437E-01***
	(0.1952E-01)	(0.9674E-02)
PLANTEMP	–0.1858E-03***	–0.9208E-04***
	(0.6999E-04)	(0.3468E-04)
PLANTEMP2	0.7461E-07**	0.3698E-07**
	(0.3260E-07)	(0.1616E-07)
MULTI	–0.1249E-01	–0.6190E-02
	(0.2357E-01)	(0.1168E-01)
CR5	0.1523E-02	0.7548E-03
	(0.1270E-02)	(0.6290E-03)
MES	0.5785E-02	0.2867E-02
	(0.5188E-02)	(0.2571E-02)
MSHR	0.1168E-04	0.5789E-05
	(0.1369E-03)	(0.6785E-04)
Constant	–0.1442**	–0.7015E-01**
	(0.6706E-01)	(0.3323E-01)

Log likelihood function = 28.77.
Number of observations = 304.
Standard errors in brackets. Significant at **5%, ***1% on a two-tailed t-test.

vation intensity among innovators, and the change in conditional mean arising from the change in probability of being an innovator. The first element is calculated as

$$A = 1 - \frac{zf(z)}{F(z)} - \frac{f(z)^2}{F(z)^2}$$

where $f(z)$ is the unit normal density. The value of A is 0.361, indicating that 36.1% of the overall marginal effect is due to the change in innovations per employee for those firms which are already innovators, while 63.9% of the marginal effect arises from the changed probability of non-innovators becoming innovators.

The discussion so far has centred entirely on the direct effects of factors influencing plant-level innovation. The final phase of the empirical analysis is to determine whether the indirect effects could be sufficiently large to offset or reinforce the direct effects. In terms of Equation (5), the indirect effects are given by $\alpha_1(\partial\pi^e/\partial M)$, $\alpha_1(\partial\pi^e/\partial S)$, $\alpha_1(\partial\pi^e/\partial Z)$ and $\alpha_1(\partial\pi^e/\partial T)$ respectively. To save space, these are considered for the number of innovations (INNOV_i) only. Consideration of these effects first requires the estimation of a rational expectations model of the effects of innovation on profitability, of the form:

$$\pi_i = \Psi_0 + \Psi_1\text{INNOV}_i + \Psi_2 X_i + \varepsilon \tag{7}$$

where $\varepsilon \equiv \pi_i - \pi^e_i$, and X_i is a vector of monopoly power, market structure and corporate structure variables. This clearly involves consideration of the potential simultaneity alluded to earlier between innovation and profitability. Equation (7) was estimated using 2SLS, with the vector X_i given by FOREIGN, RANDD, PLANTEMP, MSHR, CR5 and MES, and all exogenous variables in the system used as instruments for INNOV. When multiplied by 3.157 (the coefficient on π^e obtained from Table IV), the resulting coefficients provide estimates of indirect effects.

The level of aggregation of the profitability data prevents the coefficients obtained from Equation (7) being regarded with great confidence as true indicators of the effect of innovation on profitability,[8] but our concern is merely with their approximate magnitudes relative to the estimated direct effects. These are shown in Table VI for those variables with statistically significant coefficients from Equation (6), where the direct effects are the coefficients estimated in Table IV. In all cases the direct effects massively outweigh the indirect effects.[9]

6. Summary and conclusions

The literature reviewed earlier suggested that external control, plant size, and the presence of

TABLE VI
Estimates of direct and indirect effects

	Direct effect	Indirect effect
FOREIGN	0.4983	–0.0363
RANDD	0.9782	–0.0767
PLANTEMP	0.6198E-03	–0.4704E-04
MES	0.0806	–0.0159

Direct effects are significant coefficients from Table IV. Indirect effects are estimates derived from Equation (7) as discussed in the text.

R&D activity were likely to have some influence on the extent of innovation within manufacturing plants in a regional economy. However, there have been few previous attempts to differentiate between the direct and indirect effects of these variables. The present research avoids this problem by providing estimates for the direct effects of industrial and corporate structure variables, that is those effects not mediated through changes in price-cost margins, and of the relative magnitudes of indirect effects.

The results of the empirical analysis indicate that, when set within a formal model of the determinants of innovation, these factors are indeed of some importance. Large plants have more innovations, but fewer innovations per employee, at least until some limit. The importance of size lies principally in encouraging further innovations among plants which are already innovators. However, this may not be a simple linear relationship. The results of size on both number of innovations and innovations per employee suggest that larger size does encourage more innovations, but less than proportionately with the increase in employment up to a limit of c.1200 employees; thereafter, the increase in innovations induced by increasing size is more than proportionate. Because plants with more than 1000 employees represent a tiny fraction (0.5%) of manufacturing plants in Scotland,[10] for most practical purposes smaller plants are indeed more "innovation intensive" than their larger counterparts. By contrast, the presence of R&D and, to some extent, foreign ownership helps firms to become innovators, but does little to increase the number of innovations among innovating plants. R&D, but not foreign ownership, also helps to increase innovations per employee.

In contrast to the importance of corporate structure effects, there is little evidence of a systematic effect resulting from market structure effects. Although this may stem in part from the relatively high (two-digit) level of industrial aggregation used in the empirical analysis,[11] there are clear parallels with the findings of Love and Roper (1999) on a different data set which uses a more detailed level of industrial disaggregation. An interpretation appears to be that while market forces influence innovation at the *market* level, they have little direct effect on the innovation decisions being made at the level of the individual plant.

Finally, the results suggest that, although the profits proxy is imperfect, direct effects are the dominant element of the overall effects of corporate structure influences on innovation.

One implication of these findings is that – contrary to the hypotheses developed in much of the literature – external control is not necessarily inimical to innovation within the manufacturing sector of the regional Scottish economy. Indeed, there is a slight positive effect of foreign ownership, although not of intra-U.K. ownership. However, this is critically linked to the R&D issue, where it is clear that *plant*-level facilities are of great importance in making a plant an innovator, but play a much less important role in enhancing *innovativeness* once the intitial threshold has been overcome. Since externally owned branch plants are less likely to have in-house R&D facilities than their indigenous counterparts,[12] this conclusion supports the suggestion of Ashcroft et al. (1995) that policy initiatives to encourage inward investing multinationals to set up research facilities in Scotland would be worthwhile.

Such an initiative would, however, do nothing to encourage innovation among indigenous concerns, which must be the principal concern of government. Given the relative innovation-intensiveness of smaller plants, it would appear that the U.K.'s policy stance of providing innovation support mainly for SMEs is sensible. However, recent research by the present authors and colleagues (Roper et al., 1996) suggests that U.K. firms are less likely to innovate than their German counterparts, and Scottish-based firms particularly unlikely to do so. The key, therefore, would appear to be finding some method of helping smaller indigenous concerns overcome the hurdle of the initial innovation.

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Notes

[1] The exceptions to this are discussed in the next section.

[2] The issue of endogeneity between INNOV and π is considered later.

[3] The presence or otherwise of specific R&D facilities is an issue of corporate organization, independent in principle from the *extent* of R&D carried out by the plant. We acknowledge that there will, in practice, be at least some link between the two (see also note 5).

[4] Geroski (1990) tests both actual industry profit data and estimates of post-innovation profitability generated by a rational expectations model, and finds that his overall results are virtually identical in both cases.

[5] Because of the possibility of endogeneity between RANND and R_i in Equation (3), some upward bias may be imparted in the parameter estimate for this variable.

[6] The truncation procedure does not merely remove non-innovators from the initial estimation. Rather, it applies the model to a distribution of ys which apply only to values above zero.

[7] This conclusion is strengthened by the results of a binomial logit regression similar to Equation (6) but with a dummy dependent variable taking the value 1 if the plant was an innovator and zero otherwise. This estimation resulted in positive and significant coefficients for FOREIGN and RANDD, but a coefficient on PLANTEMP which was positive but insignificant at the 5% level.

[8] For this reason we do not show estimates of Equation (6) using proxies of π^e generated from Equation (7).

[9] Paralleling this result, Geroski (1990) finds that in all cases the direct effects of monopoly power and rivalry on innovation are much larger than the indirect effects.

[10] Figure derived from Business Monitor PA1003, 1990. The dataset is slightly biased towards larger establishments (3.3% of the 304 observations), but this is unlikely to undermine the general conclusion on the relative innovation intensiveness of large and small plants.

[11] The two-digit level of aggregation was determined by the way in which the survey sample was collated. As a check on "technological opportunity" effects, negative binomial estimations of INNOV_i were undertaken which included the corporate structure and ownership variables and a series of two-digit sectoral dummies. In all cases the dummy variables had highly insignificant marginal effects.

[12] Data from the postal questionnaire indicated that 39% of overseas-owned plants undertook some form of in-plant R&D compared with 50% of Scottish-owned plants.

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