THE EFFECT OF TECHNOLOGICAL, COMMERCIAL AND HUMAN RESOURCES ON THE USE OF NEW TECHNOLOGY

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FUNDACIÓN DE LAS CAJAS DE AHORROS
DOCUMENTO DE TRABAJO
Nº 505/2010

De conformidad con la base quinta de la convocatoria del Programa de Estímulo a la Investigación, este trabajo ha sido sometido a evaluación externa anónima de especialistas cualificados a fin de contrastar su nivel técnico.

ISSN: 1988-8767

La serie **DOCUMENTOS DE TRABAJO** incluye avances y resultados de investigaciones dentro de los programas de la Fundación de las Cajas de Ahorros.
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Abstract

Our objective in this paper is to analyze the determinants of the use of process technologies among in manufacturing firms. We go beyond more traditional approaches and consider the role of complementarities in technology adoption at two levels. First, we adapt Teece's (1986) framework study the incentives to use new technology that stem from investments in the knowledge base of the firm and in marketing assets. We also take into account the quality of the services provided by employees. Second, we analyze whether technology use is conditioned by a system effect that arises from the use of related technologies. We test our hypotheses on a representative sample of manufacturing firms.

*Key words***:** Technology adoption, diffusion, complementarily, multivariate probit.
*JEL classification***:** O33, M19.

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Acknowledgements: We acknowledge financial support from the Spanish Ministry of Science and Technology and FEDER (project ECO2008-04129), the Regional Government of Aragón (project S09/PI138-08) and Universidad de La Rioja (project API 19/08). We are grateful for the comments and suggestions provided by Dolores Añón, Sergio Palomas and participants at seminars held at the Universities of Zaragoza and La Rioja.

1. INTRODUCTION

Our objective in this paper is to understand the role of complementarities in explaining technology use in 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 recently been shown (Greve, 2009) that differences in technology adoption could be more persistent than predicted by traditional economic models. Proving that complementarities between firm resources and new technologies are important in explaining adoption would provide us with an additional reason to reassess the idea that new technologies do not have any durable impact on performance. In other words, firm heterogeneity could provide an additional explanation to the observation that firm performance differs after adoption.

Rather than paying attention to more traditional explanations of diffusion, such as the ones provided by epidemic models, we focus on the interaction of firm resources and new technologies when developing our hypotheses. In doing so, we contribute to the literature by conciliating the idea that the returns on new technology are difficult to appropriate with the observation that the incentives to use new technologies are different, which suggests that firms could expect different returns from them, at least in the short run. More precisely, and taking into account the arguments provided by the resource-based view (Wernerfelt, 1984, Barney, 1986), we examine the role of the differences in resource endowments through the framework provided by Teece (1986, 2006). Given the weak appropriability of new technologies our attention focuses on the role of certain difficult-to-obtain assets in explaining the different stimuli that firms may have to use new technologies. Accordingly, we develop hypotheses that relate the presence of technological, commercial and human resources within the firm with the likelihood of observing technology use.

We test our hypotheses on a representative sample of firms operating in the manufacturing sector of 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. The four technologies that we examine 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 is in line 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 helps us to explore the hypothesis that the use of any technology could also be explained by the use of other technologies with which it forms a system (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 use of each technology would be inadequate, given that the decisions to adopt are potentially correlated. A solution to this problem may be through the estimation of a multivariate model, which takes the potential correlation into account. Looking at the correlations before and after the consideration of complementary assets would also allow us to evaluate the extent to which they are due to complementarities among the technologies or among these and firm resources.

The rest of the paper is organized as follows. In the next section, we integrate Teece's (1986) framework, the resource-based view and the literature on technology diffusion in order to develop four hypotheses on the role of complementary assets. This is followed by a section that 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. The final section concludes and discusses the implications for new technology management.

2. HYPOTHESES

To understand the factors that explain technology use by firms, we need to understand how firms profit from it. Early work on the diffusion of new technologies tended to concentrate upon epidemic models (Karshenas and Stoneman, 1993). However, contemporary approaches are characterized by less emphasis on information spreading and more attention on the heterogeneity in the population of potential adopters (rank models) in order to explain the incentives to adopt (see, for example, Karshenas and Stoneman, 1993). In this paper, we follow this second line of research and offer a view on technology use that is based on the differences in a firm's endowment of complementary resources. In order to do this, we first briefly outline Teece's (1986) framework on profiting from innovation and adapt it to the opportunities for profiting from technology use. We then focus on the analysis of complementarities. Accordingly, we develop hypotheses that relate technology use to the amount and/or quality of technological, marketing and human resources within the firm. Finally, we also consider the possibility that technology use could be driven by the presence of complementary technologies within the firm.

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. The appropriability regime is defined by (1) legal and (2) technological factors. The first refer 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.

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 include, for example, 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 boundaries in order to acquire the services needed to extract the returns from 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.

Teece's framework could be easily adapted to the analysis of how adopting firms profit from new technologies. The fact that new technologies are freely available in the market (there are no legal barriers protecting the adopter) has led some researchers to conclude that, in the long run, technology adoption might only provide competitive parity (Barney, 1991). Some authors have enunciated this as the strategic necessity hypothesis (Clemmons and Kimbrough, 1986; Clemmons and Row, 1991). Following this hypothesis, a focal firm would have incentives to adopt a valuable new technology. However, this would create incentives in rival firms to invest in the same technology in order not to obtain below normal profits. As long as new technologies are freely available in the market, the long-run result would be that rival firms would erode the rents accruing to first adopters, leading to competitive parity.

However, despite the weak appropriability regime of new technologies, the returns from their use 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). Despite the clear relationship between technology adoption and innovation (Koellinger, 2008; Santamaría, Nieto and Barge-Gil, 2009), the consideration of complementary resources in the context of technology adoption has mainly focused on their moderating role between the use of new technologies and performance. In other words, their use as determinants of adoption has been scarce. However, the existence of complementary resources could be an indicator of the stimuli that a firm has to adopt a new technology, given that their combination could provide the basis for sustainable competitive advantage. The idea that the combination of different resources could explain superior long-run performance is not only present in Teece's framework, but also in other papers. For example, trying to explain the sustainability of competitive advantage, Dierickx and Cool (1989: 1508) use the concept "interconnectedness" to reflect the fact that "*the difficulty of building one stock of resources is related not to the initial level of that stock, but to the low initial level of another stock which is its complement*". Similarly, Rivkin (2000) suggests that the complexity created by a large number of elements that positively interact can deter imitation.

Selecting the types of resources more likely to be positively combined with new technologies in order to provide competitive advantages is a difficult task. Although both tangible and intangible assets play an important role in creating an organization's value, intangible assets frequently present time compression diseconomies and they are typically tacit and hard to codify (Kogut and Zander, 1992; Conner and Prahalad, 1996). Additionally, they are likely to be traded in imperfect factor markets (Barney, 1986) and are not consumed by their use (Collins and Montgomery, 1998). Teece (2000) suggests that a firm's superior performance depends on its ability to defend and use the intangible assets it creates. Accordingly, in the following lines, we argue that technology adoption is conditioned by the possession of certain complementary resources that are difficult to acquire or copy, namely, technological, commercial and human resources.[1] Given that the use of new technologies could also be conditioned by the presence of other related technologies within the firm, we also analyze the presence of complementary relationships between technologies.

Technological resources and technology adoption.

Investments in research and development 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

[1] We are not claiming that difficult-to-imitate complementary resources are the only ones likely to interact with new technologies to provide competitive advantage. In fact, Rivkin (2000) points out that complex systems could be inimitable, even if their elements are not.

deeply embedded in the firm (Winter, 1987), which makes it difficult for competitors to copy them. 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, the knowledge base of the firm has frequently been related to technology adoption through the absorptive capacity concept. A firm's 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 greater ability of firms to understand valuable information, we should emphasize its role in the exploitation of 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. For example, this knowledge could be used to better understand and to refine a firm's productive process.

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 with more technological resources are more likely to use a new technology*

Commercial resources and technology adoption.

Complementarities are also present in 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 (Dierickx and Cool, 1989) or be socially complex (Barney, 1991). Marketing assets interact with new technologies in several ways. Investments in marketing activities help the firm to develop a good reputation or a brand image. These assets are quasi-public, in the sense that they can continue to deliver services after being used. In other words, once they have been developed, they can be used to support product development, market development or diversification (Ansoff, 1965). New technologies 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 also allow more frequent changes in the line of production, which could 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. New technologies may also complement marketing resources by making an improved use of this information. For example, computer aided design technologies are used to foster cooperation with providers and customers (Bharadwaj, 2000), because they provide a common language for electronic communication between firms (Sánchez, 1996). As mentioned above, new technologies could also be used to better adapt the product to consumer requirements, detected through investments in market research.

Hypothesis 2: *firms with more commercial resources are more likely to use a new technology*

Human resources qualifications and technology adoption.

The use of new technologies could be also related to workers' qualifications. The most common theory is the skill-bias technical change hypothesis, which states that there is a relationship of complementarity between new technologies and skilled workers because the latter are the only ones able to fully implement these technologies (Piva *et al*., 2005:143). Doms *et al.*, 1997 maintain that the positive correlation between technologies and the attributes of the workforce may be explained 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 who replace skilled craftspeople but also less skilled workers. Finally, many of these technologies require qualified support staff to install and maintain them.

More qualified workers also provide other abilities related to innovation and management that are important in the use of 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, in other words, the increasing ability of educated workers to effectively integrate new technologies into 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 highly qualified personnel are more likely to use a new technology*

Complementarities between technologies

As well as the complementarities between the use of new technologies and firm assets, complementarities between technologies may also arise (Stoneman and Kwon, 1994). According to Milgron and Roberts (1990), the adoption of a cluster of technological innovations, which share some basic technological properties, is subject to significant complementarities. Under such circumstances, interdependences must be taken into account as they are likely to affect diffusion.

Adopting powerful combinations of technologies can leverage the technology gap a firm possesses over its competitors (Castelacci, 2002). The key advantage which arises from the use of multiple process technologies is that they can build complex manufacturing systems, which make manufacturing programmable and lead 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. One way to achieve this consists of building systems in which the number of elements and the degree of interaction among them is what makes them inimitable (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 (Colombo and Mosconi, 1995).

Previous work on complementary technologies has provided theoretical arguments and empirical evidence on the existence of complementarities between different process technologies (Milgrom and Roberts, 1990, Stoneman and Kwon, 1994, Colombo and Mosconi, 1995, Arvantis and Hollestein, 2001, Astebro *et al*., 2005). 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 importance of complementarities across adopted technologies. Beede and Young (1996) found enormous diversity in adoption patterns within the same industry, as well as 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*. The use of a technology is positively related to the use of the other technologies with which it forms a system*

3. 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 it 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 were only included in 1994, 1998, 2002 and 2006. This does not permit us to establish causality relationships because the date of adoption of the technology is unknown. Fortunately, we do have lagged information on other firm and market characteristics that will be used as explanatory variables, as is explained below. 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.[2]

As mentioned above, we examine four manufacturing technologies whose use is very common and has been the subject of previous diffusion studies. In fact, they are part of what is termed Advance Manufacturing Technologies (AMT). AMT is used as an umbrella term to describe "an automated production system of people, machines and tools for the planning and control of the production process,

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

including the procurement of raw materials, parts and components and the shipment and service of finished products" (Pennings, 1987: 198). These technologies tend to be classified into three types: (1) design related technologies; (2) process related shop floor technologies and (3) information and control related technologies (Swamidass and Kotha, 1998:25).

A characteristic of these technologies is that they are easy to integrate electronically. The key advantage of AMT is that complex manufacturing systems may be built that make manufacturing programmable and lead to timely information transfer across departments, employees, customers and suppliers. This adds a new element to the study of complementarities: these technologies not only interact with the endowment of resources of the firm, but they are frequently used as a system. This reinforces the idea that complementarities have a key role to play in the understanding of performance differences and adoption behaviour.

Table 1 offers a first approximation to the data, showing the distribution of adopters and non adopters by technology, firm size and year. Given the different sampling procedures used to select firms depending on their size, we have chosen to perform the descriptive analysis by splitting the sample into the group of firms with fewer than 200 employees and those with more than 200 employees. As can be seen the number of adopters is different depending on the technology. CNC is the most used technology (51% in 2006), followed by CAD (40% in 2006). Robotics and flexible manufacturing systems show the lowest figures (32% and 22 %). A second clear conclusion from the data is that firm size conditions the introduction of the new technologies. For all the technologies and the years included in the sample, the group of firms with more than 200 employees presents a higher percentage of adopters than their smaller counterparts.

Table 1. Number of adopters and non adopters by technology, firm size and year

	CNC						ROBOTICS						CAD						SSFN					
	Total		Firm size < 200 employees		Firm size >= 200 employees		Total		Firm size < 200 employees		Firm size >=200 employees		Total		Firm size < 200 employees		Firm size >= 200 employees		Total		Firm size < 200 employees		Firm size >= 200 employees	
	Yes	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
1994	283	572	149	434	134	138	155	700	54	529	101	171	207	648	86	497	121	151	183	672	63	520	120	152
1998	521	667	271	518	250	149	312	876	112	677	200	199	420	768	196	593	224	175	317	871	117	672	200	199
2002	634	679	409	567	225	112	346	967	168	808	178	159	485	828	300	676	185	152	293	1020	157	819	136	201
2006	547	515	326	404	221	111	334	728	155	575	179	153	425	637	245	485	180	152	288	774	141	589	147	185

The expressions “Yes” and “No” indicate whether the firms have adopted or not

Looking at the distribution of adopters by industry (Table 2) we can detect clear differences. Firms in the “Motors and autos” industry are the most active in the adoption of CNC machines, followed by the ones operating in “Other transport material” and “Furniture”. The adoption of robotics shows its highest values in the “Motors and autos” sector, with the “Beverages” industry and “Other transport material” following. Firms belonging to “Other transport material”, “Motors and Autos” and “Machinery for agriculture and industry” are the most frequent users of computer aided design. Finally, in the case of flexible manufacturing systems the industries are “Motors and Autos”, “Other transport material” and “Paper”. In contrast, “Meat products” is the least active industry when adopting CNC, CAD and Flexible manufacturing and “Other manufacturing” in the case of Robotics.

Table 2. Number of adopters and non adopters in 2006 by technology and industry

	CNC		Robotics		CAD		SSFN	
Industry	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
Meat products	8	20	6	22	1	27	2	26
Food and tobacco	39	55	26	68	10	84	19	75
Beverages	6	10	7	9	4	12	6	10
Textiles and clothing	31	53	14	70	36	48	18	66
Leather and footwear	8	15	4	19	4	19	2	21
Wood industry	19	21	10	30	7	33	5	35
Paper	22	17	16	23	18	21	15	24
Edition and graphical arts	22	36	10	48	18	40	14	44
Chemical products	24	45	13	56	16	53	22	47
Plastic and rubber	32	29	26	35	26	35	18	43
Non-metallic minerals	35	41	27	49	24	52	17	59
Metallurgy	31	19	21	29	28	22	19	31
Metallic products	77	47	43	81	56	68	37	87
Machinery for agriculture and industry	49	27	25	51	53	23	24	52
Machinery for offices, data processing, etc.	6	7	4	9	7	6	3	10
Electrical material and accessories	31	23	21	33	31	23	17	37
Motors and autos	46	15	38	23	43	18	28	33
Other transport material	12	4	7	9	14	2	7	9
Furniture	41	20	13	48	24	37	12	49
Other manufactures	8	11	3	16	5	14	3	16
Total manufacturing	547	515	334	728	425	637	288	774
χ^2	72.22***		68.50***		160.18***		44.01***	

Hypotheses measurement

Stock of technological resources. We approximate the stock of technological resources by using the ratio of research and development capital to sales[3]. For any given year (t) for which data on technology adoption is available, we compute research and development capital (K) through a partial inventory of past (3 previous years) and present annual internal R&D expenditures (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% in accordance with Griliches (1981), Griliches *et al.*, (1981), Adams (1999) or Villalonga (2004). The use of a depreciation rate can be explained by the decay of knowledge over time (Argote et al., 1990) and by the loss of economic value due to the development of new knowledge and technologies (Oriani and Sobrero, 2003).

Stock of commercial resources. Similarly to technological resources, the stock of commercial resources is measured as the ratio of commercial capital to sales. As with technological capital, for any given year (t) for which data on technology adoption is available, the value of commercial capital (P) is constructed using a partial inventory of past (3 previous years) and present annual advertising expenditures (A) with a constant depreciation rate, δ:

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

Even though there is no consensus in the literature on the rate of depreciation, we follow Hirchey and Weygandt (1985) and Villalonga (2004) 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 possess a university degree. With this information, we calculate the ratio of the number of employees with a university degree to the total number of employees of the organization. This measure has been used in previous papers (Doms et al., 1997; Arvanitis and Loukis, 2009).

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[3] Sales, R&D Spending and advertising have been deflated using the Industrial Index (IPRI).

Control variables

Firm Size. Firm size has traditionally played 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 about the underlying mechanism still remains. 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 possesses in areas such as production or marketing would positively influence profitability. Hence, larger firms would obtain more profitability from the technology and would have more incentives to adopt it early (Teece, 1986; Colombo and Mosconi, 1995). A second explanation focuses on the concept of economies of scale. Larger firms are able to spread the cost of investing in 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 better able to finance the adoption of new technologies.

Although there are some studies that have found a negative impact of firm size on inter-firm diffusion (Oster, 1982), the empirical evidence tends to favour the positive effect (Astebro, 2002). This positive influence is consistent across different sectors and technologies and examples are found in the electric utility industry (Rose and Joskow, 1990), in the engineering and metalworking industries (Baptista, 2000, Swamidass, 2003) and in the banking industry (Hannan and McDowell, 1984a,b,1986; Sharma, 1993, Buzzachi *et al*., 1995). Hence, a positive relationship between firm size and the probability of adoption is hypothesized. We measure firm size through the number of workers of each firm.

Financial constraints. The literature on diffusion attributes a role to financial constraints in the determination of a firm’s adoption behaviour. Despite the foreseeable significance of this variable at explaining diffusion, only a few papers pay 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 intrafirm diffusion. Fuentelsaz, Gómez and Polo (2003) assess the impact of firm profitability and total reserves on 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 the 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 with 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 assets.

Corporate status. The corporate status of a firm may also have an impact on the decision to adopt. By corporate status we mean 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), Bartoloni and Baussola (2001), the effect of this variable on the 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, 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 the 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 favour 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 favour 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 its life cycle (Kleinknecht and Poot, 1992). Previous evidence on adoption models revealed a positive impact of foreign ownership (Baldwin and Diverty, 1995; Bosworth, 1996; Faria *et al.*, 2003), 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. 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 in the international arena. Research on the determinants of R&D investments has shown a positive association between export intensity and R&D (Veugelers and Cassiman, 1999, and Beneito, 2003). However, the available evidence in a context of technology adoption does not offer conclusive results. Cohen (1975) and Riedel (1975) analyzed the relationship between the adoption of new technologies and the export performance of electronic firms in developing countries, finding a positive relationship between the use of advanced technologies and exports. However, more recently, Lal (1999, 2002) found that export intensity did not affect the adoption of information technologies. The ratio of total exports to sales is used in order to capture the effect of this variable.

Industry specific rank effects. We also consider two industry specific influences on technology adoption. First, market structure has been frequently linked 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 (Pavitt, 1984) across different industries. Although we do not make any conjecture on the effect of the industry on technology adoption, our empirical model does consider the fact that some technologies may not be as adequate in some industries as in others. Accordingly, we introduce 19 dummy variables to account for the 20 different sectors identified in the survey.

Finally, and due to the fact that traditional models of diffusion have also taken into consideration other determinants of technology use, we introduce epidemic and stock effects into our model (Karshenas and Stoneman, 1993). Both effects are taken into account through the inclusion of time variables. The passage of time has two opposite 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 produce 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 ambiguous (Baptista, 2000; Luque, 2002). 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.

Table 3 shows a first assessment of the hypotheses developed above. It presents mean values and standard deviations for the variables defined in this section and for the different technologies considered, distinguishing between firms that use the technology and those which do not. Table 3 also provides evidence about the existence of a positive relationship between technology use and several of the variables considered in this research, namely, firm size, the stock of technological resources, human resources, export propensity, the fact that the firm is integrated in a business group and the presence of foreign investors in its capital.

Table 3. Explanatory variables and the adoption of manufacturing technologies in Spanish manufacturing

	Numerically controlled machines					Robotics					CAD					SSFN				
	Yes 1985			No 2433		Yes 1147			No 3271		Yes 1537			No 2881		Yes 1081			No 3337	
	Mean		SD		Z (p v)	Mean		SD		Z (p v)	Mean		SD		Z (p v)	Mean		SD		Z (p v)
	Yes	No	Yes	No		Yes	No	Yes	No		Yes	No	Yes	No		Yes	No	Yes	No	
Firm size	0.31	0.15	0.78	0.44	8.08***	0.48	0.14	1.03	0.35	11.20***	0.37	0.16	0.83	0.46	8.43***	0.49	0.14	1.09	0.32	10.36***
Firm debt ratio	0.55	0.56	0.22	0.23	-0.37	0.53	0.56	0.21	0.23	-4.08***	0.50	0.55	0.21	0.23	2.08**	0.53	0.56	0.21	0.23	-4.16***
Stock technological resources	0.01	0.01	0.04	0.04	5.88***	0.02	0.01	0.04	0.03	7.14***	0.03	0.00	0.04	0.03	10.72***	0.02	0.01	0.05	0.03	8.30***
Stock commercial resources	0.02	0.03	0.05	0.16	-2.29**	0.03	0.02	0.13	0.12	1.96**	0.06	0.03	0.12	0.05	-2.08**	0.02	0.03	0.06	0.14	-0.35
Human resources	0.12	0.09	0.12	0.13	5.52***	0.13	0.09	0.12	0.13	7.82***	0.12	0.09	0.23	0.13	9.02***	0.14	0.10	0.14	0.13	9.49***
Export propensity	0.24	0.15	0.27	0.24	11.51***	0.30	0.15	0.27	0.24	16.04***	0.21	0.14	0.28	0.23	14.55***	0.27	0.16	0.27	0.20	11.11***
Market concentration	0.40	0.40	0.13	0.12	0.96	0.41	0.40	0.13	0.13	2.17**	0.40	0.40	0.14	0.12	1.33	0.40	0.40	0.13	0.12	-0.73

		Numerically controlled machines				Robotics				CAD				SSFN			
		Yes	No	χ^2	Phi	Yes	No	χ^2	Phi	Yes	No	χ^2	Phi	Yes	No	χ^2	Phi
Integrated in business group	**Yes**	852	624	146.63***	0.18	660	816	405.55***	0.30	696	780	149.38***	0.18	580	896	263.67***	0.24
	No	1133	1809			487	2455			841	2101			501	2441		
Foreign capital	**Yes**	472	340	70.03***	0.13	387	425	243.67***	0.24	393	419	81.22***	0.14	325	487	130.27^{**0}	0.17
	No	1513	2093			760	2846			1144	2462			756	2850		

*, **, *** coefficient statistically significant at a 90%, 95% or 99% level.

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Estimation strategy

The data set we use describes adoption as a discrete choice, which suggests 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 make 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, 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 some other technology, this means the two decisions are interdependent. Therefore, the estimation of any model of adoption should consider the fact that the firm may be using other complementary technologies.

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; Santamaria and Rialp, 2007). In fact, the arguments that we have used in this paper about the existence of complementarities between resources and technology could be extended to other assets that are unobservable. 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.

4. RESULTS

Table 4 shows the results of estimating a multivariate probit on the 4,418 observations available. Columns 1 to 4 estimate four models in which only control variables are included. They are used as a benchmark. A second set of estimations is presented in columns 5 to 8, which introduce the variables that help us to test our hypotheses. As we can see, all the models are globally significant, given the high values of the LR statistic. Furthermore, their comparison favors the estimations presented in columns 5 to 8. As shown at the bottom of Table 1, the LR test is highly significant, pointing to the importance of complementary resources for explaining adoption. Importantly, not only the coefficients but also the t-ratios accompanying them remain fairly stable across the two sets of estimations.

Hypothesis 1 argued that firms with more technological resources would be more likely to use 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. Therefore, the evidence confirms our hypothesis that the use of new technologies is favoured by the presence of higher levels of R&D-derived knowledge inside the firm.

Similarly, Hypothesis 2 stated that firms with more marketing resources would be more likely to use new process technologies. In this case, we find clear differences between the four technologies analyzed. 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 result contradicts our expectations to find a positive effect for all the technologies considered.

Finally, 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. 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 result seems to resemble that of Dunne and Troske’s (2005) paper. These authors found that the effect of skilled labour on technology use varied across technologies, finding a stronger correlation between technologies associated with design and engineering functions and human resources than those more closely associated with production activity.

Our analysis also included a set of control variables that are frequently used in the literature. Firm size is an important predictor of the likelihood of using a technology. Having controlled for size, the importance of financial constraints is also significant for both robotics and flexible manufacturing.

Table 4. The effect of technological, commercial and human resources on new technology adoption

	CNC(1)	Robotics(2)	CAD (3)	SSFN (4)	CNC (1)	Robotics (2)	CAD (3)	SSFN (4)
Firm size	0,17*** (3.76)	0.38*** (7.77)	0.19*** (4.47)	0.48*** (9.35)	0.16*** (3.50)	0.36*** (7.28)	0.17*** (3.89)	0.46*** (8.82)
Firm debt ratio	-0.08 (-0.87)	-0.29*** (-2.92)	0.10 (1.11)	-0.33*** (-3.41)	-0.07 (-0.83)	-0.28*** (-2.80)	0.12 (1.29)	-0.33*** (-3.36)
Stock of technological resources	--	--	--	--	1.61*** (2.86)	2.42*** (4.12)	3.66*** (6.32)	2.81*** (4.86)
Stock of commercial resources	--	--	--	--	-0.22 (-0.91)	0.42*** (2.70)	0.32* (1.74)	-0.33 (-0.95)
Human resources	--	--	--	--	0.12 (0.71)	0.14 (0.73)	0.66*** (3.64)	0.71*** (3.88)
Export propensity	0.44*** (5.17)	0.63*** (7.13)	0.51*** (5.74)	0.33*** (3.75)	0.41*** (4.81)	0.60*** (6.65)	0.44*** (4.92)	0.28*** (3.13
Market concentration	-0.38 (-1.32)	-0.26 (-0.84)	0.20 (0.64)	0.31 (0.99)	-0.35 (-1.22)	-0.23 (-0.74)	0.23 (0.75)	0.32 (1.02
Integrated in a business group	0.30*** (5.69)	0.47*** (8.39)	0.33*** (6.01)	0.39*** (7.10)	0.29*** (5.37)	0.45*** (7.95)	0.28*** (4.93)	0.35** (6.21)
Foreign capital	-0.02 (-0.01)	0.16** (2.49)	-0.04 (-0.64)	-0.01 (-0.21)	-0.00 (-0.08)	0.18*** (2.82)	-0.01 (-0.22)	0.00 (0.02
Year 1998	0.24*** (3.98)	0.23*** (3.36)	0.35*** (5.37)	0.14** (2.16)	0.24*** (4.02)	0.25*** (3.64)	0.37*** (5.60)	0.14** (2.17
Year 2002	0.34*** (5.69)	0.27*** (3.95)	0.38*** (5.84)	0.02 (0.31)	0.34*** (5.66)	0.29*** (4.17)	0.39*** (5.87)	0.01 (0.09)
Year 2006	0.40*** (6.48)	0.39*** (5.72)	0.45** (6.84)	0.13* (1.93)	0.40*** (6.44)	0.42*** (5.98)	0.47*** (6.88)	0.11* (1.68)
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-0.87*** (-4.32)	-1.44*** (-6.30)	-2.47*** (-9.28)	-1.74*** (-7.32)	-0.89*** (-4.38)	-1.49*** (-6.52)	-2.54*** (-9.52)	-1.76*** (-7.36)
Rho2,1	0.409*** (17.46)				0.409*** (17.40)			
Rho3,1	0.457*** (21.18)				0.458*** (21.16)			
Rho4,1	0.292*** (11.80)				0.290*** (11.67)			
Rho3,2	0.405*** (16.77)				0.403*** (16.53)			
Rho4,2	0.297*** (11.69)				0.294*** (11.48)			
Rho4,3	0.413*** (17.13)				0.404*** (16.54)			
No. Observations	4,418				4,418			
Wald Test	1907.70***				1992.44***			
LR test of Rho2,1=Rho3,1=Rho4,1= Rho3,2= Rho4,2=0 Rho4,3=0	1047.75***				1025.56***			

*, **, *** coefficient statistically significant at the 90%, 95% or 99% level.

Three other firm-specific variables present a significant impact on the adoption of new technologies. The propensity to export and the integration of the firm into a business group is positively associated with adoption in all the cases. Foreign ownership is only significant in the case of robotics. This is consistent with previous literature on the diffusion of new technologies, in which the variable is significant depending on the technology (Faria *et al.*, 2003; Gómez and Vargas, 2009). 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.

Apart from assessing the impact of certain complementary resources on adoption, the use of the multivariate probit model also allows us to estimate the correlations between the technologies once the variables included in Table 1 have been controlled for. These correlations are presented at the bottom of Table 1 and provide us with a way of testing Hypothesis 4. They could be interpreted in two ways. 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. Therefore, they provide us with a way of assessing the influence of unobservable firm effects. Second, a positive correlation could mean that the technologies form part of a system. Hence, the adoption of one technology would increase the probability of the adoption of the other technologies of the system. 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 can be observed, the variation is almost negligible, which leads us to think that positive values of the correlations are motivated by the fact that the technologies analyzed tend to be used jointly.

A possibility to further investigate Hypothesis 4 could be to re-estimate our full model adding other technologies that we suspect of not being related to advanced manufacturing technologies. In other words, the correlations between non-related technologies should capture the influence of non-observable firm-specific effects related to the adoption of *all* the technologies. Fortunately, our data set also contains information on the adoption of three Internet technologies. In particular, from 2002, and every four years, the survey includes a question on whether the firm "buys goods or services (providers) through the Internet" (S2B), whether "it sells to final consumers through the Internet" (B2C) and whether "it sells to firms through the

Internet" (B2B). Given that the three technologies supporting these systems are not obviously related to advanced manufacturing technologies, a dramatic reduction in the value of the correlations should be observed. Unfortunately, this significantly restricts our observation window (to years 2002 and 2006) and the number of available observations (to 2,367).

The correlations resulting from estimating a full model[4] with the seven technologies are presented in Table 5. The conclusion is that the correlations between advanced manufacturing and Internet technologies are clearly lower than the ones within the groups. The highest correlation between the two groups is 0.199 (B2B and SSFN), the value is non-significant in two of the cases (CAD-B2B and CAD-B2C) and three correlations are below 0.10. Although we cannot interpret this as conclusive evidence that the correlations are not due to firm-specific factors, given that some of the inter-group correlations are positive and significant, the data shows the importance of the identity of the technologies analyzed. In other words, our results do confirm that complementarities between related technologies exist and that they are very different from the ones corresponding to unrelated technologies, confirming Hypothesis 4.

Table 5. Correlation matrix between process and information technologies

	CNC	Robotics	CAD	SSFN	B2B	B2C
CNC	1	--	--	--	--	--
Robotics	0.414***	1	--	--	--	--
CAD	0.470***	0.396***	1	--	--	--
SSFN	0.337***	0.357***	0.436***	1	--	--
B2B	0.105***	0.090*	0.075***	0.122***	1	--
B2C	0.138***	0.130**	0.009	0.199***	0.797***	1
S2B	0.080***	0.067*	0.131***	0.178***	0.373***	0.355***

*, **, *** coefficient statistically significant at the 90%, 95% or 99% level.

5. CONCLUSIONS AND IMPLICATIONS

In this paper, we have argued that complementary resources are one of the mechanisms that firms use to profit from the use of new technologies. One implication of this hypothesis is that the use of new technologies should be more likely in those firms that possess more complementary assets. The evidence presented in this paper seems to confirm our conjecture: complementary resources are associated with a firm's technology use.

[4] Results of the multivariate probit model are shown in appendix 1.

Clear differences in adoption behaviour are identified depending on the technologies analysed. More precisely, 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 this result. These technologies are related to product manufacturing and design. Therefore, investments in the knowledge base of the firm could have served to understand and refine both processes, detecting the need and the role of new technologies. Marketing and human resources are also important, although they present different effects depending on the technologies analyzed. Marketing investments are only related to robotics and computer aided design, whereas the quality of the services provided by human resources is positively related to computer aided design and flexible manufacturing.

Finally, we also explain the use of new technologies through the complementarities that arise within systems of technologies. In fact, the interrelations between some of the technologies are the main reason that we observe positive correlations between them, once we control for the determinants of adoption. This supports the view of those that contend that the diffusion of new technologies should not be analysed in isolation.

Our results have implications for the study of technology diffusion and competitive advantage. With respect to the former, they support the move from epidemic to rank models undertaken by the literature on diffusion in recent years. Epidemic models contend that firms adopt new technologies once information on their characteristics reduces the uncertainty surrounding the innovation. However, although important, research has shown that information diffusion is not the only mechanism that explains why some firms are early users and others delay the adoption of the technology until the latest stages of the diffusion process or do not invest in it at all. Although the range of factors involved adds complexity to any explanation provided, the literature and our results show that complementarities play an important role.

These results also have implications for understanding firm heterogeneity and competitive advantage in the context of technology diffusion. The main argument for maintaining that, despite their positive effects on firm activities, new technologies are not related to sustainable competitive advantage is based on the idea that they can be acquired in the market. The literature on information systems has coined the term *strategic necessity hypothesis* to refer to this idea (Clemmons and Kimbrough, 1986; Clemmons and Row, 1991). However, recent research in strategic management has concluded that the process of technology diffusion among firms may not be as regular and widespread as expected. Greve (2009) has shown that social networks and cluster theory affect the diffusion of technologies. Our results contribute to this line of research by showing that the initial levels of heterogeneity of firm resources could produce very different results. In fact, they suggest that complementarities between firm resources and new technologies create varying incentives for firms to adopt, providing an additional dimension (the technology) through which to differentiate themselves.

In other words, far from leading to resource similarity and competitive parity, the process of technology diffusion could create further heterogeneity, at least in the short run. The questions that remain are whether this increased heterogeneity is permanent and whether it can create competitive advantages. The answer, again, seems to depend on the balance between differentiation and homogenization. Although research on the interfirm dimension of diffusion tends to show that the process of adoption affects the majority of the firms operating in an industry (but see Greve, 2009), research on the intrafirm dimension shows that differences in the intensity of technology adoption increase over time (Fuentelsaz, Gómez and Palomas, 2009). However, the role of competitive imitation seems to be important when determining the effect on performance. Although research on the diffusion of new technologies has recognized that a firm's returns cannot be assessed in isolation when arguing in favour of stock and order effects (see, for example, Kashernas and Stoneman, 1993) and has also studied the influence of rivals' adoptions on the diffusion of new technologies (Hannan and McDowell, 1994), the predominant view conceives competitors as information diffusers. Therefore, the role of competition, heterogeneity generation and competitive advantage creation should be more explicitly considered in technology diffusion studies. In the end, imitation would depend on the characteristics of the systems created and their inimitability and on the actions of competitors, which could progressively erode the rents of early adopters (Koellinger, 2008). In any case, the confirmation of the idea that complementary resources explain technology adoption and increase firm heterogeneity should not necessarily lead us to conclude that the net effect of technology on profitability is positive. Even if the relative positions of the firms are maintained or even if some firms improve their advantage over their rivals, the high investments necessary to acquire new technologies could imply that all the firms reduce their initial levels of profitability if they are not able to compensate for them.

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APPENDIX 1. Additional results.

Table 6. Multivariate probit estimation with all the technologies

	CNC(1)	Robotics(2)	CAD (3)	SSFN (4)	B2B (5)	B2C (6)	C2B(7)
Firm size	0,15** (2.36)	0.34*** (5.06)	0.07 (1.21)	0.37*** (5.71)	0.15** (2.94)	0.11* (1.75)	0.08* (1.72)
Firm debt ratio	-0.04 (-0.34)	-0.27** (-2.04)	0.07 (0.53)	-0.39** (-2.98)	0.20 (1.16)	-0.05 (-0.25)	0.33** (2.40)
Stock of technological resources	-0.78 (-0.54)	2.09** (2.35)	3.87*** (4.02)	2.29** (2.63)	1.00 (0.90)	1.10 (0.81)	2.83*** (3.24)
Stock of commercial resources	-0.22 (-0.54)	0.44* (1.82)	0.34 (1.14)	-0.63 (-1.09)	0.51 (1.64)	0.40 (0.90)	0.62** (2.69)
Human resources	0.08 (0.38)	0.12* (0.51)	0.74*** (3.26)	0.81*** (3.56)	0.67** (2.27)	0.96** (3.02)	0.73*** (3.18)
Export propensity	0.45*** (3.94)	0.66*** (5.62)	0.51*** (4.31)	0.18 (1.53)	0.18 (1.11)	0.03 (0.17)	0.35** (2.82)
Market concentration	-0.39 (-0.75)	-0.31 (-0.57)	0.46 (0.86)	-0.33 (-0.60)	-0.08 (-011)	-0.12 (-0.13)	-0.31 (-0.55)
Integrated in a business group	0.29*** (4.12)	0.44*** (6.03)	0.18** (2.47)	0.25*** (3.39)	0.26** (2.68)	0.06 (0.57)	0.15* (1.88)
Foreign capital	-0.02 (-0.18)	0.15* (1.78)	-0.06 (-0.64)	0.07 (0.77)	0.19* (1.78)	0.02 (0.13)	-0.04 (-0.39)
Year 2006	0.61 (1.09)	0.13** (2.09)	0.10 (1.63)	0.16** (2.53)	0.29*** (3.32)	0.07 (0.75)	0.45*** (6.88)
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-0.59* (-1.95)	-1.16*** (-3.47)	-2.17*** (-9.83)	-1.66*** (-4.35)	-2.16*** (-4.64)	-2.27*** (-4.03)	-1.79*** (-5.11)
No. Observations	2367						
Wald Test	1220.78***						

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