Intangible Assets and the use of new Technologies in Manufacturing.[i]

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Abstract:

In this study, we analyse the role of complementarities between the use of process technologies and intangible assets. More precisely, we examine the influence of technological, commercial and human resources on the use of new technologies in Spanish manufacturing firms from 1994 to 2006. The four technologies examined are numerically controlled machines, robotics, computer aided design and flexible manufacturing. Our results are different depending on the technology under consideration. On the one hand, the complementarily relationship between technological resources and the use of several technologies is always highly significant. On the other hand, the results on commercial and human assets depend on the type of technology analysed. Finally, the analysis also considers the existence of complementarily relationships between different types of technologies.

Keywords: Technology adoption, diffusion, complementarily, multivariate probit.

Introduction

Our objective in this paper is to understand the role of complementarities at explaining technology diffusion among firms. This question lies at the heart of the explanation of performance differences. Although some authors have stressed the commodity character of new technologies and they have been defined as strategic necessities (Clemmons and Kimbrough, 1986; Clemmons and Row, 1991), it has been recently shown (Greve, 2009) that differences in technology adoption could be more persistent than predicted by traditional economic models. Therefore, this heterogeneity could provide an additional explanation to the observation that firm performance differs.

Rather than focusing on more traditional explanations of diffusion, such as the ones provided by epidemic models, we focus on the interaction of firm resources and new technologies at the time of developing our hypotheses. In doing so, we contribute to the literature by conciliating the idea that the returns to new technology are difficult to appropriate, with the observation that the incentives to adopt new technologies are different, which suggests that firms could expect different returns from them, at least in the short run. More precisely, we examine the role of the differences in resource endowments through the framework provided by Teece (1986, 2006). Given the weak appropriability regime associated to new technologies, our attention focuses on the role of certain difficult-to-obtain assets at explaining the different stimuli that firms may have to adopt new technologies. Accordingly, we develop hypotheses that relate presence of technological, commercial and human resources within the firm, with the likelihood of observing technology adoption.

We test our hypotheses on a representative sample of firms operating in the manufacturing sector in the Spanish economy. The available information allows us to calculate the stock of technological and commercial resources and to evaluate the quality of the services provided by employees. We are also able to relate this information to the use of certain process technologies within firms from 1994 to 2006. In particular, the four technologies examined are numerically controlled machines, robotics, computer aided design and flexible manufacturing. Given that the literature has shown that the factors explaining new technology adoption are, to some extent, technology dependent, the use of different technologies will help us to understand the degree to which our predictions are generalizable. Using information on several technologies also agrees with the suggestion of the literature on technology diffusion that, rather than analyzing technologies in isolation, the fact that they frequently appear forming systems implies that their adoption could be related. This also addresses one of the shortcomings of the technology diffusion literature, provided that the adoption of any technology could also be explained by the use of other technologies that form systems (Colombo and Mosconi, 1995; Sinha and Noble, 2008).

A problem introduced by the consideration of the role of complementarities is that the decisions to adopt several technologies could be related. In such a setting the independent estimation of the models explaining the adoption decision of each technology would be inadequate, given that the decisions to adopt are potentially correlated. A solution to this problem may be implemented through the estimation of a multivariate model, which accounts for the potential correlation. Looking at the correlations before and after the consideration of complementary assets would also allow us to value the extent to which they are due to complementarities among the technologies or among these and firm resources.

The rest of the paper unfolds as follows. In the next section we integrate Teece framework and the literature on technology diffusion in order to develop three hypotheses on the role of complementary assets. Section 3 explains the methodology, describes the sample and defines the variables that are going to be used in the empirical estimation. Section 4 presents the results of the estimation of our empirical model and performs some robustness test in order to confirm our results. Finally, Section 5 concludes and discusses the implications for new technologies management.

Hypotheses

To understand the factors that explain technology adoption by firms and the heterogeneity this creates we need to understand how firms profit from innovation. The capacity of a firm to appropriate the returns from innovation mainly depends on two types of factors (Teece, 1986): the appropriability regime and the possession of complementary assets. On the one hand, the appropriability regime is defined by (1) legal and (2) technological factors. The first refers to the degree to which intellectual property rights in the form of patents, copyrights or trademarks secure the rent of the innovator. The second include two characteristics of the innovation that limit the ability of other firms to imitate or copy: the degree of complexity and codificability of the knowledge embodied in the innovation.

On the other hand the rents accruing to the innovator also depend on the possession of complementary assets. By complementary assets Teece (1986) understands all the resources that need to be jointly used with the innovation, in order to exploit it. They, for example, include the manufacturing, distribution or service resources that are needed to operate the different stages of the value chain. The lack of these resources would oblige the firm to look outside its limits in other to acquire the services needed to extract the returns to the innovation. However, this would be done at the risk of revealing critical information and, hence, increasing the capacity of competitors to copy it. Therefore, the possession of complementary resources becomes a determinant of the ability of the firm to profit from the innovation.

Despite the clear relationship between technology adoption and innovation (Koellinger, 2008) the consideration of complementary resources in the context of technology adoption has mainly focused in their moderating role between the use of new technologies and performance. In other words, their use as determinants of adoption has been scarce. Thus, early work on the diffusion of new technologies tended to concentrate upon epidemic theories of diffusion (Karshenas and Stoneman, 1993). Epidemic models assumed that diffusion is not instantaneous because information on the technical and economic attributes associated with the new technology takes time to spread amongst the population of potential adopters. As a result, the adoption depends on the process by which people become informed about the existence and characteristics of the technology (Baptista, 2000; Geroski, 2000). Contemporary approaches to technology diffusion are characterized by less emphasis on information spreading. Contrarily, they pay attention to the heterogeneity in the population of potential adopters (rank models) in order to explain diffusion (see, for example, Karshenas and Stoneman, 1993). This heterogeneity is represented by one or more firm characteristics (such as size, absorptive capacity, the possession of financial resources or exports intensity) that are assumed to be crucially important in determining responsiveness to the technology. However, the arguments underlying the use of these variables tend to be developed in terms of economies of scale, the need of substituting older technologies, information flows reaching the firm or the capacity to assimilate new information. Contrarily, in this paper we offer a view on technology adoption that is based on the differences in their endowments of complementary resources.

An important characteristic of new technologies is that they are widely available in the market. Therefore, their returns cannot be protected from imitation through secret, intellectual property rights or relying on their complex or non codificable nature. This has led some researchers to conclude that, on the long run, technology adoption could only provide competitive parity (Barney, 1991). Some authors have enunciated this as the strategic necessity hypothesis of technology adoption (Clemmons and Kimbrough, 1986; Clemmons and Row, 1991). Following it, new technology adoption by rivals creates the need for a focal firm to adopt the new technology in order to match their performance. However, despite their weak appropriability regime, at least in the short run the returns of new technology could be captured if the firm possesses complementary resources that are difficult to obtain. Research has shown that the link between information technologies and profitability is frequently explained through the consideration of complementary resources under the control of the firm (Powell and Dent-Micallef, 1997).

In this way, the existence of complementary resources could be an indicator of the stimuli that a firm has to adopt a new technology. Accordingly, in the following lines, we argue that technology adoption is conditioned by the possession of certain complementary resources that are difficult to acquire, namely, technological, commercial and human resources. Given that the use of new technologies could be also conditioned by the presence of other related technologies within the firm, we also analyze the existence of complementarily relationship between technologies.

Technological Resources and Technology Adoption.

Investments in research and development have frequently been linked to technology adoption through the absorptive capacity concept (see, for example, Cohen and Levinthal, 1990). Generally speaking, these investments contribute to the knowledge base of the firm, increasing their capabilities, and may also result in process or product innovations. Like other intangible resources, they tend to be tacit, idiosyncratic and deeply embedded in the firm (Winter, 1987), which makes it difficult to copy for competitors. Imitation may be also complicated by the fact that this knowledge may be path dependent and subject to time compression diseconomies (Dierickx and Cool, 1989).

There are different ways in which the knowledge base of the firm interacts with new technologies to allow the firm to generate and capture value. On the one hand, as stated above, the knowledge based of the firm has been frequently related to technology adoption through the absorptive capacity concept. A firms absorptive capacity is defined as the "ability of a firm to recognize the value of new, external information, assimilate it and apply it to commercial ends" (Cohen and Levinthal, 1990:128). Although absorptive capacity tends to be related to adoption through the higher ability of firms to understand valuable information, we should emphasize their role at the time of exploiting new technologies. In other words, once a new technology is adopted, its use would require relating the knowledge embodied in the innovation to the internal processes taking place inside the organization. Therefore, a better knowledge base could help firms to exploit new technologies more effectively and to capture the results.

On the other hand, new technologies may also help the firm to take advantage of the results of the innovation process. In fact, research has shown that new technologies frequently enable process and product innovations (Koellinger, 2008). Therefore, new technologies may provide an adequate channel for converting the knowledge base of the firm into profitable products and services.

Hypothesis 1: *firms possessing a higher amount of technological resources are more likely to use a new technology*

Commercial Resources and Technology Adoption.

Complementarities also extend to marketing activities (Teece, 1986). Like technological resources investments in marketing create intangible resources, such as reputation, brand image or closer relationships with customers. These resources are frequently difficult to imitate: they may be subject to time compression diseconomies (Dierixk and Cool, 1989) or they may be socially complex (Barney, 1991). Marketing assets may interact with new technologies in several ways. Investments in marketing activities may help the firm to develop a good reputation or a brand image. These assets are cuasipublic, in the sense that their ability to deliver services is not undermined by their use. In other words, once they have been developed, they may be used to support product development, market development or diversification. New technologies may leverage the effects of reputation and brand image by allowing the firm to increase the frequency of product improvements. Product improvements may, for example, be facilitated by the use of design technologies such as computer aided manufacturing

(Thomke, 1998). Similarly, new technologies may also allow more frequent changes in the line of production, which may be used to satisfy the diverse needs of consumers and provide the firm with a way to obtain scope economies. Investments in marketing may also be used to improve the relationship with customers and to acquire information on their needs. Again, new technologies may also complement marketing resources by making an improved use of this information. For example, computer aided design technologies may be used to foster cooperation with providers and customers (Bharadwaj, 2000).

Hypothesis 2: *firms possessing a higher amount of commercial resources are more likely to be using a new technology*

Human Resources Qualifications and Technology Adoption.

It is also commonly argued that the diffusion of new technologies is related to workers qualifications. In this sense, the most common theory is the skill-bias technical change hypothesis, which states that there is a complementarity relationship between new technologies and skilled workers as far as the latter are the only ones able to fully implement those technologies (Piva *et al*., 2005:143). Doms *et al*., 1997 maintain that the positive correlation between technologies and workforce attributes may be justified at least, using three arguments. First, at a general level, process technologies increase the level of automation in a factory. Workers using these machines must, at least, have reasonable language, reading and basic math skills. Thus, more automated plants will employ relatively more educated and skilled workers. Second, the introduction of a more technology-specific level may affect the organization of the workforce and will require skilled operators and technicians which replace skilled craftspeople but also less skilled workers. Finally, many of these technologies require significant qualified support staff to install and maintain them, which may affect the requirements in terms of technical skills.

Apart from arguing in terms of technology related skills, more qualified workers provide other innovation and managing related abilities that are important to use new technologies. First, as mentioned above, new technologies frequently enable process and product innovations (Koellinger, 2008). Education contributes to the innovation process by increasing a "person's capacity to think systematically and creatively about techniques" (Wozniak, 1984: 71). Second, education may also be related to management skills. Here, we refer to the increasing ability of educated workers to effectively integrate new technologies within the activities of the firm. In fact, given that technology related knowledge may be contracted and it is not firm (but technology) specific, it has been argued that management skills are the only likely source of competitive advantage: they are path dependent, they tend to be tacit and firm specific, and they may be socially complex (Mata, Fuerst and Barney, 1995).

Hypothesis 3: *firms with more qualified personnel are more likely to be using a new technology*

Complementarities Between Technologies

Besides the complementarities which take place between the use of new technologies and firm assets, complementarities between technologies may also arise (Stoneman and Kwon, 1994). The idea is that although some technologies are able to work independently they can also build systems in which complementarities arise. The incentives to form these complex systems are likely to affect diffusion (Colombo and Mosconi, 1995). This ideas are in with the Advance Manufacturing Technology (AMT) research. The term AMT is used as an umbrella to describe "an automated production system of people machines and tools for the planning and control of the production process, including the procurement of raw materials, parts and components and the shipment and service of finished products" (Pennings, 1987: 198). There are several multidimensional views on AMT but all tend to agree on three technology types: (1) design related technologies; (2) process related shop floor technologies and (3) information and control related technologies (Swamidass and Kotha, 1998:25).

All the technologies that make up the multiple dimensions of AMT can be easily integrated electronically with each other. In this line, the key advantage which arises with the use of AMT is that they can build complex manufacturing systems which make manufacturing programmable and leads to timely information transfer across departments, employees, customers and suppliers. These systems are important, since most manufacturing technologies are relatively available on the open market and any particular competitive advantage is difficult to defend[ii]. In this context, one way to succeed consist of building systems in which the number of elements and the degree of interaction among them is what makes them inimitable, given their complexity (Rivkin, 2000). In other words, while the adoption of individual technologies may no have effect on competitive advantage, certain technology combinations may help in building and sustaining it (Sinha and Noble, 2008) due to complementarities with past adoptions, learning curve advantages, or other factors (Colombo and Mosconi, 1995).

From an empirical point of view Stoneman and Kwon (1994), Colombo and Mosconi (1995), Arvantis and Hollestein, (2001) and Gómez and Vargas (2009), demonstrate the influence of complementary issues across technologies. Beede and Young (1996) found enormous diversity in adoption patterns in the same industry and also found important differences in the effect of various technology combinations on performance suggesting the need to consider technology bundles in assessing adoption scenarios. More recently, Sinha and Noble (2008) found that firms that adopted several technologies were best positioned to survive, illustrating the importance of cumulative technology adoption.

Hypothesis 4. *There are complementary relationship in the adoption of multiple technologies.*

Methodology, Sample and Variables

Sample Description

The dataset used for this study is drawn from the Survey of Business Strategies (ESEE). This is an annual survey on the activity of Spanish manufacturing firms and their business strategies financed by the Ministry of Industry and carried out by the SEPI foundation. Although this survey is not specifically designed to analyze technology adoption, it includes information on a number of technologies that are used by firms. Among them, we focus on numerically controlled machines, computer aided design, robotics and flexible manufacturing, given that these are the technologies for which a longer observation window is available. The survey covers firms which have 10 or more employees and whose principal economic activity is listed in one of the two digit manufacturing industries of the NACE-Rev.1. In the base year, surveyed firms employing between 10 and 200 people were selected by means of a random sampling scheme, while firms with more than 200 were surveyed on a census basis. Although the survey has been administered annually to firms since 1990, questions regarding adoption behavior have only been included in 1994, 1998, 2002 and 2006. This precludes us from establishing causality relationships, given that the date of adoption of the technology is unknown. Therefore, our objective is to find the combination of resources that is more likely to be used with new technologies. After selecting all the observations for which data on the independent variables is available, we are left with 4,418 observations that will be used in the empirical analysis.[iii]

As mentioned above, we examine adoption of four manufacturing technologies: numerically controlled machines, robotics, computer aided design and flexible manufacturing. The use of these technologies in manufacturing is very common and they have been the subject on previous diffusion studies.

Hypotheses Measurement

Stock of technological resources. We approximate the stock of technological resources by using the ratio of research and development capital to sales. We compute research and development capital (K) through a partial inventory of past and present annual internal R&D expenditure[iv], R, with a constant depreciation rate, δ:

$$K_t = \sum_{k=0}^{3} (1-\delta)^k \times R_{t-k}$$

The annual depreciation rate (δ) was assumed to be 15%. The use of a depreciation rate is justified by the decay of knowledge over time and by the loss of economic value due to the development of new knowledge and technologies.

Stock of commercial resources. Similarly to technological resources, the stock of commercial resources is measured as the ratio of commercial capital to sales. Commercial capital is constructed using the following calculation:

$$P_t = \sum_{k=0}^{3} (1-\delta)^k \times A_{t-k}$$

where $A_{i,t}$ is the current period advertising spending[v]. While there is no consensus in the literature on the rate of depreciation and use a depreciation rate of 45% for previous year's expenditures going back four years.

Human resources. The available information also allows us to calculate a measure of employee skills, using the number of employees who own a University degree. With this information we calculate the ratio of the number of people having a University degree to the total number of employees of the organization. This measure has been used in previous papers.

Control Variables

Firm Size. Firm size has traditionally had a prominent role in rank models of diffusion, usually presenting a positive effect on the probability of adoption. The explanations provided for this positive impact are different and, despite recent efforts (see, for example, Astebro, 2002), some confusion on the underlying mechanism still remains. First, firm size has been positively related to the existence of complementary assets within the firm. Under this interpretation, the interaction of the technology with other resources and capabilities that the firm may possess in areas such as production or marketing would positively influence profitability, as it has been argued. Hence, larger firms would obtain more profitability from the technology and would have more incentives to early adoption (Teece, 1986; Colombo and Mosconi, 1995). A second explanation focuses on the concept of economies of scale. In particular, larger firms are able to spread the cost of investing into a new technology among a higher number of units (Cohen and Levin, 1989), making adoption more profitable. Finally, firm size has also been specifically related to the possession of financial resources (Canepa and Stoneman, 2005). Larger firms are likely to have more financial resources and, therefore, are more likely to be able to finance an investment and to absorb a loss. The adoption of certain technologies is frequently associated with large investments in fixed capital as well as significant costs for training human resources (Mansfield, 1993; Romeo, 1975). Therefore, larger firms would be more capable to finance the adoption of new technologies.

Financial constraints. The literature on diffusion attributes a role to financial constraints in the determination of firm's adoption behavior. Despite the foreseeable significance of this variable at explaining diffusion, only a few papers pay adequate attention to it, separating the effect of firm size from financial constraints. For example, Romeo (1975) and Mansfield (1963) find a positive influence of liquidity on the rate of intra firm diffusion. Fuentelsaz, Gómez and Polo (2003) assess the impact of firm profitability and total reserves in the intra firm diffusion process of automated teller machines. Similarly, Canepa and Stoneman (2005) consider the effect of cash flow on the decision to adopt computerised numerically controlled machine tools in an inter firm diffusion context.

The arguments in favour of a positive relationship between financial constraints and adoption take three factors into account: uncertainty, information asymmetries and specific assets (Stoneman, 2001; Canepa and Stoneman, 2005). First, the existence of uncertainty on the cash flows to be perceived from adoption creates difficulties to raise funds externally. Second, the existence of information asymmetries between borrowers (the firm adopting the technology) and lenders and moral hazard resulting from the separation of ownership and control may also have a role to play. Finally, in some settings the diffusion process will be associated to investments in intangible or technology specific assets, whose economic value could be very difficult to recover. As a consequence, we expect the availability of financial resources to have a positive impact on technology adoption. This variable is measured as the ratio of debts to total assests.

Corporate status. The corporate status of a firm may also have an impact on the decision to adopt. By corporate status we are referring to whether the firm is a part of a larger business group or not. As noted by Rose and Joskow (1990), Karshenas and Stoneman (1993), Baptista (2000), the effect of this variable on adoption decision is likely to be ambiguous. On the one hand, independent firms may be better positioned with regard to implementation, once the decision to adopt has been made. On the other, those firms that are part of a larger institution may be better informed and bear less risk in adopting new technologies. Corporate status is measured through a dummy that takes a value of "one" in those cases in which the firm is part of a larger corporate unit.

Ownership. The fourth variable considered in the analysis is the type of ownership. In the case of diffusion, the literature has analyzed the extent to which the firm is owned by a national or a foreign firm. The argument in favor of a positive effect is that the subsidiaries of a foreign firm may have access to the resources of the parent firm. Foreign investment may be a vehicle for the introduction of superior technology and scientific knowledge. However, arguments in favor of a negative relationship have also been put forward based upon an underlying product life cycle. According to this view, multinationals tend to transfer new technology as it approaches the late stages of the life cycle. Previous evidence on adoption models revealed a positive impact of foreign ownership (Baldwin and Diverty, 1995), although this relationship was only significant in the case of certain technologies. The presence of foreign capital in the focal firm is measured through a dummy that takes a value of one when the presence of foreign investors in the capital is higher than 30%

Propensity to export. Finally, the literature on adoption considers that the propensity of a firm to sell its products abroad is a determinant of adoption. Exporting firms can be expected to face more competitive international markets. This, in turn, would provide them with incentives to adopt new technologies in order to confront the higher levels of competition of the international arena. Research on the determinants of R&D investments has shown a positive association between export intensity and R&D. However, the available evidence in a context of technology adoption does not offer conclusive results. The ratio of total exports to sales is used in order to capture the effect of this variable.

Time variables. The passage of time has two confounding influences on technology adoption. On the one hand, the stock effect should mean that as the number of adopters grows the probability of adoption should be lower, given the lower returns. On the other, the epidemic effect acts through a learning-by-contact process. Hence, the number of previous adopters would also bring forth a positive effect on adoption, as information flows increase in the industry. Such an effect could counteract the expected stock effects, making the net effect of the variable ambiguous (Baptista, 2000). We measure epidemic and stock effects through three dummy variables that take a value of one for the years 1998, 2002 and 2006, leaving 1994 as the base year. Therefore, if learning effects are strong enough to compensate for stock effects the technology should continue its diffusion and we would find that the three variables are positive and significant.

*Industry specific effects***.** Finally, we consider two industry specific influences on technology adoption. First, market structure has been frequently liked to the incentives of the firm to adopt a new technology. However, the arguments focus on two conflicting predictions (Reinganum, 1981). On the one hand, competition could provide firms with an incentive to adopt new technologies. On the other hand, as the appropriability of the returns depends on the intensity of competition, profiting from technology adoption would be more difficult in less concentrated markets. We measure market concentration through the market share of the four largest firms (CR_4).

Second, one of the conclusions from the literature on technology diffusion is the importance of industry effects. Technology diffusion is largely determined by the technological characteristics of a given production process and this, in turn, is intimately linked to the sector of activity in which the firm is operating. As such, one might expect different technological trajectories across different industries, which implies that a given technology will have different diffusion paths for different industries. Although we do not make any conjecture on the effect of particular activities on technology adoption, our empirical model does consider the fact that some technologies could not be as adequate for some industries as in others. Accordingly, we introduce 19 dummy variables to account for the 20 different sectors identified in the survey.

Estimation Strategy

The data set we use describes adoption as a discrete choice, what suggest using qualitative dependent variable models (either logit or probit). In other words, we model the probability of adoption of the technology as a function of multiple explanatory variables capturing the rank, stock and epidemic effects described above. The probability of adoption may be expressed as a function of a vector of variables reflecting all the three effects. Given the documented similarities between the logit and probit specifications and the considerations that we made below, we chose the probit link to perform our estimations.

As mentioned when developing our empirical model, technologies may be complementary. In the case of the technologies analyzed here, it has been argued that they form a cluster in which we could include numerically controlled machines, computer aided design or robots. Recent research has extended the number of factors affecting adoption in order to take into account that technologies are complementary. The idea is that some technologies are difficult to use in isolation and, therefore, they need to be adopted as systems that are jointly used in the development of certain activities. From an empirical perspective, the assumption that technologies do not operate in isolation has an important methodological implication. If the profitability of adopting a given technology is related to the adoption of a different technology, this means that both decisions are interdependent. Therefore, the estimation of any model of adoption should consider the fact that other complementary technologies could be in use by the firm.

Given that our data on adoption provides us with information on the use of several technologies, we estimate the decision to use the technology through a multivariate probit model. This model can be seen as a generalization of the bivariate probit model, allowing more than two equations to be simultaneously estimated. The model captures the complementarities in the adoption of different technologies by allowing the disturbances of the different equations to be correlated. Such correlations may be due to complementarities (positive correlation) or substitutabilities (negative correlation) between different technologies. Nevertheless, correlation could also be the result of unobservable firm-specific characteristics that affect adoption decisions, but that are not easily captured by measurable proxies (Belderbos *et al*, 2004). In fact, the arguments that we have used in this paper in terms of the existence of complementarities between resources and technology could be extended to other assets that are unobservable to us. Therefore, the multivariate probit model takes into account the interrelationships arising in adoption, although it is not able to distinguish between the two sources of correlation described. However, if correlation exists, the estimates of the separate equations would provide us with inefficient estimates.

The estimation is carried out using Stata's mvprobit command which applies the method of simulated maximum likelihood (SML) that uses the Geweke-Hajivassiliour-Keane (GHK) smooth recursive conditioning simulator to evaluate the multivariate normal distribution. Following Cappellari and Jenkins (2003), the simulated probabilities are unbiased and bound within the (0, 1) interval. The variance-covariance matrix V of the cross-equation error terms has values of 1 on the leading diagonal, and the off-diagonal elements, correlations $\rho jk=\rho kj$, are to be estimated. The parameter ρjk is the co-variance between the error terms of equations j and k.

Results

Table 1 shows the results of estimating a multivariate probit over the 4,418 observations available. As we can see, the models is globally significant, given the high values of the LR statistic. As shown at the bottom of Table 1, the LR test is highly significant, pointing to the importance of complementary resources at explaining adoption. Importantly, not only the values but also the t-ratios accompanying the coefficients remain fairly stable across the two sets of estimations.

Table 1. The effect of technological, commercial and human resources on new technology adoption

	CNC (1)	Robotics (2)	CAD (3)	SSFN (4)
Firm size	0.16^{***} (3.50)	0.36^{***} (7.28)	0.17^{***} (3.89)	0.46^{***} (8.82)
Firm debt ratio	-0.07	-0.28^{***}	0.12	-0.33^{***}

	(-0.83)	(-2.80)	(1.29)	(-3.36)
Stock of technological resources	1.61***	2.42***	3.66***	2.81***
	(2.86)	(4.12)	(6.32)	(4.86)
Stock of commercial resources	-0.22	0.42***	0.32*	-0.33
	(-0.91)	(2.70)	(1.74)	(-0.95)
Human resources	0.12	0.14	0.66***	0.71***
	(0.71)	(0.73)	(3.64)	(3.88)
Export propensity	0.41***	0.60***	0.44***	0.28***
	(4.81)	(6.65)	(4.92)	(3.13)
Market concentration	-0.35	-0.23	0.23	0.32
	(-1.22)	(-0.74)	(0.75)	(1.02)
Integrated in a business group	0.29***	0.45***	0.28***	0.35**
	(5.37)	(7.95)	(4.93)	(6.21)
Foreign capital	-0.00	0.18***	-0.01	0.00
	(-0.08)	(2.82)	(-0.22)	(0.02)
Year 1998	0.24***	0.25***	0.37***	0.14**
	(4.02)	(3.64)	(5.60)	(2.17)
Year 2002	0.34***	0.29***	0.39***	0.01
	(5.66)	(4.17)	(5.87)	(0.09)
Year 2006	0.40***	0.42***	0.47***	0.11*
	(6.44)	(5.98)	(6.88)	(1.68)
Industry dummies	Yes	Yes	Yes	Yes
Constant	-0.89***	-1.49***	-2.54***	-1.76***
	(-4.38)	(-6.52)	(-9.52)	(-7.36)
Rho2,1	0.409*** (17.40)			
Rho3,1	0.458*** (21.16)			
Rho4,1	0.290*** (11.67)			
Rho3,2	0.403*** (16.53)			
Rho4,2	0.294*** (11.48)			
Rho4,3	0.404*** (16.54)			
No. observations	4418			
Wald Test	1992.44***			
LR test of Rho2,1=Rho3,1=Rho4,1= Rho3,2= Rho4,2=0 Rho4,3=0	1025.56***			

Hypothesis 1 argued that firms with a higher amount of technological resources would be more likely to be using new technologies. This is, in fact the case for the four technologies. In all the cases the variables accompanying the “technological resources” variable present a positive and significant coefficient. This coefficient presents a higher value for computer aided design, followed by systems of flexible manufacturing. Therefore, the evidence confirms our hypothesis that new technologies and research and development expenditures are more likely to be used in combination.

Similarly, Hypothesis 2 stated that those firms with more marketing resources would be more likely to use new process technologies. In this case, we find clear differences between the technologies. Whereas the variable “commercial stock” is significant for robotics and, to a lesser extent, for computer aided manufacturing, marketing resources are not significant in the case of numerically controlled machines and flexible manufacturing. This observation and the comparison of the magnitude of the coefficients of this variable and the ones corresponding to “technological resources” clearly shows that marketing resources do have a much lower importance to explain new process technologies usage. An explanation to this result could come in terms of the type of technologies that are analyzed, given that they are mainly used in production.

Hypothesis 3 stated that technology adoption should be also conditioned by the qualifications of human resources. Again, we observe clear differences between the different technologies analyzed. Thus, the variable “human resources” is highly significant in the case of computer aided design and flexible manufacturing, whereas the other two technologies do not show any impact. This seems to be in line with evidence provided by Dunne and Troske (2005), who investigated the relationship between technology adoption and the skill mix of the workforce in US manufacturing plants. These authors found that the effect of skilled labour varied across technologies, presenting a stronger correlation with technologies associated with design and engineering functions than with the technologies more closely associated with production.

Lastly, hypothesis 4 considered the complementarities arising between technologies. In particular, we expect a positive relationship in the adoption of several technologies. As has been mentioned previously, the multivariate probit model allows us to estimate the correlations between the technologies once we have controlled for the influence of the variables included in Table 1. These correlations are presented at the bottom of Table 1 and could be given two interpretations. First, a positive correlation could be due to the influence of firm specific factors that are not included in our estimations and that determine the propensity of some firms to adopt all the technologies. Second, a positive correlation could mean that the technologies form part of a system. Hence, the adoption of one technology would increase the probability that the other technologies of the system would also be adopted. The comparison of the changes in the value of the correlations between the first (first four columns) and the second (from the fifth to the eighth column) set of estimations provides us with some information on their origin. As it could be observed, the variation is almost negligible, what leads us to think that the relationship between the use of the technologies could be due to the fact that they tend to be used jointly.

Our analysis also included control variables that are frequently used in the literature. In the case of firm size, the variable is shown to be an important predictor of the likelihood of having adopted that technology. This result is consistent for all the four technologies, although flexible manufacturing and robotics are the most responsive to size. Having controlled for size, the importance of financial constraints is also significant for both robotics and flexible manufacturing.

Three other firm specific variables present a significant impact on the adoption of new technologies. First, the propensity to export and the integration of the firm into a business group is positively associated with adoption in all the cases. Second, foreign ownership is only significant in the case of robotics. Finally, our results are also generally consistent with the persistence of an epidemic effect. The time dummies show that the use of all the four technologies is more frequent in 2006.

Conclusions and Implications

The evidence presented in this paper seems to confirm that the existence of certain complementary resources is associated to technology adoption. However, clear differences in adoption behaviour are identified depending on the technologies analysed. Our results show that only technological resources are unequivocally related to the use of new technologies in manufacturing firms. The fact that we have studied the use of advanced manufacturing technologies could help us to understand why these are the only complementary resources with explanatory power.

Our results add interesting evidence on the link between technology adoption and firm attributes. Although research in the information systems and technology adoption literatures has argued that complementary resources are needed to appropriate value creation, it has mainly focused on the analysis of performance. In this sense, this paper contributes by showing that the incentives of firms to adopt new technologies depend on the amount of complementary resources they possess. This not only adds some support to the hypothesis that complementary resources could help us to understand the link between technology adoption and competitive advantage, but also introduces a new, firm specific, element in the explanation of diffusion patterns. Moreover, we also add evidence into the existence of a complementarily relationship between process technologies.

In any case, the confirmation of the idea that complementary resources explain technology adoption should not lead us to necessarily conclude that they provide firms firm competitive advantages. This implication could only be maintained depending on the characteristics of the systems created and their inimitability and on the actions of competitors, which could progressively erode the rents (Koellinger, 2008).

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[ii] According the RBV, the adoption of new technologies per se may not generate a sustainable advantage because it can be commoditized through competitive imitation and acquisition (Clemons and Row, 1991; Mata et al., 1995; Powell and Dent Micallef, 1997). This notion, that has received increasing support in recent years, is known as the *strategic necessity hypothesis*.

[iii] The usual tests show that the sample is representative of the total population.

[iv] R&D spending has been deflacted using the Industrial Index (IPRI).

[v] Advertising spending has been deflacted using the Industrial Price Index (IPRI).