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Dynamic Complementarities in Innovation Strategies: paradigm shift or business as usual?

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Abstract

We investigate claims of a ?paradigm shift? towards firms using open innovation as a conscious strategic choice. Such a claim implicitly involves two elements: first, there should be some evidence that firms are increasingly likely to use a combination of internal and external knowledge in their innovation activity, and second, there should be some evidence that firms derive a systematic advantage from so doing. Using a panel of Irish manufacturing plants over the period 1991-2008 we develop four archetypal innovation strategies. We find little evidence, either from considering successive cross-sectional waves of comparable surveys, or in terms of the strategy switch choices of specific plants, that there has been a systematic move towards the use of an ?open? innovation strategy. We then test for the presence of complementarities in the joint use of internal R&D and external innovation linkages. In static terms we find no evidence of complementarity, but in dynamic terms found evidence that strategy switches by individual plants towards an open innovation strategy is accompanied by increased innovation outputs.

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Abstract
We investigate claims of a ‘paradigm shift’ towards firms using open innovation as a conscious strategic choice. Such a claim implicitly involves two elements: first, there should be some evidence that firms are increasingly likely to use a combination of internal and external knowledge in their innovation activity, and second, there should be some evidence that firms derive a systematic advantage from so doing. Using a panel of Irish manufacturing plants over the period 1991-2008 we develop four archetypal innovation strategies. We find little evidence, either from considering successive cross-sectional waves of comparable surveys, or in terms of the strategy switch choices of specific plants, that there has been a systematic move towards the use of an ‘open’ innovation strategy. We then test for the presence of complementarities in the joint use of internal R&D and external innovation linkages. In static terms we find no evidence of complementarity, but in dynamic terms found evidence that strategy switches by individual plants towards an open innovation strategy is accompanied by increased innovation outputs.

Keywords: Innovation strategies; dynamic complementarities; open innovation; Ireland

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1. Introduction

The choice between internal and external knowledge sources in innovation has been of academic interest for decades. Since the early work of the SAPPHO project (Rothwell et al. 1974) through research on networks of innovators and the sources of innovation (Freeman 1991; von Hippel 1998), it has been recognised that innovation cannot be regarded purely as an internal matter: firms' external linkages or networks may also play a potentially important role.

There is now a considerable body of literature which supports the idea that openness to external knowledge sources, whether through search activity or linkages to external partners in new product development, helps to boost innovation performance, but that there are limits to the beneficial effects of external links (Ahuja 2000; Love and Roper 2001; Katila and Ahuja 2002; Laursen and Salter 2006; Leiponen and Helfat 2010). This has been overlaid with the suggestion that firms are systematically switching from a model of closed innovation to more open innovation strategies (Chesbrough, 2003ab; 2006), and that a 'paradigm shift' has occurred in the way firms consider innovation. However, as pointed out by Barge-Gil (2011), much of the work looking at identifiable open innovation strategies deals with the determinants of such strategies, not their effects (e.g. Van de Vrande et al 2009; Barge-Gil 2010).

This paper examines two aspects of the open innovation debate. First, is there any evidence of a systematic shift of firms towards more open innovation? Specifically, is there a tendency for firms to shift more towards identifiable open innovation strategies through time? And second, where individual firms do move towards a more open innovation strategy, is this accompanied by increased innovative activity? In order to consider these issues it is necessary to use panel data, preferably involving a lengthy time period. By contrast, the majority of work on open innovation uses cross-sectional data, which cannot identify how innovation strategies change through time, nor what the effects of these changes are on firm performance.[1]

[1] An exception to this is Poot et al (2009), who examine changes in open innovation in the Netherlands over the period 1994-2004 but do not formally assess the effect of this change on firm innovativeness.

In assessing the value of adding external knowledge sources to existing internal knowledge we make use of the concept of dynamic complementarities. Two activities are (Edgeworth) complementary if doing more of one activity increases the returns from doing the other. This implies that the benefit of adding a new activity depends not simply on what the firm currently does, but on what it did in the past: it concerns adding something to an existing strategy. This can therefore only be determined by considering the effects of a specific change in strategy *by a given firm* relative to the option of sticking with the existing strategy. This is an intrinsically dynamic analysis, and so needs information on strategy choice decisions through time. In order to examine these questions in a dynamic context we use a unique dataset which comprises an unbalanced panel of Irish manufacturing plants which covers six successive three-year periods spanning the years 1991 to 2008. By analysing the strategy choices and innovation performance of these plants through time we are able to shed light on the two key issues identified above.

We therefore make two contributions to the literature. First, we are able to examine, over an extended period of time, whether there is any evidence of an increasing tendency for firms in Ireland to use an open innovation strategy. We do this both on average by comparing representative cross-sectional samples of establishments at different points in time, and secondly by examining how manufacturing plants change their innovation strategies through time, therefore exploring changes in open innovation practice. No other dataset we are aware of is able to examine these changes over such a long time period using comparable data. Second, we are able to investigate the effects of *actual* strategy choices using the concept of dynamic complementarities, a significant advance over the static complementarity analysis usually employed in innovation studies (Cassiman and Veugelers 2006; Schmiedeberg 2008; Love and Roper 2009) which implies the complementarity between internal and external knowledge sources from changes in strategies which are not observed in practice.

In the remainder of the paper we develop ideal type innovation strategies which are suitable for testing both the ‘paradigm shift’ hypothesis and for analysis of complementarity. We find little evidence of a systematic shift towards an open innovation strategy in Irish manufacturing. Further, our analysis of static complementarities suggests that there is no evidence of (strict) complementarity between internal R&D and external innovation linkages. However, when dynamic complementarities are considered, there is systematic evidence that switching to an open innovation strategy is accompanied by increased innovation outputs. We end by considering the implications of these findings for the open innovation debate.

2. A typology of innovation strategies

Although open innovation advocates the use of both internal and external sources of knowledge as inputs to innovation, the issue of whether internal R&D and external knowledge sources are complements or substitutes is essentially an empirical one. There are arguments for and against expecting a complementary relationship between internal and external knowledge resources in innovation. The use of external sources, for example, may have advantages for firms in overcoming the limitations of in-house R&D budgets, or in gaining access to the economies of scale and scope available to specialist research organizations. External links may also be a useful method of searching the technological environment in a systematic fashion, permitting access to improved technology developed elsewhere (Mowery, 1990; Niosi, 1999). Using external knowledge, however, also has potential disadvantages. Difficulties assigning intellectual property rights may make external sources unattractive, as may the lack of appropriate expertise of potential contractors compared to those within a firm's own R&D department. Conversely, under conditions of asymmetric information which will often prevail in the context of research and innovation, a combination of uncertainty and principal-agent type arguments may make external R&D seem more attractive, but can lead to problems of monitoring as the agent is able to exaggerate the costs and commercial potential of their innovations (Audretsch et al, 1996; Ulset, 1996).

Increasingly, therefore, the theoretical and empirical literature is emphasizing the possibility that the relationship between internal and external knowledge sourcing for innovation is not 'either/or', but one which may involve significant complementarities between these two sources. For example, the absorptive capacity role of internal R&D is now widely recognized (Cohen and Levinthal 1989; Zahra and George, 2002; Roper et al., 2008) suggesting that some internal capacity is needed not only to permit scanning for the best available external knowledge, but to enable the efficient absorption and use of this knowledge, and to help in the appropriation of the returns from new innovations. However, perhaps reflecting the ambiguity in the theoretical literature, the empirical evidence is mixed, with some authors finding a complementary relationship between internal R&D and external knowledge sources, while other find a predominantly substitute relationship (Arora and Gambardella, 1990, 1994; Veugelers and Cassiman, 1999; Love and Roper, 1999, 2001, 2002; Cassiman and Veugelers, 2006).

The essence of (inward) open innovation is a combination of internal R&D and external knowledge sources or collaborations in the production of new products and processes (Chesbrough 2003b). Reduced to its simplest formulation, we can identify four possible innovation strategies which employ different combinations of internal R&D and external knowledge linkages:

1. No R&D or external linkages (NEITHER)
2. No R&D but with external linkages (EXTERNAL)
3. R&D but no external linkages (CLOSED)
4. Both R&D and external linkages (OPEN)

By design these four categories are mutually-exclusive strategies which do not allow for nuances of the extent of R&D or the nature of external interaction with innovation partners. This is appropriate, as our objective is to examine the potential dynamic complementarities between internal and external knowledge sources which are encapsulated by these four 'ideal types'. Therefore the purpose of the four strategic choices is to reduce the choice between internal and external inputs to its most elemental configuration.

Nevertheless, each of the categories is a legitimate innovation strategy in reality. Although firms in the NEITHER category appear to have no conventional inputs into innovation, they may still be able to introduce new products either from knowledge resources built up previously, or by making new or improved products which require relatively little technological or other knowledge inputs. EXTERNAL companies are relatively common among SMEs (Kleinknecht 1987), and rely on internal knowledge generation which is not supported by any formal in-house R&D and on ideas and knowledge generated from contact with customers, suppliers and other external agencies. CLOSED firms engage in 'closed' innovation, in which internal R&D is the only source of innovation inputs. OPEN firms engage in 'open' innovation, where both internal R&D and external sources are used.

If the open innovation 'paradigm shift' argument has any empirical validity, two dimensions have to be established. First, there should be a systematic trend through time towards firms adopting an OPEN strategy. Second, we should be able to detect some benefit to firms resulting from any systematic move towards open innovation. The trend towards an open strategy can be examined in two mutually-exclusive but complementary ways. First, for a given country, region or sector, is there any evidence that, collectively, firms are more likely to adopt an open innovation strategy than in the past? Second, is here any evidence that a given sample of firms shows a tendency to *shift* towards the use of an open innovation strategy through time? The first question can be examined by comparing representative cross-sectional samples of firms at different points in time, and we do this for Irish manufacturing. Answering the second question requires longitudinal firm-level data, ideally a cohort study. We make use of the panel element of the Irish plant-level data described below to explore this dimension of changes in open innovation practice.

To identify any benefits from moving towards open innovation there should be evidence of dynamic complementarities in the use of internal R&D and external linkages. This involves more than testing whether OPEN firms are more innovative than those in the other categories: rather we have to demonstrate formally that firms which move towards OPEN from either CLOSED or EXTERNAL (i.e. which add R&D to existing external linkages or vice versa) experience larger effects on innovation performance than those which add either R&D or external linkages to having NEITHER, after allowing for other determinants of innovation. This is formally tested in the empirical analysis below. In the next section we describe the dataset used to perform this analysis.

3. Data and Descriptives

Our empirical analysis is based on data from the Irish Innovation Panel (IIP) covering the period 1991 to 2008. The IIP provides information on the innovation activities of manufacturing plants in Ireland and Northern Ireland and comprises six plant-level surveys[2]. These were conducted every three years using similar survey questionnaires with common questions, and capture the same indicators of open innovation during this period. The initial IIP survey used here covered the period 1991-93, and had a response rate of 32% (Roper et al 1996). The second survey covered plants' innovation indicators for the 1994-96 period, and had a response rate of 32.9 per cent (Roper and Hewitt-Dundas, 1998). The next IIP survey covered the 1997-99 period and reached a response rate of 32.8 per cent. The survey covering the 2000 to 2002 period achieved an overall response rate of 34.1 per cent. Subsequent surveys covering the 2003 to 2005 and 2006 to 2008 periods achieved response rates of 28.7 per cent and 38 per cent respectively. The resulting panel is unbalanced, due both to entry and exit of plants and varying survey samples.

In terms of external linkages, our focus here is on responses to a question asked in each of the different waves of the IIP: *Over the last three years did you have links with other companies or organisations as part of your product or process development?* Plants responding in the affirmative were then allocated to either the EXTERNAL or OPEN categories, depending on whether or not they also reported having in-house R&D. This measure of external involvement makes no allowance for the extent (i.e. breadth) of external involvement in innovation. However, this may be less of an issue than might be thought. Plants that confirmed having linkages were subsequently asked to indicate which types of external partners they had during the 3-year period covered by the survey. Eight partner types of external linkages were outlined in the survey questionnaire: linkages to customers, suppliers, competitors, joint ventures, consultants, universities, industry operated laboratories, and government operated laboratories. On average the average breadth of innovation linkages over the period is just 1.1 types of innovation partner, suggesting that the dichotomous variable catches the essence of the EXTERNAL strategy.

Descriptive data for observations in each category are shown in Table 1. Overall, plants with no R&D or external innovation linkages (NEITHER) account for just over one third

[2] The IIP dataset is at plant level. However, most of the observations are single plant firms. Overall, 58 per cent of all observations in the IIP are from single plant firms: among small plants this figure is significantly higher at 77 per cent.

of observations; those with only external linkages (EXTERNAL) account for approximately 15% of observations, R&D only (CLOSED) for 21%, and open innovators (OPEN) for approximately 29% of observations. Table 1 also shows how the distribution of plants among strategic categories has changed through time[3]. Overall, there is a remarkable degree of stability among the categories through time, with slight evidence of an increase in 'open innovation' evident in the final time period. There is little evidence of a paradigm shift over this lengthy time period, at least in terms of the overall distribution of plants across categories. Since each wave of the IIP is designed to be representative of Irish manufacturing at the time of survey, this suggests that innovation in Irish manufacturing has not become more 'open' during the period, at least in terms of selected strategies[4].

Table 2 shows the innovation performance of plants using each strategy. All strategies include both innovators and non-innovators, and as might be anticipated, there is a clear hierarchy in terms of the proportion of plants of different types which are product innovators; less than one third of NEITHER plants innovate, compared with over 90% of OPEN plants, with the two remaining categories lying between these figures. A broadly similar hierarchy is evident with respect to the proportion of new and improved products for each category of plant. Interestingly, this hierarchy is still to some extent evident even when considering the proportion of new and improved products among innovators in each category: in other words, open innovators tend not only to be more likely to innovate, but also have some tendency to be more innovation intensive even than innovating firms which lack any conventional innovation inputs.

These descriptive data appear to suggest that there has been little systematic shift towards open innovation, but give some support for the contention that open innovation is associated with a greater probability and intensity of innovation. However, in order to explore this further we need to take into account other possible influences on innovation activity, and to test formally for the existence of complementarities between internal R&D and external knowledge sourcing. We do this in two stages. First, we test for

[3] Because the panel is unbalanced the proportions of plants in each category includes a combination of strategy switches and entries and exits to/from the panel.
[4] Elsewhere we have noted there is no systematic tendency towards increased 'breadth' of innovation linkages in the IIP over the same time period, casting further doubt on the paradigm shift issue (Vahter et al 2012).

complementarity in the standard (static) sense, then we explore the possibility of dynamic complementarities in innovation strategies.

4. Estimating static complementarities

Two activities are (Edgeworth) complementary if doing more of one activity increases the returns from doing the other. This is a precise definition in which complementarity exists only when these beneficial marginal effects are realized. Two approaches are commonly used to determine the existence of complementarities . The 'adoption' approach simply regresses a set of exogenous variables on the strategy choice variables, and interprets (positive) pair-wise correlation between the error terms of the regressions implying a complementary relationship. However, this cannot be regarded as definitive: common unobserved variable or measurement error may result in correlation of error terms where complementarity is absent (Athey and Stern 1998).

In order to determine the existence of complementarity empirically, we adopt the production function or 'direct' approach (Athey and Stern 1998; Cassiman and Veugelers 2006; Schmiedeberg 2008). This has the advantage over the simpler adoption or correlation approach of not relying merely on conditional correlations between the residuals of reduced-form estimations of the relevant strategies, and therefore allows a direct test for complementarity (Carree et al 2011). The production function approach operates by regressing a measure of innovation performance on mutually-exclusive strategy choices and other suitable exogenous variables, then applying the formal tests of complementarity outlined below. Note that this involves more than simply estimating the determinants of innovation with each of the four mutually exclusive strategies as dependent variables, and comparing the relative sizes of the coefficients in each strategy variable. Such an approach would amount to little more than a pairwise comparison between two possible modes of innovating (i.e. internal R&D and external linkages). Our concern is not simply whether open innovation leads to a higher level of innovation activity than other strategies, but specifically whether there is complementarity between R&D and external linkages.

If I_i is a measure of the innovation outputs of firm i, C_i is an indicator variable indicating whether a firm combines R&D and external linkages in activity i, and Z_i is a vector of control variables, we can write:

$$I_i = \gamma_i C_i + \beta Z_i + \varepsilon_i \qquad (1)$$

Here the C_i can indicate the four discrete innovation strategies outlined earlier. Such strategies can be conceived as discrete choices, with the potential for different strategy choices to yield different patterns of complementarities.

To test for complementarities between the strategy choice variables – i.e. the C_i in equation 1 – we use the framework proposed by Mohnen and Röller (2005) and Cassiman and Veugelers (2006).[5] Although there are four strategies, there are only two innovation activities (R&D and external linkages) and therefore two strategy choice variables C_1 and C_2 such that the vectors (00), (01), (10) and (11) define all possible combinations of strategy options. Thus (11) would here represent the adoption of both R&D and external linkages in the innovation process (i.e. OPEN), while (00) would represent the opposite extreme (i.e. NEITHER). Complementarity between the two strategy choices, or here the equivalent notion of supermodularity, in the innovation production function then requires that:

$$I(10,Z) + I(01,Z) \leq I(00,Z) + I(11,Z) \qquad (2)$$

That is adopting R&D and external linkages produces more positive effects on innovation outputs than the sum of the results produced by the adoption of R&D and external linkages individually. Equivalently, equation (2) can be expressed as:

$$I(10,Z) - I(00,Z) \leq I(11,Z) - I(01,Z)\,. \qquad (3)$$

[5] Athey and Stern (1998) provide a detailed overview of this approach to assessing complementarity and a range of other possible approaches.

In estimating equation (1) I_i is an innovation output indicator, defined as the percentage of plant *i*'s sales derived from innovative products (i.e. those products improved or newly introduced over the previous three years) and *Z* is the set of plant level, industry and regional controls. Although the elements of vector Z are principally designed to control for plant-level heterogeneity, they are also variables which have previously been shown to be relevant determinants of innovative activity at the plant level (Love and Roper, 1999, 2001; Roper et al 2008), including plant size, access to group resources, workforce qualifications, exporting, and the presence of government support for innovation. Since the dependent variable measures the percentage of plants' sales due to innovative products a tobit estimator is employed. Descritive statistics for the main variables are shown in Table 3.

As noted *inter alia* by Athey and Stern (1998), an empirical issue in estimation of this form is that unobserved heterogeneity between observations in the sample of plants can cause bias in the estimation results. This can occur if heterogeneity in the determinants of the choice of strategy is correlated with the error term of innovation production function estimating the effects of the strategies. While the use of panel data mitigates to some extent the issue of firm heterogeneity, the issue of endogeneity may still occur. On possible solution, applied by Athey and Stern (1998) and Cassiman and Veugelers (2006), is to jointly estimate both the adoption process[6] and the innovation production function in a two-step estimator or a simultaneous system. Two conditions must be satisfied for such a procedure to generate reliable results. One is that there must be independent variables that can identify the adoption process, and the other is that the two-step estimator or the simultaneous estimator should have sufficient predictive power. As discussed previously elsewhere (e.g. Cassiman and Veugelers, 2006) it is difficult empirically to satisfy these conditions.

The second way, perhaps more pragmatically, of dealing with such potential endogeneity is to apply some form of instrumental variable approach (e.g. Mohnen and Röller, 2005). However, this approach has generally proved unsuccessful. In the case when highly specific microeconomic datasets are used, and when the observations cannot be merged with other datasets which might provide suitable instruments for, say, variations in

[6] These are the choice of organizational form in Athey and Stern (1998), and make/buy choices in Cassiman and Veugelers (2006) . We can probably doe this – we have estimates of the determinants of the four strategies

managerial expertise, suitable instruments become quite unobtainable. This has led both Mohnen and Röller (2005) and Cassiman and Veugelers (2006) to conclude that attempts at instrumentation, or even joint estimation as suggested by Athey and Stern (1998), are unlikely to lead to improved estimation and may actually be counterproductive unless much better – i.e. truly exogenous – instruments can be found[7].

By way of experimentation, we applied an estimation approach similar to the robustness test in Cassiman and Veugelers (2006). Like them, we do not find strong instrumental variables that are at the same time both valid and strong instruments for choices between the innovation strategies. In this robustness test we have modelled the choice of the four innovation strategies (NEITHER, EXTERNAL, CLOSED, OPEN) as dependent variables on sector- and plant-level variables, using a multinomial logit model. Then, in order to try to account for the potential endogeneity of these category dummies, we included the predicted probabilities of each strategy from this adoption equation to the knowledge production function (Equation 1), instead of the standard strategy dummies.

The plant-level predictors of choice of each category included the standard inputs in knowledge production function (skill intensity, ownership size, age, export orientation, government support for product innovation, productivity). The sector-level predictor variables in the multinomial logit of choice between the four categories include trade openness, trade growth, FDI presence in a sector and Herfindahl index. Unfortunately, these sector-level variables did not predict well the choice between the different innovations strategies. They are largely not significant as determinants of the choice of innovation strategies. This leaves us with the adoption equation of different innovation strategies that is identified by largely the same plant-level variables that need to be included as standard controls in the second stage of the IV model i.e. the knowledge production function itself. As could be expected, this produces implausible coefficients for some of the key explanatory variables in the knowledge production function[8]. Due to the lack of suitable instruments we rely here on the standard Tobit based estimation

[7] In the case of panel data analysis, Leiponen (2005) deals with this issue by assuming that unobserved heterogeneity does not change over time, so that the GMM systems estimation controls for unobserved firm fixed effects. Miravete and Pernías (2006) attempt an econometric model which separately identifies the unobserved heterogeneity in their panel of Spanish ceramics firms. However, they admit that many of the regressors used in their estimation are actually themselves endogenous and that they too lack suitable instruments (p 19 footnote 9).

[8] Results available on request.

results.We nevertheless acknowledge the potential for endogeneity and recognize that our results must be interpreted in this light.

Results of estimating equation (1) are shown in Table 4: estimations are carried out without a constant to show the effect of all four strategy options. As might be anticipated, the hierarchy of innovation described in the basic data (cf Table 2) is again evident. Thus after allowing for the effects of plant- and industry-level conditioning variables, the coefficients on all four strategy variables are significant, with a monotonic increase in the size of the coefficients.

By itself this does not indicate that open innovation is a superior strategy to the others in terms of innovation outputs. To determine this we must test for complementarity between internal R&D and external innovation linkages as suggested by equation (3) i.e.

$$I(10,Z) - I(00,Z) \le I(11,Z) - I(01,Z)\,.$$

The null hypothesis of complementarity is clearly rejected using the direct test (Table 4, final row). Thus even though open innovators appear to be more innovative than other types of plants, there is no statistical evidence that being an open innovator is a superior strategy choice. The reasons for this are immediately clear by examining the coefficients for each strategy in Table 4. Compared to NEITHER, having either R&D (CLOSED) *or* external linkages (EXTERNAL) involves a much larger level of innovative sales – in the region of 30-44 percentage points higher. By contrast, the added advantage of being OPEN is more modest, adding around 11-17 percentage points to innovative sales. Thus, in static terms, the additional benefit of moving from either CLOSED or EXTERNAL to OPEN is less than that of moving from NEITHER to either of the intermediate strategies, which is what the complementarity test formally establishes.

5. Estimating dynamic complementarities

Even with the use of a panel structure, there is still a somewhat static quality to the analysis above. The concept of (Edgeworth) complementarity is implicitly dynamic: it involves the *addition* of something else to what the firm currently does. However, the testing of complementarities is typically comparative static, involving the comparison of the strategic options of different firms at a single point in time (Cassiman and Veugelers 2006; Cozzarin and Percival 2006; Love and Roper 2009). Thus the static approach effectively infers the outcomes of changes in innovation strategies which are not actually observed in practice.

The use of panel data mitigates this effect somewhat, but does not eliminate it. For example, in a panel context the coefficient on OPEN in Table 3 implies that a firm becoming an exporter will increase its proportion of innovative products by 4.5 percentage points, but also that ceasing exporting reduces innovation intensity by a similar amount. In reality, this scale of this effect may not be symmetrical, and unless we have information on the nature of moves into and out of exporting we cannot be sure of how switching from one state to the other affects innovation: it is conceivable that the absolute (positive) effect of moving into exporting is larger than the (negative) effect of ceasing to do so.

The same is true of the innovation strategy variables. The coefficient on OPEN can be interpreted as a combination of the effect of moving to that strategy from any of the other categories, or (in a negative sense) of moving from OPEN to another strategy. But in order to understand precisely how the movement from a certain strategy towards OPEN affects innovation we need to map the actual movements of individual establishments, and trace the effects of these moves on innovation output. Thus by examining how innovation strategies change (or do not change) through time we can compare the actual effects of adding new elements of strategy to an observed set of firms across time periods. This is a much 'cleaner' test of complementarity in the Edgeworth sense, as it shows directly how, for example, adding external linkages to an existing R&D presence has an effect on innovation outcomes, based not on implied strategy changes but on actual observed strategy switches through time. This approach also has the advantages of telling us something about the nature of the strategy switches which occur in reality, as opposed to those which might occur in theory.

To do this we restrict the analysis to those plants for which we have at least two observations in the IIP. This restricts the empirical analysis to 2096 observations. The first issue is the extent to which plants switch between different strategies though time, and whether there is any systematic patterns to theses changes. This allows us to shed further light on 'paradigm shift' issue, this time by examining whether there is any systematic movement towards a more open innovation approach among an identifiable group of manufacturing plants in Ireland.

Table 5 shows the transition matrix for plants with more than one observation in the IIP. The proportion of plants falling into each category in the reduced sample is almost identical to that for the IIP as a whole (cf Table 1), suggesting that the smaller sample is representative of the IIP at least in terms of strategy choices. The transition matrix shows that switching between categories of innovation strategy is relatively commonplace; of the 2096 observation, 1037 (49.5%) show at least one movement of strategy during the period of the panel. It should, of course, be borne in mind that the IIP covers a relatively long time period, and so alterations to innovation strategy might be expected to occur. In addition, all cells of the transition matrix are populated, suggesting that all strategy switch choices were enacted in practice, and so do not represent merely theoretical possibilities.

The interpretation of the transition matrix can be shown by example. Take the case of plants in the NEITHER category. Of the 789 plants which were first observed in this category, 484 (61.3%) remained in that category, 122 (15.5%) switched to EXTERNAL; 103 (13%) switched to CLOSED, and 80 (10.1%) travelled to whole distance to OPEN. For both NEITHER and OPEN a majority of plant stayed within their original category. However for the intermediate strategies there is more evidence of switching. This is most notable for the EXTERNAL category, where only 32% of firms remained within that category, with approximately as many either dropping their external connections and adopting a NEITHER strategy, or incorporating R&D and moving towards OPEN. Despite the incidence of switching, there is little overall evidence of a systematic movement towards a more open innovation approach, or indeed towards any other specific strategy. Overall, the outcome of the observed switches during the course of the IIP leaves the proportions of plants in each category little changed, with a slight increase in the proportion of OPEN plants (from 26.4% to 29.5%) and a very slight fall in the NEITHER category (from 37.6% to 35.6%). Taken in conjunction with the evidence in Table 1 that the overall proportion of plants in each category in the whole IIP have changed little across the whole time period, this evidence lends little support to the contention of a paradigm shift towards open innovation, at least in Irish manufacturing.

The nature of the switching process in the transition matrix might appear to indicate that there is almost a random process occurring, with little consistency or strategic intent among the plants in the sample. However, this would be a premature conclusion. It may be that, for individual plants, the process of switching has led to a more optimal choice of strategy: it is conceivable that while the proportions of plants in each category remain similar, the distribution may have changed in such a way that plants are collectively more innovative than before as a result of having moved to a more appropriate innovation strategy. Thus although there may be little direct evidence of a paradigm shift in terms of the *number* of plants adopting an open innovation strategy, there may nevertheless be some advantage through time resulting from beneficial switches in innovation strategy.

To test this we need to examine whether there is any evidence of *dynamic* complementarities in terms of R&D and external innovation linkages. This involves considering not simply static complementarity between R&D and external linkages (i.e. the four strategy choices) as before, but extending the case to consider the effects on innovation output of the decision to change strategy or remain with the original strategy. This involves not four strategy options as before, but sixteen strategy-switch possibilities, comprising twelve possible 'switch' decisions plus the decision to remain with each of the four original strategies.

To do this we re-estimate equation (1), but replacing the original four strategy choices with sixteen 'strategy switch' dummy variables. The results of estimating the revised innovation production function is shown in Table 6 (column 1). Each of the strategy variables is now either a move between strategies or a decision to remain with an existing strategy. Thus option SW22 involves remaining with the second (EXTERNAL) strategy, while SW34 involves switching from strategy 3 to strategy 4, i.e. from CLOSED to OPEN, and so on. The coefficients on each of the 15 strategy-switch options can be interpreted as being relative to the base option of remaining with the NEITHER strategy (i.e. SW11). In all cases except two the strategy-switch coefficients are positive and significant, indicating that most 'switch' options are superior to that of consistently doing neither R&D nor engaging in external linkages. The exceptions are SW41 and

SW13. In the former case, the insignificant coefficient suggests that moving from an open innovation strategy to having no innovation inputs is equivalent in innovation terms to maintaining a NEITHER strategy. In the case of SW13 switching from NEITHER to CLOSED has an apparently counterintuitive negative sign, indicating that firms setting up an in-house R&D facility where none existed previously tend to have a slightly reduced degree of innovation intensity. This may be a reflection of the disruption to the introduction of new products in the short run caused by establishing an in house R&D facility *de novo*.

However, our interest is not in the absolute value of the strategy-switch coefficients *per se*, but in whether certain strategy switches are more productive than others. As before, this involves testing for the inequality embodied in equation (3). Thus in order to test for dynamic complementarity we now want to test whether adding external linkages to an existing R&D capability has a greater effect than adding linkages where there is no R&D (i.e. that the coefficient on SW34 is greater than that on SW12), and whether adding R&D to existing linkages has a greater effect than adding R&D where no linkages exist (i.e. SW24>SW13). In both cases the null hypothesis of complementarity cannot be rejected using the direct test (final row of Table 6), demonstrating the existence of dynamic complementarities in innovation strategies.

We perform two robustness checks. In the first case we perform the estimation only on innovating firms, and in the second we replace the dependent variable with a dummy product innovator variable. In both cases the results remain essentially unchanged (columns 2 and 3, Table 6), and in both cases the complementarity tests cannot be rejected. In dynamic terms, switching to an open innovation strategy pays off in terms of innovation outputs.

6. Discussion and Conclusions

The purpose of this paper was to shed further light on the suggestion that there has been a paradigm shift towards firms using open innovation as a conscious strategic choice. We argue that such a claim implicitly involves two elements: first, there should be some evidence that firms are increasingly likely to use a combination of internal and external knowledge in their innovation activity: and second, there should be some evidence that firms derive a systematic advantage from so doing.

Using a panel dataset of Irish manufacturing plants covering the period 1991-2008 we are able to examine both aspects of the paradigm shift hypothesis. Considering four archetypal innovation strategies, we find little evidence, either from considering successive cross-sectional ‘waves’ of comparable surveys, or in terms of the strategy switch choices of specific plants, that there has been a systematic move towards the use of an ‘open’ innovation strategy. We then test for the presence of complementarities in the joint use of internal R&D and external innovation linkages, the essence of (inbound) open innovation. In static terms we find no evidence of complementarity, but in dynamic terms find evidence that strategy switches by individual plants towards an open innovation strategy are accompanied by increased innovation outputs.

The inherent difficulty of adequately allowing for endogeneity in a large number of possible strategy choice means that we must be circumspect in suggesting that there is strict complementarity between internal R&D and external innovation linkages, and therefore that switching to an open innovation strategy will necessarily make an establishment more innovative. What we can unambiguously say is that over the course of the IIP there has been a tendency for strategy switches to occur in such a way that open innovation strategies tend to be associated with more innovation intensive manufacturing plants. The extent to which this reflects self-selection rather than the beneficial effects of the strategy switches cannot be determined for certain, although it is difficult to imagine why the most innovative firms in a fairly large sample would systematically gravitate towards a specific strategy over an extended time period unless it conferred some advantage

However, even if self selection were an important driver behind the observed strategy switches and performance results, this provides important information on the issue of the supposed paradigm shift. As discussed earlier, the ‘raw’ data as shown in the transition matrix suggests that there has been no coherent shift towards open innovation among a given sample of firms over an extended timescale, and therefore appears to shed doubt on the ‘paradigm shift’ towards open innovation. However, the fact that, through time, enterprises make conscious strategy choices which tend to result in open innovation being associated with high levels of innovation performance suggests that some systematic and subtle movement towards open innovation may indeed have occurred, a movement which is masked by simply examining aggregate data on numbers of establishment in different strategic categories. In this sense, there has been a movement towards a more optimal set of strategy choices. Therefore, our results could be interpreted as lending some support for the contention that, when considered in a dynamic context, there has been a coherent move towards open innovation: where plants make a switch to the OPEN strategy this has been accompanied by improved innovation performance.

This is somewhat different from an overall ‘paradigm shift’, but may suggest that, over time, those firms which are able to benefit most from employing open innovation are gravitating towards such a choice, and where this occurs it tends to be accompanied by improved innovation performance. This also suggests that establishing whether there really has been a paradigm shift towards open innovation is a much more subtle and complex task than might be first imagined: it involves determining not just whether firms have shifted towards more open innovation practices, but whether there are dynamic complementarities arising from such strategy switches. This implies that very micro-based and longitudinal data is required to determine the answer.

The present analysis has a number of limitations. By design, our strategy categories are starkly defined, and cannot reveal the subtleties of different degrees and types of openness in innovation, although this aspect has been widely studied elsewhere. In addition, enterprises may use a mix of different strategies in different innovation projects, something which cannot be detected in large-scale surveys of the present type. We also know little about the process which leads to switches in innovation strategies, and which is clearly central to the findings reported above: how do firms learn that switching to openness pays? There is some evidence that firms can learn from their openness to external sources, specifically related to external innovation linkages (Love et al 2011), suggesting that a process of organizational learning may play a part in the process. Further detailed work here would be welcome. Finally, our findings are, of course, restricted to manufacturing firms in Ireland, a relatively small, open economy. Other countries may have different stories to tell, but our analysis does suggest the value for long-term panel data to consider issues of openness in innovation.

Table 1 Proportions of sample in each strategy by time period.

Strategy	1991-2008 % (No.)	1991-93	1994-96	1997-99	2000-02	2003-05	2006-08
NEITHER	35.8 (1653)	37.1	35.3	33.2	39.5	38.0	29.8
EXTERNAL	14.6 (673)	11.9	14.5	16.4	17.1	13.1	13.1
CLOSED	21.0 (967)	24.8	21.8	20.2	18.4	19.0	22.7
OPEN	28.6 (1318)	26.2	28.4	30.2	25.0	29.9	34.4
Total	100.0 (4611)						

NEITHER= No R&D and no linkages
EXTERNAL = No R&D and has linkages
CLOSED = R&D and no linkages
OPEN = R&D and linkages

Table 2. Innovation performance by strategy

Strategy	Product innovators (%)	Average innovation intensity*	Average innovation intensity* (innovators only)
NEITHER	31.5	9.4	32.4
EXTERNAL	69.8	29.0	42.8
CLOSED	79.9	31.0	38.6
OPEN	92.4	41.2	44.9

* Proportion of new and improved products in total sales.

Table 3. Descriptive statistics

Variable	Observations	Mean	Std. Dev.
Share of new products in sales (%)	4408	25.428	30.720
Exporter dummy (0/1)	4329	0.592	0.492
Log of employees	4629	3.876	1.133
Log of employees squared	4629	16.303	9.611
Age (years)	4594	29.574	30.454
External ownership (0/1)	4795	0.310	0.463
Share of employees with degrees (%)	4493	9.764	12.974
Government support for product innovation	4722	0.191	0.393
Northern Ireland dummy	4795	0.396	0.489

Notes: Figures relate to pooled data from six waves of the IIP relating to the periods 1991-1993, 1994-1996, 1997-1999, 2000-2002, 2003-2005, 2006-2008.

Table 4. Testing for static complementarities

	Dependent variable: Sales from new or improved products (%)
NEITHER	-23.347***
	(3.214)
EXTERNAL	7.790**
	(3.281)
CLOSED	13.959***
	(3.278)
OPEN	24.672***
	(3.282)
Exporter	4.153***
	(0.735)
lnSize	2.612*
	(1.493)
lnSize squared	0.007
	(0.184)
Establishment age (years)	-0.106***
	(0.012)
Externally-owned	3.465***
	(0.827)
Workforce with degree (%)	0.237***
	(0.026)
Govt. support for product innov.	7.109***
	(0.795)
Northern Ireland dummy	-1.042
	(0.750)
Sector dummies	Yes
Period dummies	Yes
Observations	3506
Log-likelihood	-68797.7
Complementarity test:	
H0: 11-10>01-00	chi2=270.6 (p=0.000)

Panel (RE) Tobit model. Standard errors in parentheses. * p<0.1, ** p<0.05, *** p<0.01.

Table 5: Transition matrix of the four innovation strategies (number of observations in parentheses)

		End category:				
		1	**2**	**3**	**4**	*Total*
Starting category:	**1**	61.34% (484)	15.46% (122)	13.05% (103)	10.14% (80)	*100% (789)*
	2	33.01% (102)	31.72% (98)	9.71% (30)	25.57% (79)	*100% (309)*
	3	22.7% (101)	6.74% (30)	37.3% (166)	33.26% (148)	*100% (445)*
	4	10.85% (60)	9.76% (54)	23.15% (128)	56.24% (311)	*100% (553)*

Source: IIP. Period 1991-2008.

1= NEITHER (No R&D and no linkages)
2 = EXTERNAL (No R&D and has linkages)
3 = -CLOSED (R&D and no linkages)
4 = OPEN (R&D and linkages)

Table 6. Testing for dynamic complenentarities

	(1) Panel Tobit, all plants	(2) Panel Tobit, plants with innovative sales	(3) Panel probit, all plants (marginal effects reported)
Dependent variables	Share of sales of new of modified products (%)	Share of sales of new of modified products (%)	Product innovation dummy
Category dummies:			
sw22	24.803***	11.570***	0.174***
	(2.284)	(2.176)	(0.021)
sw33	40.864***	6.515***	0.471***
	(1.840)	(1.578)	(0.02)
sw44	50.569***	15.757***	0.549***
	(1.644)	(1.425)	(0.019)
sw12	27.678***	10.075***	0.207***
	(1.980)	(1.882)	(0.017)
sw13	-8.200***	-9.770***	-0.022
	(2.722)	(2.229)	(0.029)
sw14	43.659***	16.183***	0.352***
	(2.304)	(1.984)	(0.023)
sw21	11.649***	15.056***	0.056***
	(2.151)	(2.312)	(0.018)
sw23	29.005***	5.631*	0.33***
	(3.591)	(3.112)	(0.035)
sw24	39.615***	9.380***	0.398***
	(2.392)	(2.003)	(0.025)
sw31	20.470***	6.821***	0.154***
	(2.079)	(1.982)	(0.019)
sw32	27.985***	0.135	0.295***
	(3.603)	(3.150)	(0.033)
sw34	52.803***	19.571***	0.474***
	(1.927)	(1.629)	(0.022)
sw41	2.665	3.001	0.027
	(2.920)	(3.122)	(0.024)
sw42	28.094***	11.385***	0.199***
	(2.745)	(2.491)	(0.026)
sw43	38.841***	6.316***	0.404***
	(1.927)	(1.647)	(0.019)
Exporter	4.823***	1.000	0.047***
	(1.015)	(0.882)	(0.01)
lnSize	-1.429	-10.270***	0.029
	(2.302)	(2.039)	(0.023)
lnSize_sqr	0.478*	1.260***	-0.001
	(0.277)	(0.239)	(0.003)
Establishment age (years)	-0.158***	-0.165***	0.0002
	(0.016)	(0.013)	(0.0002)
Externally-owned	2.341**	-0.338	0.032**
	(1.189)	(1.001)	(0.013)
Workforce with degree (%)	0.069*	0.038	0.001***
	(0.037)	(0.031)	(0.0004)
Govt. support for product innov.	7.131***	2.306***	0.111***
	(1.079)	(0.858)	(0.013)
Northern Ireland dummy	0.585	-0.875	0.002
	(0.992)	(0.862)	(0.01)
Sector dummies	Yes	Yes	Yes
Period dummies	Yes	Yes	Yes
Constant	-16.395***	49.807***	-
	(4.773)	(4.329)	-
Observations	1539	946	1616

Log-likelihood	-29268.6	-25229.1	-4812.347
Test of inequality (one sided z-test):			
H0: sw24>=sw13	chi2=172.57 (p=1)	chi2=40.17 (p=1)	chi2=108.10 (p=1)
H0: sw34>=sw12	chi2=110.35 (p=1)	chi2=21.83 (p=0.999)	chi2=91.37 (p=1)

Notes: Panel (RE) Tobit model. Standard errors in parentheses. * p<0.1, ** p<0.05, *** p<0.01.
Dependent variable in Column (1) and (2): Sales from new or improved products (%). Dependent variable in Column (3): product innovation dummy.
Categories, first number denotes the starting category among the 4 below, second number denotes the next category in the following year:
No R&D and no linkages: 1.
No R&D and has linkages: 2.
R&D and no linkages: 3.
R&D and linkages: 4.

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