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How to manage R & D in uncertain environments

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HOW TO MANAGE R & D IN UNCERTAIN ENVIRONMENTS

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ABSTRACT: The benefits of doing R & D activities have been unanimously stated in the academic literature. Although a clear answer on what is the best way to manage these activities has not yet been reached. This lack of definition is exacerbated in uncertain environments where it is difficult to predict future developments.

The purpose of this paper is to obtain a single answer on whether to integrate R & D in uncertain environments. To do this we use a multisectoral sample. The results obtained allow us to reject full integration strategies in favor of those other strategies based on the participation of external agents.

Keywords: R&D integration, market uncertainty, technology uncertainty.

1. 1. Introduction

The role of uncertainty as a determining factor on the degree of vertical integration has been considered in the literature from very different viewpoints with results far from agreeing. To be more concrete, regarding the sign of the mutual relation between uncertainty and integration, the disagreement is so deep that a positive sign, a negative sign, and even the lack of any interdependence have all been obtained. From a critical discussion of the results it could be claimed that uncertainty affects integration only randomly (Krickx, 2000).

The disagreement appears to an even larger scale as soon as we consider the effects on R&D activity, two distinctive features of this activity being, precisely, uncertainty, and the need to keep the secrecy of any achievements (R&D protection). Further, the necessary requirements for in-house activity, namely, the availability of the appropriate resources and the absence of any market failures (Santamaría & Surroca, 2004), can be fulfilled only to a small extent, thus encouraging R&D outsourcing (Howells, 1999; Silipo, 2008) or, at least, some wise combination of in-house and outsourced resources (Harrigan, 1986; Van de Vrande, Lemmens, & Vanhaverbeke, 2006).

Once the disagreement among researchers in this field has been acknowledged, it appears a most important task to shed light on the possibility of a unifying view, dismantling such a conflicting panorama. With this objective in mind, we have conducted a test on the relation between uncertainty and R&D integration in a large multisectoral sample provided by the Enquiry on Business Strategy (ESEE) database. The conclusions obtained may prove insightful both for the academic and research community, and for those involved daily in down-to-earth business management, having at the reach of their hands guidelines on how to best manage innovation.

2. 2. Uncertainty and Integration

The very idea of a business organization facing a changing environment with its ensuing uncertainty involves the need for the constant adaptation of the business organization to both internal and external factors. In particular, in the midst of complex or uncertain settings, it proves a most efficient practice to establish incompletely specified hiring terms due to the fast rise of costs in identifying contingencies and *ex ante* responses.

On the opposite, whenever the settings are simple and the execution schedule is tight, completely specified hiring terms are the most advisable because, on the one hand, *ex ante* costs will be low as a consequence of the greater ease in taking the contractual terms to their factual completion and, on the other, such contractual terms will lower the number of *ex post* opportunistic tentatives as well as any potentially distorting tract in the investments when they have been made on incompletely stated contractual terms. Likewise, with time, agreements should tend to be stated in more complete terms as a consequence of the natural resolution of intertemporal and technology uncertainties (Crocker & Reynolds, 1993).

As for the uncertainty types, Krickx (2000) relates Transaction Costs Theory and Strategy Theory in order to elaborate a typology of uncertainty by distinguishing among three types: internal, external, and strategic.

External uncertainty, also known as exogen uncertainty, has its origins in the industry, appears for both technology-related and market-related reasons, and is cleared off with time (Van de Vrande, Lemmens, & Vanhaverbeke, 2006). It is important to make a clear difference between market and technology uncertainty because each has its own characteristic effects on R&D investments (Oriani & Sobrero, 2008). Market uncertainty sprouts from the variability in demand, whereas technology uncertainty appears due to the existence of a large amount of competing alternative technologies. Consequently, even though market uncertainty has to do with the economy cycles, it is not so with technology uncertainty because the latter does not depend on those cycles, but only on the patterns of industrial technological change (Oriani & Sobrero, 2008).

There is no agreement among academic researchers on the relation between uncertainty and the optimal extent to which vertical integration should be performed. The best-fit adaptive features of integrated management forms (Transaction Costs Theory), support the preference for such structures when facing large uncertainty (John & Weitz, 1988; Gulati & Singh, 1998; Oxley, 1997; Masten, 1984; Masten, Meehan, & Snyder, 1991; Subramani & Venkatraman, 2003). Likewise, it has been tested that the faster the innovation, the larger the extent to which the necessity of keeping any R&D-related activity in-house is perceived. This is because in that way the development of the activity can be kept under control and the provision of the most advanced technology is ensured (Nakamura & Odagiri, 2005).

With the arguments involving opportunism and asymmetric information, some studies have confirmed that both market (Gençtürk & Aulakh, 2007; Levy, 1985; MacMillan et al., 1986) and technology (Joshi & Stump, 1999; John & Weitz, 1988; Masten, 1984; Masten, Meehan, & Snyder, 1991; Gulati, 1995; Oxley, 1997, 1999; Gulati & Singh, 1998) uncertainty can lead to raising the degree of integration.

On the other hand, it has been proved that technological intensity discourages integration (Lambertini & Rossini, 2008) and encourages resorting to cooperation (Schartinger, Rammer, Fischer, & Fröhlich, 2002; Pangarkar & Klein, 2001) with the aim to keep the innovating pace (Gooroochurn & Haley, 2007). High technology and market uncertainty, as well as fast technology changes, will lower the degree of integration, making a mixture of in-house and outsourced R&D activity a wiser strategy (Harrigan, 1986; Van de Vrande, Lemmens, & Vanhaverbeke, 2006). Strategy Theory states that environmental uncertainty and volatility demand a larger flexibility degree (Sharfman & Dean, 1997; Bello & Gilliland, 1997) and a smaller commitment (Skarmeas, Katsikeas, & Schlegelmilch, 2006). Larger flexibility of non-integrated forms and the possibility to gain synergies in trading with specialized agents provide support for this hypothesis (Harrigan, 1986).

Oriani & Sobrero (2008) harmonize the results of preceding research by conducting a test on the existence of more complex relations between uncertainty and the value of R&D investment. In this way, market uncertainty will lower the value of R&D investment until some degree of uncertainty is reached, starting from which a raise in uncertainty will have a positive effect on the value of investment, "because while the possible loss is limited, the potential gain from future growth opportunities has no upper bound" (p. 346). And it will be the reverse about technology uncertainty, having a positive effect on the value of R&D investment up to some value, starting from which the effect becomes negative as a consequence of the rise of risk from the adoption of emerging technologies.

Following these authors and building up from the current situation, usually characterized for a high uncertainty in demand as well as in technology (Political Overview, 2010; Malloch-Brown, 2012; Meardi, Martín, & Riera, 2012), we consider the following two hypotheses:

Hypothesis 1: Market uncertainty encourages R&D integration.

Hypothesis 2: Technology uncertainty discourages R&D integration.

3. 3. Quantitative Measures

The vertical integration strategy which is adopted by a company is determined by its location in the continuum market-hierarchy for the development of each kind of activity. The large number of existing research contributions focused on different aspects of vertical integration has led to an also large number of proposals regarding the most useful ratios to quantifying vertical integration. In this sense, different types of measures have been suggested based on whether the quantification proceeds as a discrete or as a continuous variable.

Continuous measures (Ettlie & Sethuraman, 2002; Holmes, 1999) have their origin in the added value over sales ratio put forward by Adelman (1955). Even though this type of measures has many methodological advantages, the latter disappear when we consider a conceptual approach, because they make for only partial measures corresponding to just a single dimension of vertical integration, namely, the degree of vertical integration (Harrigan, 1986).

Discrete measures, on the other hand, are those for which vertical integration can take only a few predefined values, most frequently of a dichotomic nature (López Bayón, Ventura-Victoria, & González-Díaz, 2002; Lyons, 1994; Masten, Meehan, & Snyder, 1991; Kaserman & Mayo, 1991). This method's most significant hindrance is its poor representation of the variable under study: vertical integration is by no means a dichotomic, "all-or-nothing", variable (Camisón Zornoza & Guía Julve, 1999; Joskow, 1996). Nevertheless, it must be said in its favor that it is able to compile all the dimensions involved in the notion of integration, thus making them more appropriate as global measures. The enhancements that have been suggested for this kind of measures have followed the venues of (1) expanding them to ternary-valued variables depending on whether the relation is contractual, cooperative, or integrative (Joskow, 1985; Rialp & Salas, 2002), and (2) compiling the number of production stages involved in the company's activity (Armour & Teece, 1980). In this way we can preserve both the simplicity and computational power of dichotomic variables, and the global understanding of the notion of integration.

Considering the advantages and the limitations of the two basic venues taken in regard to the quantification of integration, and given the scope of our work, which is focused on the integration of a single activity resorting to data from a multisector enquiry, we have considered using a discrete measure of R&D integration - analogue to that one used by authors such as Masten, Meehan, & Snyder (1991), or Kaserman & Mayo (1991) - resulting from the combination of variables set to 0 when there is integration and to 1 otherwise. In this sense, integration will be evaluated in terms of its opposite, non-integration.

Our dependent variable, with the label "Outsource", is comprised by the following items¹: **ajt** (existence of agreements for joint technological activity), **totj** (technological activity being developed jointly with clients, suppliers, competitors, universities and technological centers), **pcti** (participation in companies developing technological innovation projects), and **rait** (resort to advisors with the objective to gain information about technology).

Besides making for an easier calculation procedure, with this variable we can gather every dimension relevant to integration, which boosts its representation capability regarding the degree to which innovation activity is outsourced in any given company.

With respect to the independent variables, let us say first that market uncertainty is determined by the variability in the product's demand (Oriani & Sobrero, 2008) and by the company's experience in the market under consideration: the company's knowledge about the market improves with time, so that the deeper the learning experience and the ensuing expertise, the lesser the remaining market uncertainty (Van de Vrande, Lemmens, & Vanhaverbeke, 2006).

¹ We use tag identifiers different from those in the ESEE database in order to bring them closer to the English expressions of the variables to which they refer. In the table at the end of this contribution we include both the Spanish language-based tags, as they can be found in the ESEE database, and the form we have used for them in this paper.

As for variability in demand, it will be expressed in terms of the variable “market dynamics”, tagged as follows: **mkd1** (expansive market), **mkd2** (stable market), and **mkd3** (contracting market). Regarding expertise, it can be quantified in terms of the number of years since the company's founding; i.e., the company's “age”, tagged **age**.

The variables above will comprise market uncertainty and lead us to a twofold first hypothesis:

Hypothesis 1a: Expertise gained from experience in R&D activity lowers R&D integration.

Hypothesis 1b: Demand variability raises R&D integration.

Two further generating elements have been considered with regard to technology uncertainty, to wit: environmental changes and competition (Pateli, 2009). The faster technology changes and the larger the number of different contending technologies in a given industry, the higher the degree of technology uncertainty. This is because determining the main future technology under those circumstances becomes a more difficult, or prone to error, task (Oriani & Sobrero, 2008).

Regarding competition, it has been tested that it encourages investment, ameliorating the negative effect of industry uncertainty on the latter (Bulan, 2005). Lambertini & Rossini (2008) highlight as R&D-encouraging formulae both competition and outsourcing because the spillover effect turns the security of R&D activity into a difficult task, thus leading to the activity's disintegration. Such an effect on knowledge encourages the development of new business forms (Won, Lee, & Foo, 2008). Our variables in regard to the above elements are tagged as follows: **epct** (evaluation of perspective of technological change) and **eat** (evaluation of alternative technologies).

Moreover, we have appended yet another variable as one further tag for technology change. This stands as a measure of the type of technological content in the given industry sector: **sctr_h** (high-technology content), **sctr_m** (middle-technology content), **sctr_l** (low-technology content).

As it was already the case with our first hypothesis, our second hypothesis appears in the form of a twofold statement:

Hypothesis 2a: Technology changes lower R&D integration.

Hypothesis 2b: Technological competition lowers R&D integration.

4. 4. Empirical Test

We have resorted to the database made available through the Enquiry on Business Strategy database (ESEE) for the year 2007. This enquiry was conducted on a large sample of Spanish companies devoted to manufacturing. In the table 1 we have a summary of descriptive statistics and correlations.

Insert table 1 here

The dependent variable count the number of situations which the firm no integration his R&D activities. Nonetheless, the ratio of companies for which the variable cancels is quite large: no fewer than 1205 companies as displayed in the frequencies table, corresponding to 63% of the sample. On the other hand, since a requirement for the companies to be involved in our study is their having R&D activity, the sample has been shrunk to those that have made investments in R&D in that year, leading to a final selected sample comprised of 675 companies where the R&D outsourcing variable shows isodispersion.

In Table 2 we display the results obtained in a Poisson model to the final selected sample². We also show the results of a Poisson model without the variable “permanent staff” (**pstf**), which is useful as a tag for the company's bulk size and is positively correlated with the company's age. Our reading of the three models involved is alike and we reject the simultaneous nullity of all the coefficients (LR chi2).

² At the first moment, although the frequency table shows isodispersión in our dependent variable, we did a negative binomial estimation test over the selected sample. The results --the estimated dispersion parameter, alpha, as well as the chibar2 statistic-, support the adequacy of Poisson-based regression for the selected sample.

Insert table 2 here

Market uncertainty measured in terms of experience and demand variability shows weak results regarding compliance with our Hypothesis 1. On the one hand, demand variability is tagged by market dynamics; expanding markets (**mkd1**) have a significant positive effect on the outsourcing degree of R&D activity, much the opposite of the case of stabilized markets (**mkd2**) with respect to contracting markets. The company's experience, measured in terms of its age (**age**), does not appear to have important effects.

Regarding technology uncertainty, the outcomes comply with our hypotheses. The evaluation of perspective of technological change and the evaluation of alternative technologies both affect positively the degree of R&D outsourcing, the second one to a larger extent. The technological complexity of the sector where the company belongs has a positive effect on the outsourcing degree, too, as proven by the range of the coefficients corresponding to the variables **sctr_h** and **sctr_m** with respect to the category taken as a reference, low technology content

5. 5. Discussion

Regarding our Hypothesis 1a, we check that age, as a measure of a company's experience, weakly encourages R&D outsourcing, thus corroborating the tenets of the transactional approach: those companies with a longer experience will be prone to perceiving less market uncertainty (Van de Vrande, Lemmens, & Vanhaverbeke, 2006) and, consequently, also less risk in leaving R&D activity to a third party. Much in the same way, expertise gained through long-term experience allows those companies to evaluate easily the behavior of their partners, which helps in enlarging the extent to which innovation is outsourced. In this direction, it is to be emphasized that in-house resources are useful due to the (advisable) keeping of key core competence and the enhanced capability for absorbing outsourced resources (Howells, 1999). Such a capability is deemed important because innovative firms face constantly changing technologies and markets, thus working in an environment where gathering renewed and up-to-date knowledge is a requirement that can be fulfilled only with difficulty (Hashai & Almor, 2008).

As for our Hypothesis 1b, we get the proposed result. Demand variability is tagged by market dynamics - **mkd1** for expansive markets and **mkd2** for stabilized ones. Our results tell us that only **mkd1** has a significant effect; i.e., it is in expansive markets that companies rely most on outsourcing their R&D activity. Such an effect cannot be confirmed in stabilized markets with respect to those in a contracting process, which means, as had been put forward by Oriani & Sobrero (2008), that there is some degree starting from which the relation becomes significant but, quite on the contrary to their thesis, this is with a positive sign.

Therefore, in the sample used for our test, we can confirm that the value of investment raises with market uncertainty, and companies have the perception that the chance to grow offers more market advantages than hindrances, or outweighs risk (Oriani & Sobrero, 2008:346). In this way, a larger dynamic range leads to larger market uncertainty and R&D integration -- something which is explained in terms of Transaction Cost Theory -- as a consequence of the need to adapt, to protect and to keep under control the most advanced technologies (Subramani & Venkatraman, 2003; Nakamura & Odagiri, 2005; Gençtürk & Aulakh, 2007).

Both statements comprising our Hypothesis 2 are accepted, including the signs we put forward therein. The higher the technology involved in the sector, the wider the landscape of technology change appearing on the horizon; and the more technology alternatives, the deeper the technology-related uncertainty so that the companies will be prone to join efforts with others in order to undertake R&D projects. Once more, the proposals made by the approaches based on Strategy Theory come to the point, this time advising cooperation in order to be able to keep with the pace of innovation (Gooroochurn & Haley, 2007).

The small value of the coefficient for business size - our control variable - reinforces our belief in the fitness of the other relations and confirms the role that uncertainty has in integrating the innovation activity.

6. 6. Conclusions

After reviewing the existing literature supportive of the existence of a causal interconnection between uncertainty and integration, we put forward a model stating the existence of a negative relation between the two of them independently of the business sector and size.

As a consequence of the results of the test we have conducted over a large multisector sample, we accept the transactional proposals regarding the preference of integrated forms in the face of market uncertainty, but we reject these transactional proposals in the face of technology uncertainty. Thus, we accept that there are differences between market and technology uncertainty on the basis that large market uncertainty raises the chances of gain to the point that the consideration of risk appears only in the background.

The approaches based on Strategy Theory are supported by our results regarding the technology uncertainty. These approaches advise resorting to cooperation in order to keep pace with the flow of innovation, to distribute risk elements, and to be provided with more flexibility. It is worthy of note the positive effect that experience gained through time has on outsourcing, highlighting not only uncertainty drop but also the gathering of knowledge, which makes room for the enhancement of the company's capability to handle relations with third parties and thus for a larger chance of success.

Our results are useful for both theoretical research and the practice of business management. In regards to the former, we have now the possibility to understand the reasons for past disagreement and to harmonize different approaches. As for the latter, we suggest the integration of R&D activities when there is only market uncertainty, but, if we add technology uncertainty, we recommend the rejection of those business strategies which are based on diversification and expansion of the firm and which had been considered appropriate for a crisis scenario such as the current one. In its place, we would rather advise quite the opposite: dropping investments to a minimum and establishing cooperation terms in order to reduce risks and raise the real options in a, hopefully, better future.

All in all, we have to keep in mind that the variables have been measured under the market circumstances of a particular point in time, and we must expect that the perception of the companies included in the sample over which we have conducted our test mirrors that particular scenario. Further studies are to be made and corresponding tests conducted in years ahead in order to evaluate the effect of the evolution of uncertainty on the R&D integration.

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Table1. Correlations

	mean	sd	ln result	out source	mkd3	mkd2	mkd1	sctr_h	sctr_m	sctr_l	epct	eat	age
Inresult	17.508	1.719											
outsources	2.307	1.661	0.247										
Mkd3	.196	.397	-0.145	-0.070									
Mkd2	.466	.499	0.026	-0.066	-0.463								
Mkd1	.336	.472	0.094	0.129	-0.353	-0.665							
Sctr_h	.473	.499	0.082	0.117	-0.066	0.014	0.041						
Sctr_m	.256	.437	-0.013	-0.005	0.033	-0.051	0.026	-0.557					
Sctr_l	.269	.444	-0.080	-0.126	0.042	0.034	-0.072	-0.576	-0.357				
epct	.518	.500	0.131	0.450	-0.067	0.035	0.019	0.037	-0.019	-0.023			
eat	.521	.499	0.155	0.477	-0.057	0.033	0.013	0.029	-0.038	0.004	0.759		
age	34.529	23.617	0.282	0.085	-0.077	0.109	-0.050	0.031	-0.038	0.003	0.058	0.029	
pstf	440.605	1074.762	0.566	0.153	-0.058	0.016	0.032	0.085	-0.019	-0.077	0.070	0.080	0.141

Table2. Results

ESEE 2007 Poisson regression (N= 675)			
outsources	Coef	Coef	Coef
mkd3	-.137* (.073)	-.131* (.073)	-.147** (.073)
mkd2	-.174 *** (.056)	-.171 *** (.056)	-.179*** (.056)
sctr_h	.202*** (.064)	.206*** (.064)	.213*** (.063)
sctr_m	.154** (.073)	.159** (.073)	.158** (.073)
epct	.289*** (.081)	.295*** (.081)	.291*** (.081)
eat	.497*** (.082)	.495*** (.082)	.505*** (.082)
age	.001* (.001)	-.001 (.002)	.002** (.001)
age2		.000 (.000)	
pstf	.000** (.000)	.000** (.000)	
cons	.236*** (.083)	.280*** (.093)	.240*** (.083)
Log likelihood	-1161.84	-1161.30	-1164.1
LR chi2(d.f.)	237.05*** (8df)	238.12*** (9df)	232.46*** (7df)
Pseudo R2	0.0926	0.0930	0.0908
AIC:	3.469	3.471	3.473
BIC:	-2015,107	-2009.66	-2017.028

* p-value<0.1; **p-value<0.05 ***p-value<0.01. Std. Err. in parentheses