THE PRODUCTIVITY EFFECTS OF INTRAFIRM DIFFUSION

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Abstract. This paper studies the performance impact of the intrafirm diffusion of new technologies. We argue that little connection between the literatures on technology diffusion and on the performance effects of adoption exists. We analyze the approaches taken when studying the performance effects of innovation and propose a method that accounts for the pace of intrafirm diffusion. Our sample describes the within-firm diffusion of the ATMs among the Spanish savings banks from 1986 to 2004. We conclude that, after controlling for the endogeneity of adoption, only this new approach is able to capture the contribution of the technology to productivity.

Key Words: Innovation, Intrafirm diffusion, Productivity, ATM.

JEL Codes: L80, O31, O32

Introduction

Research devoted to the study of new technologies in management and economics has addressed two main topics, namely, their introduction and the performance impacts of technology adoption. When studying the introduction of new technologies, researchers have considered two different dimensions of the process: *interfirm diffusion* and *intrafirm diffusion.* The former is an external dimension, which refers to the process that leads firms to the adoption (of one unit) of a new technology (see, for example, Levin, Levin and Meisel, 1987; Mansfield, 1989 or, more recently, Astebro, 2002). The latter is the internal perspective of technology adoption, which has received much les attention in the literature. The idea of intrafirm diffusion refers to the level of usage of the new technology within the firm (Mansfield, 1963; Karshenas and Stoneman, 1993; Fuentelsaz, Gómez and Polo, 2003; Battisti and Stoneman, 2003; 2005). One straightforward conclusion reached on this research stream is that the adoption of a technology and its posterior diffusion within the firm is a complex and irregular process which takes some time to be completed.

The second topic refers to the consequences that technology adoption has on firm performance. Researchers working on this subject have attempted to understand how a new technology can improve the productive process of adopters, and the factors that moderate the relationship. Despite the fact that both research streams focus on the two sides of the same coin, there exist little knowledge transfer between them. As we will point out later, just a few papers devoted to the analysis of the consequences of adoption have incorporated the stylized facts stemming from technology adoption research. One particular point attracts our attention in this paper: most of previous research considers technology adopters as an homogeneous group, and, thus, they do not distinguish among the different stages of internal development of the technology. In contrast, our approach attempts to integrate both research streams by recognizing that the decision to adopt an innovation does not imply an immediate and full use of it within the organization.

The main objective of this article is to clarify the effects that the introduction and intrafirm diffusion of new technologies may have on firm productivity (i.e. enhance the productive capacity of the adopter). We achieve this goal by integrating both, the literature on the diffusion of new technologies and the one analyzing the effects on new technology adoption on performance. In order to reach that target, we analyze previous research on the advantages stemming from technology adoption. Our review leads us to examine the approaches followed in that literature and the conception of the process of technology diffusion that can be inferred from them. After that, we propose what we consider is a more appropriate approach, by analyzing the effect of intrafirm diffusion on firm productivity.

The paper is structured as follows. The next section focuses on reviewing the literatures that link technology adoption and performance and the one on intrafirm diffusion, pointing at the opportunities for improvement. After that our hypothesis that the level of use of the new technology has a positive impact on productivity, is tested. In order to do this, we use a sample of Spanish savings banks for which data on the diffusion of an innovation (Automated Teller Machines) is available for the last 20 years. The paper closes with a description of the main conclusions and implications for future research.

The impact of technology adoption on performance

If we consider the vast amount of literature devoted to the issue, researchers have been very concerned with the importance of innovation on the competitiveness of the companies at the aggregated level (Geroski, 1991; Ray, 1991; Brynjolffson and Yang, 1996; Mayhew and Neely, 2006). Despite the fact that their conclusions are in some cases still far from being uniform, the results on aggregated levels of analysis show a positive effect of technology adoption on productivity and, in turn, on competitiveness.

From a micro level analysis, research on the effects of innovation on productivity has investigated its consequences on two different dimensions of the productive process: total factor productivity and labor productivity (Mayhew and Neely, 2006). For both dimensions, it has been demonstrated that innovations do have a positive effect, with adopters increasing their competitiveness and outperforming non-adopters (Cainelli, Evangelista and Savona, 2006)

The approach usually employed to assess the consequences of technology adoption on labor productivity is to directly compare labor productivity of adopters versus non adopters (Cainelli, Evangelista and Savona, 2006; Llorca, 2002). A distinction is usually made between product innovations (those which imply the launch of a new product or improvements on the present line of products) and process innovations (those which imply changes on the productive process of the firm). Process innovations usually show a significant positive effect on productivity, while the significance of the positive effect of product innovations over productivity seems to be less clear.

As mentioned above, the second variable of interest for investigations grounded on economics is total factor productivity (Griffith et al., 2006; Parisi, Schiantarelli and Sembenelli, 2006). In accordance with the conclusions drawn from the literature, a significant and positive effect of innovation on productivity is found when process innovations are analyzed. Globally, all these results provide us with enough arguments to defend that innovations actually influence productivity in a positive manner. The agreement reached regarding process innovations seems natural, given that their nature necessarily implies increases on firm efficiency.

A common feature of the research devoted to the analysis of the impact of innovation on performance is that it tends to compare the productivity of the firm before and after the adoption of the new technology (Cainelli, Evangelista and Savona, 2006; Griffith et al., 2006; Llorca, 2002; Parisi, Schiantarelli and Sembenelli, 2006). However, these papers do not control for the potential different levels of usage of the new technology. If the relationship between innovation and productivity were as simple as implicitly constrained by this approach, the whole benefits stemming from an innovation would be realized at the date of adoption. This static approach has been useful since it has allowed researchers both to demonstrate that there is a real effect of innovation on productivity and to test different moderating effects. In contrast, this approach neglects extant knowledge about the technology diffusion process. Research on technology diffusion suggests that an innovation evolves within the firm in a dynamic manner, following a diffusion process which begins with the adoption of the technology and needs time before being completed, thus some delay on the achievement of the predicted productivity gains would be expected. The next section reviews the literature that integrates both knowledge on intrafirm diffusion and the performance effects of new technologies. It analyses the main drawbacks in the literature and proposes a new approach to assess productivity effects.

Intrafirm diffusion and productivity

The papers reviewed above tend to consider the adoption of a new technology as the key event determining productivity effects. However, as the literature on diffusion recognises, the adoption of an innovation can be considered an evolution rather than a shock on the productive process. A firm should expect the gaining stemming from innovations to take some time before it is completely finished. There are different reasons for this assumption. The diffusion process takes some time before being completed due, for example, to the presence of time compression diseconomies. This means that the faster the increase on internal level of usage of the technology, the higher the cost of introducing it because of the efforts needed to train employees in its use or the opportunity costs of waiting for decreases on the price of the innovation. In addition, customers may need some time to get accustomed to the new characteristics of the product when the innovation changes it in a significant manner.

Just a few papers have considered that the benefits stemming from innovation are received through time, improving the analyses performed by the empirical research reviewed above. It is the case of the work by Dos Santos and Peffers (1995) that study the banking sector in the USA. Their dependent variable is the loan market share premium obtained by first movers and early followers in the banking industry when adopting ATMs. In this work, authors point at advantages such as learning effects, preemption of cospecialized assets, reputation or privileged access to critical resources as the causes of sustained performance premiums obtained by early adopters. Their findings show that the sooner the adoption has taken place, the greater is the loan market share premium for the firm (after controlling for other factors). In a later work, Peffers and Dos Santos (1996) study the temporal evolution of the performance gains obtained with ATMs adoption. They conclude that these gains increase through time, and they can be better explained with an exponential or a logistic relationship. In both papers, authors study the market performance impact of innovation, and the main driver of performance is the time elapsed from adoption.

In a more recent work, Haynes and Thompson (2000) measure the productivity impact of information technologies in order to deal with the so called "IT paradox". They attempt to assess productivity gains stemming from the new technology on the five years following adoption. Their results show positive and significant productivity improvements for that period, with a seemingly increasing effect on productivity through time, which, as they point out, could be a consequence of certain degree of endogeneity (best managers adopt before).

Although these papers incorporate a dynamic dimension to the analysis of the effects of technology adoption, they fail to incorporate knowledge on the literature on diffusion. First, this conception about the productivity impact of technology adoption maintains that early adopters obtain greater rents. However, early adopters do not necessarily have to obtain greater rents from the adoption of technologies than later adopters will do. As Jensen (1988) suggests, the moment of adoption might depend both of the opportunity cost of the adoption (there exist potential benefits of waiting to gather more information about the technology) and the expected gains foregone in the case of waiting. This implies that more skilled firms (i.e. those with higher absorptive capacities) could have a real option (Dixit and Pyndick; 1995) on delaying the investment on the new technology in order to gather more information and reduce uncertainty and costs. Therefore, the order in adoption would not reflect the order in absorptive capacities. In addition, Parisi, Schiantarelli and Sembenelli (2006), employing expenses on R&D as proxy for absorptive capabilities, conclude that organizations with higher absorptive capabilities obtain superior productivity gains related to technology adoption than those firms with lower absorptive capabilities. These two results together call into question the consideration of time elapsed from adoption as the main driver of productivity gains.

Second, and more important, their analyses focus on the interfirm dimension of diffusion, failing to incorporate existing knowledge on intrafirm diffusion. Authors on the aforementioned articles exclusively consider the initial moment of adoption of the new technology. In other words, in those articles it is considered that once the technology is adopted, both the diffusion path within the firm and the productivity gains are settled. However, the literature on intrafirm diffusion shows that, for a wide range of innovations, the adoption of the first unit of the technology is just the starting point of a complex and potentially long process of internal diffusion.

There are a few papers that have recognized the importance of intrafirm diffusion when assessing productivity effects. However, either their approach to the analysis or the availability of adequate data have prevented them from incorporating existing knowledge on the intrafirm diffusion process. Thus, Stoneman and Kwon (1996) study the profitability increase stemming from the adoption of several technologies, namely, CNC, computers, microprocessors and Coate Carbide Tools. They asses the importance of rank (characteristics of the firm), order (position occupied by the firm amongst the adopters), stock (number of adopters) and epidemic (technology transmission as a consequence of information externalities) effects on performance. They find that there are significant rank and stock effects, but they reject the influence of epidemic or order effects. These authors acknowledge the important role of intrafirm diffusion on productivity, but they argue that it could be approximated by the time elapsed from adoption. Its impact on performance, after controlling for the aforementioned effects, is shown to be non-significant.

Similarly, Kwon and Stoneman (1995) study the changes on productivity stemming from the adoption of new process technologies. Again, the time elapsed between the date of adoption and the date of observation is supposed to reflect the process of intrafirm diffusion of the technologies studied. Their findings are that two out of five technologies show a positive and significant impact of time from adoption on productivity. The other three technologies showed non-significant parameters.

In these articles, the time from adoption is used either as a proxy for intrafirm diffusion or for a non-specified dynamic aspect of innovation (e.g. learning) to assess the effect of technology adoption on productivity. However, based on the literature of intrafirm diffusion, the level of use of the technology rather than the time from adoption should be the real driver of productivity. It seems obvious that if a new technology results more productive than the old one (and this seems to be the case, according to the findings of the literature), the global productivity of the firm would only increase as the new technology replaces the old one. As mentioned above, time from adoption has been considered a proxy for intrafirm diffusion (Kwon and Stoneman, 1995; Stoneman and Kwon, 1996), an approach which can result useful in case of unavailability of sufficient information. However, it neglects the specificities of the intrafirm diffusion process. The time profile of the intrafirm diffusion presents a logistic or an S-shape form, which has been justified both theoretically (Stoneman, 1981; Jensen, 2001) and empirically (Mansfield, 1963). Therefore, a linear approach, despite its high potential correlation with intrafirm diffusion, could be improved by using the actual level of usage. In addition, when using time from adoption to capture intrafirm diffusion, homogeneity in both the level of usage and the rate of intrafirm diffusion amongst adopters in similar dates is imposed. This is counterfactual, according to Mansfield (1963), Fuentelsaz, Gómez and Polo (2003) or Battisti and Stoneman (2003), who report very heterogeneous rates of intrafirm diffusion and levels of usage in firms operating in the same industry and adopting in similar dates of time.

Our intention in the following sections is to incorporate extant knowledge on technology diffusion to improve the efforts previously devoted to the analysis of the productivity impact of technology adoption. It seems clear that it is the intrafirm diffusion of the technology rather than the date of adoption by itself or the time using a technology which generates productivity increases. Previous research on the topic has failed at capturing the dynamic nature of intrafirm diffusion by conceptualizing technology adoption in inaccurate manners.

Methodology, sample and variables

The innovation for which we are going to analyze the relationship between intrafirm diffusion and productivity is the Automated Teller Machine (ATMs). One of the reasons to focus on ATMs for empirical work lies on its marked double character as innovation. From a certain point of view, its introduction may be considered as a process innovation, since ATMs allows customers to make some transactions without a branch and without depending on opening hours. It is therefore a rationalisation process innovation, with a direct clerk labour saving orientation. ATMs can also be considered a product innovation since it can be used to attract new customers by improving present services, and can act as surrogate branches (this reinforces both process and product innovation perspectives). ATMs not only complement traditional financial services but also replace them during office hours. Therefore, they imply an obvious increase on the productive capacity of financial intermediaries.

A second reason to study ATMs is the high availability of information. We have at our disposal a very long observation window. It is three decades since the first ATM terminal was installed, and the intrafirm diffusion has not still finished, with financial intermediaries increasing their ratio of ATM terminals per branch. In addition, the adopters of ATMs are the financial entities, which are also subject of a very strict public monitoring, a situation that forces these organizations to make publicly available financial and technical information about their activity.[1] These two conditions jointly provide us with an excellent sample from which to obtain valuable information about the long term impact of innovations on productivity and about the intrafirm diffusion of a process and product innovation.

The last reason to use ATMs in our empirical analysis is that they have been subject to a large number of empirical studies, both from the technology diffusion research stream (Hannan and McDowell, 1984; Sharma, 1993; Saloner and Shepard, 1995; Gourlay and Pentecost, 2002; Ingham and Thompson, 2003; Fuentelsaz, Gómez and Polo, 2003) and from the performance impact of innovation research stream (Dos

[1] The industry on which we study the diffusion process of ATMs is the Spanish banking sector that consists of three types of agents: savings banks, commercial banks and credit unions. In this study we focus on savings banks given their emphasis on retail activities, those which are better complemented by the introduction of ATMs. With regard to the other types of intermediaries, commercial banks are often involved in wholesaling activities, and these kind of operations have little to do with ATM technology. In order to avoid the distorting effects that wholesaling activities could have on our estimations, we drop commercial banks from our sample in the empirical analysis. On the other hand, we neither consider credit unions, given that they only represent around 5% of total banking assets.

Santos and Peffers, 1995; Peffers and Dos Santos, 1996; Haynes and Thompson, 2000). This means that ATMs have been for a long time considered an appropriate research subject. As a consequence, there exist abundant literature which can be employed as a benchmark for our arguments and estimations.

As mentioned in the introduction, we focus on the productivity effects of intrafirm diffusion. Following previous research on the productivity impact of innovations, we will use a Cobb-Douglass function (Haynes and Thompson, 2000) on which we incorporate the intrafirm diffusion of ATMs, in addition to firm and year fixed effects (i.e. two-way fixed effects). Our basic function is shown in (1):

$$Q_{it} = K_{1it}^{\alpha} K_{2it}^{\beta} L_{it}^{\eta} e^{(\mu i + \gamma t + \theta IDIit)} \qquad (1)$$

Where, following the intermediation approach (Sealy and Lindley, 1977), Q is the output of firm "i" in year "t", K_{1it} stands for the liquid assets, K_{2it} for physic assets and L_{it} for the number of employees, with exponents representing the output elasticity. The firm fixed effects are represented by "μ_i", the year fixed effects by "γ_t". IDI_{it} stands for the intrafirm diffusion index of firm "i" on period "t" expressed as the ratio ATMs per branch, and θ is its associated parameter.[2]

Taking logarithms on expression (1) we obtain:

$$\log(Q_{it}) = \alpha \log(K_{1it}) + \beta \log(K_{2it}) + \eta \log(L_{it}) + \mu_i + \gamma_t + \theta_1 IDI_{it} \qquad (2)$$

In order to compare the different approaches followed in the literature that studies the link between innovation and productivity, we will also estimate our model using two alternative variables. "ADOPTER" is a dummy variable that takes a value of

[2] All the variables used are defined in the Appendix

1 if the firm has already reached, at least, a 0.1 index of intrafirm diffusion and 0 otherwise. “TIME” is the number of years elapsed from the date in which the firm installed the first ATM. The introduction of these variables would, therefore, lead us to test the following alternative models:

$$\log(Q_{it}) = \alpha \log(K_{1it}) + \beta \log(K_{2it}) + \eta \log(L_{it}) + \mu_i + \gamma_t + \theta_2 \, ADOPTER_{it} \quad (3)$$

$$\log(Q_{it}) = \alpha \log(K_{1it}) + \beta \log(K_{2it}) + \eta \log(L_{it}) + \mu_i + \gamma_t + \theta_3 \, TIME_{it} \quad (4)$$

The data needed to build the production function for the savings bank and to describe the intrafirm diffusion process is collected from the Spanish Savings Banks Association (CECA), which provides information about the balance sheet, income statement, labour force composition and the number of branches and ATMs. The majority of the information is dated at the end of every year between 1986 and 2004. Therefore, we can track the evolution of the innovation for 19 years, a time period long enough to capture the long term impact of the innovation (see appendix A for descriptive statistics of our variables).

Table 1 offers a first approximation to the diffusion process of ATMs in the Spanish savings banks. It presents the evolution of different variables that describe the extent of diffusion of the technology through time. The first point to note is that the sample has been affected by mergers and acquisitions that have reduced the number of firms operating in the market from 77 savings banks in 1986 to 46 in 2004. The second column shows the evolution of installed ATMs. Given that the majority of ATMs are installed within existing bank branches, the third column presents the evolution of the latter. The figures show that the number of installed ATMs has grown from 3.058 units in 1986 to 30.349 in 2004. This increase is clearly more important than the one experienced by the number of branches, which has evolved from 11.296 units to 21.527 in 2004.

The five last columns in table 1 present a first attempt to assess the evolution of the diffusion process, both in its inter and intrafirm diffusion. In accordance with this idea, the figures show the percentage of firms adopting the technology (column 4)[3], the ratio of ATMs to branches (IDI, in column 5) and several measures that provide evidence on the heterogeneity of the intrafirm diffusion process, including the average value of the Intrafirm Diffusion Index (IDI) (column 6), the minimum and maximum of the IDI variable (columns 7 and 8), and its standard deviation (last column).

The first result that attracts our interests reflects the importance of distinguishing between the inter and intrafirm dimensions of the diffusion process. Whereas all the savings banks were operating ATMs by 1989, the process of intrafirm diffusion showed much more delay by that date, with approximately 59% of the total number of branches incorporating an ATM.

The examination of columns 6 to 9 allows us to reach a second interesting conclusion: the process of intrafirm diffusion has been clearly heterogeneous. Despite the fact that the percentage of ATMs by branch has suffered a steady increase, the evidence presented in the last three columns leads us to conclude that the differences in the extent of use of the technology are high among the savings banks. Thus, in 2004, the minimum of the IDI variable presents a value of 0.748 whereas the maximum value is 2.69. This conclusion is also confirmed if we look at the standard deviation of the variable, which has almost doubled its value from the first to the last year of our observation window.

[3] A savings bank has adopted the technology whenever it has, at least, an ATM in 10% of the branches.

Table 1. Interfirm and intrafirm diffusion of ATMs in the Spanish savings banks

	Number of firms (1)	ATMs (2)	Branches (3)	Percentage of Adopters (4)	IDI* on industry (5)	IDI* average (6)	Min. (7)	Max. (8)	St. Dev. (9)
1986	77	3,058	11,296	0.740	0.271	0.264	0.000	1.500	0.240
1987	77	3,954	11,712	0.857	0.338	0.324	0.000	1.875	0.272
1988	77	5,609	12,302	0.961	0.456	0.411	0.088	1.467	0.264
1989	76	7,808	13,143	1.000	0.594	0.511	0.116	1.467	0.298
1990	64	9,437	13,683	1.000	0.690	0.570	0.117	1.467	0.277
1991	56	11,084	13,942	1.000	0.795	0.647	0.143	1.630	0.295
1992	53	12,268	14,121	1.000	0.869	0.730	0.196	1.714	0.319
1993	51	13,346	14,262	1.000	0.936	0.810	0.280	1.808	0.336
1994	51	14,146	14,593	1.000	0.969	0.857	0.338	1.780	0.338
1995	50	15,286	15,008	1.000	1.019	0.911	0.400	1.787	0.337
1996	50	16,542	15,872	1.000	1.042	0.959	0.441	1.829	0.317
1997	50	18,979	16,645	1.000	1.140	1.017	0.493	1.862	0.334
1998	50	21,491	17,596	1.000	1.221	1.085	0.518	2.419	0.386
1999	49	23,374	19,348	1.000	1.208	1.147	0.546	2.617	0.405
2000	47	24,829	19,295	1.000	1.287	1.199	0.604	3.171	0.452
2001	46	26,237	19,840	1.000	1.322	1.248	0.648	3.209	0.462
2002	46	27,968	20,347	1.000	1.375	1.286	0.696	2.908	0.454
2003	46	29,162	20,891	1.000	1.396	1.317	0.728	2.752	0.459
2004	46	30,349	21,527	1.000	1.410	1.325	0.748	2.690	0.451

IDI: Intrafirm diffusion index
Source: own elaboration from CECA

Results

The results of our estimations are shown on table 2. The first three columns present the estimations controlling for year fixed effects (but not for firm fixed effects). Column 1 includes the Intrafirm Diffusion Index (IDI) to capture the benefits stemming from the adoption of technologies. On columns 2 and 3 the variables employed to capture the productivity impact of technology adoption are the ones usually employed in previous studies, namely, the time elapsed from adoption (TIME) and a dummy variable which takes the value 1 for firms which have already adopted the technology and 0 otherwise (ADOPTER). Similarly, columns 4 to 6 show the estimation of the three models using two-way fixed effects estimations of the same models.

As we have noted in the previous section, a specific feature of our sample is the high incidence of M&A during the observation period, which may constitute a potential source of irregularities. In order to deal with the influence of M&A on the productivity impact of technology adoption, in models 4 to 6 we allow for a new fixed effect after every operation. The rationale behind this change is the fact that, after the M&A takes place, we would expect a variation in the non-observable specific characteristics of the firm. This could generate differences in the mix of factors and products, increased scale, scope and network economies or even imply different strategies for the resulting firm. As a consequence, the previous fixed effect (i.e., that assigned before the merger or acquisition) would not be representative for the subsequent activity of the firm[4].

The comparison of the pooled and random effects (not shown) models against the fixed effects model was performed running different tests, whose results are presented at the bottom of Table 2. The F-statistic proves the relevance of the fixed effects model against the pooled estimation in the three cases. We ran a Hausman test in order to check whether a random effects model would fit better our sample than the fixed effects model. The p-value falls far below 0.001 in the three cases, supporting our fixed effects model. Finally, we ran a Breusch-Pagan test, whose result again supports the fixed effects against the random effects model by rejecting the null hypothesis of

[4] It is also important to comment that the correlation between the productive factors variables (L, K_1 and K_2) is high, which could generate multicollinearity problems. However, following Gujarati (2004), in regressions in which high R^2 and the individual coefficients are significant (i.e. high t-ratios) multicollinearity may not pose a problem. Johnston (1984) points out that this can occur when coefficients are large related to their standard errors, which make them able to keep its significance despite the inflated standard errors.

independence between the error term and the variables.

Table 2. The effect of intrafirm diffusion on productivity

	(1)	(2)	(3)	(4)	(5)	(6)
Constant	4.146***	3.968***	4.201***	9.208***	9.369***	9.458***
	(52.06)	(49.91)	(54.24	(28.93)	(30.07)	(21.52)
log (K_{1it})	0.250***	0.259***	0.255***	0.062***	0.063***	0.062***
	(14.86)	(15.12)	(15.22)	(3.93)	(3.92)	(3.93)
log (K_{2it})	0.171***	0.177***	0.163***	-0.054***	-0.054***	-0.054***
	(13.86)	(13.72)	(13.09)	(-3.98)	(-3.93)	(-3.90)
log (L_{it})	0.620***	0.611***	0.610***	0.565***	0.543***	0.543***
	(28.63)	(28.66)	(28.75)	(12.75)	(12.56)	(12.35)
IDI	0.128***	-	-	0.046**	-	-
	(6.18)			(2.39)		
ADOPTER	-	0.133***	-	-	-0.016	-
		(4.05)			(-0.61)	
TIME	-	-	0.027***	-	-	-0.032
			(7.98)			(-0.39)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm Fixed Effects	No	No	No	Yes	Yes	Yes
R^2	0.9826	0.9818	0.9825	0.9964	0.9964	0.9964
Adj. R^2	0.9822	0.9814	0.9821	0,9959	0,9959	0,9959
F	2970.07***	2694.22***	2694.53***	947.39***	933.40***	938.24***
F-fixed effects	---	---	---	36.33***	37.93***	36.31***
Haussman	---	---	---	137.45***	195.25***	168.19***
Breusch-Pagan	---	---	---	2367.93***	2371.95***	2248.42***
Obs.	1,062	1,062	1,062	1,062	1,062	1,062

***, **, *: Variable statistically significant at the 1%, 5% or 10%, respectively
Numbers in brackets are the t-ratios

The whole set of estimations presents a high coefficient of determination. Year and firm fixed effects are jointly significant in those estimations where they are included. In column 1 the sum of the elasticities of the productive factors is slightly greater than unity, with the highest elasticity associated with labor. These results provide support to arguments held in other articles, in which banking industry activities are considered to be labour-intensive (i.e. Hannan and McDowell, 1984). When we include fixed effects in our estimations (columns 4 to 6) the value of the factor-elasticities suffers a significant descent, but they remain the same in terms of the order of importance. This drop on the coefficients observed when we include fixed effects can be a consequence of taking into account firm idiosyncratic management skills, which can be considered another productive factor. Our results are consistent with previous studies which have taken the banking sector as the setting for their analysis (e.g. Haynes and Thompson, 2000).

Turning to the parameters of interest, the value of the coefficient accompanying the Intrafirm Diffusion Index is highly significant and takes a value 0.128 (when we do not control for firm fixed effects), and falls to 0.046 after controlling for fixed effects (column 4). We consider that this last result to be more representative, since intrafirm diffusion is considered a process very dependent on firm specific traits (Fuentelsaz, Gómez and Polo, 2003; Battisti and Stoneman, 2003). Therefore, if we do not control for those firm specific peculiarities, these could be included to some extent in the parameter of the intrafirm diffusion, inflating its value. Our results imply that a firm which would have incorporated an ATM terminal in each of its branches would obtain an increase on its productivity of around 4.6%[5] compared to a not adopting firm.

[5] Operating in the Cobb-Douglass function, the increase on productivity is not directly the parameter. We can obtain the actual increase on productivity by calculating $\exp(\theta) - 1$, where θ is the value of the

Operating with the parameters shown in columns (1) and (4), the estimated impact of technology diffusion on productivity would range from 4.6% (when fixed effects are included) to 13.7%[6] (when fixed effects are not included) for every ATM per branch installed.

One of the main objectives of this research is to offer an alternative approach to that held in previous empirical works. We argued that those articles which just take into account the adoption of the technology where too simplistic, and neglected the existence of a technology diffusion process. It is true that, in a number of previous papers, an explicit acknowledgment of the process of technology diffusion can be found, but it is proxied by the time elapsed from adoption. This last approach is more accurate (and concerned with the technology diffusion) than the former. However, this way of represent intrafirm diffusion still presents important problems, as we pointed before. In order to study how relevant the differences existing between the three approaches are, we compare the estimations presented in columns (4), (5) and (6). They include the IDI, ADOPTER and TIME variables as proxy of the impact of the innovation on productivity.

As commented above, the parameter of the Intrafirm Diffusion Index (column 4) shows a positive and significant value. Column (5) presents the result obtained when applying the method that we may term *static* approach, that is, the plain comparison between adopters and non adopters by including dummy variables whose value depends on the use (or not) of the technology. According to this approach, the effect of the innovation is negative, but non significant. This statistical result can be a consequence

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parameter of IDI. The same stands for the estimations on the variables TIME and ADOPTER, and for the fixed effects (both for year and firm).

[6] In this case, the parameter was 0.128. As noted before, exp(0.128)–1=0.137.

of the fact that by 1989 all the sampled firms had adopted ATMs, which makes impracticable the econometric comparison due to the small amount of observations of non adopters. Therefore, the static approach seems to be unable to properly reflect the actual effect of the adoption of a new technology when this technology has been successful and adopted by all the firms operating in the sector.

In addition, since the static approach makes no distinction between adopters, no firm is allowed to obtain superior (nor inferior) productivity gains from the technology than its competitors. Furthermore, all the benefits obtained by firms are treated as being equal and fully received at the moment of adoption. In sharply contrast, our estimations of the intrafirm diffusion effect on productivity suggest that productivity gains will differ among firms with different intrafirm diffusion processes.

Column 6 shows the result of the estimation of the productivity impact of innovation when considering the time elapsed from adoption as the main driver. The result shows a negative and non significant sign. The non significance of the parameter obtained in our estimation can be a consequence of the long period of study. Previous research on technology benefits sampling ATMs (Dos Santos and Peffers, 1995; Peffers and Dos Santos, 1996; Haynes and Thompson, 2000) use shorter periods of time after adoption, obtaining positive and significant results. In the short term, the relationship or “co-movement” between time from adoption and productivity could be significant, but it might be just as a consequence of the high correlation existing between intrafirm diffusion and time from adoption in the short term. When expanding the observation window, this correlation may become weaker as long as diffusion process comes closer to its upper bound. Then (provided that the real link seems to be “intrafirm diffusion-productivity” instead of “time elapsed from adoption-productivity”), the regression of productivity gains on time from adoption would become non-significant, as happens in our estimations.

According to our results, we can argue that the intrafirm diffusion of a technology is the actual driver of the productivity gains stemming from the adoption. Thus, the date of adoption by itself suffers a lack of explanatory power of the productivity increases that follow it. This might happen especially in the case of successful technologies adopted by all the organizations operating in the sector, or when studying technologies whose intrafirm diffusion process takes a long time before being completed (which would increase the differences between adopters). Finally, the time elapsed from adoption does not explain the long term evolution of productivity, since sooner or later the correlation between this variable and intrafirm diffusion disappears. This happens, for instance, when the technology diffusion process has been completed (in this case, time would keep passing by, but intrafirm diffusion would remain constant).

Endogeneity of the adoption

An important question that deserves further attention is the endogeneity of technology adoption and diffusion. The moment of adoption is influenced by the characteristics of the firm (Hannan and McDowell, 1984; Karshenas and Stoneman, 1993), and the same stands for the intrafirm diffusion process (Fuentelsaz, Gómez and Polo, 2003; Battisti and Stoneman, 2005). When talking about the intrafirm dimension of technology diffusion, it is usually considered that the traits of the firm restrict both the level of usage and the time needed to complete the internal diffusion of the technology. If firms with superior management skills adopted the technology earlier or diffused it faster and more intensively, the estimations of the effect of technology adoption (or time from adoption or intrafirm diffusion) would be reflecting both productivity increases caused by the technology and superior performance stemming from superior management skills[7].

In order to address this endogeneity, we have used a coarse-grained approach to control for firm idiosyncratic traits, which is implemented through the introduction of firm fixed effects[8]. Our intention has been to prevent the IDI, TIME and ADOPTER parameters from capturing the idiosyncratic traits of the firm, which would artificially inflate their value. The estimated parameters are positive and significant in columns (1), (2) and (3). It should be noticed that the estimations include year fixed effects and a constant, so the positive effect cannot be associated with industry-wide technologic progress. These results should be compared with the ones presented in columns (4), (5) and (6). In sharp contrast, when we control for firm fixed effects, ADOPTER and TIME become non significant. The IDI variable reduces its importance, but it is the only variable which continues being positive and significant.

Therefore, according to our results, the three approaches are sensitive to the control for the idiosyncratic characteristics of the firm. This traits are related both to the performance of the firm and to the adoption of technologies. When the control for firm specific effects is included in our estimations, the parameters accounting for technology diffusion should reflect just those effects directly stemming from the adoption of the new technologies. Since ADOPTER and TIME become non significant, we deduce that those methods are not adequate to estimate the productivity impact of technology diffusion. The IDI variable also seems to be related to idiosyncratic firm characteristics,

[7] For instance, Geroski, Machin and Van Reenen (1993) find a positive and significant relationship between being an adopter and firm fixed effects in their regressions of productivity on innovations.
[8] This rationale is employed, for example, in Chudnovsky, López and Pupato (2006) as a mean to control for idiosyncratic firm characteristics non directly observable.

given that after controlling for fixed effects the value of its coefficient is reduced dramatically. However, this method keeps a significant explanatory power on the productivity gains stemming from adoption.

Two conclusions may be reached from these results. Firstly, controlling for firm specific characteristics is important when estimating the productivity impact of technology adoption, regarding the potential endogeneity of the adoption decision. Secondly, after controlling for firm-specific characteristics, we find that, in the long term, only the variable capturing intrafirm diffusion maintains its explanatory power, whereas other measures usually employed in the literature, such as the time elapsed from adoption and the adoption by itself show no direct relationship to productivity.

Conclusion and discussion

We contribute to the literature with three new insights that apply to the relationship between productivity and the diffusion of technologies. Firstly, we incorporate extant knowledge on intra and interfirm diffusion by relating the productivity impact of technologies with the evolution on the level of usage of the new technology within the firm. As far as we know, this is the first empirical investigation in which this approach is taken. We find it surprising since it was in 1963 when Mansfield had already suggested the level of usage to be the driver of productivity increases. In previous research devoted to the study of the productivity gains stemming from innovation, the focus is placed in the interfirm dimension of diffusion and the moment of adoption. In other words, there is no explicit acknowledgement of the importance of the intrafirm diffusion of the technology. Just in two previous articles we find a direct mention to this internal dimension of the adoption of innovations (Kwon and Stoneman, 1995; Stoneman and Kwon, 1996). In those cases, the empirical instrumentalization fails at capturing the peculiarities of the intrafirm diffusion. Those few papers attempting to increase the accuracy of their assessments of the productivity impact of adoption have included the time elapsed from adoption, which is still deficient, as we argued above. In our empirical analysis, we find that the intrafirm dimension of the adoption process is the real driver of productivity gains. Another advantage of our approach is that it also recognizes that different firms can have different levels of productivity as a consequence of their specific level of usage. However, we still maintain an implicit assumption that could not hold. Specifically, we consider that every firm obtains the same productivity gains for every ATM installed per branch. However, this would only be true if all the firms had the same innovative capabilities. Therefore, a next step would be to determine whether every firm shows a specific productivity impact from installing ATMs, and the factors that can moderate those benefits.

Our second contribution is to incorporate a longer term on the analysis of the link between productivity and technology diffusion. In previous papers, there has never been a consideration of a period as long as ours. A shorter observation window could be enough to observe the complete diffusion process for some technologies, but in other cases, a wider observation window could be needed. ATMs have experienced a very slow process of intrafirm diffusion (at least in the Spanish banking sector), in contrast with the relatively fast interfirm diffusion process. A potential consequence of this is that previous research (in which the period considered could have been too short) may have underestimated the productivity impact of ATMs adoption, by observing periods of uncompleted diffusion of technology. The same stands for other technologies whose intrafirm diffusion process had been longer than the period studied in the corresponding investigations.

In any case, the problems associated to the availability of short observation windows may be minimized by relating productivity to intrafirm diffusion, instead of considering time from adoption or the static approach. It may also be that other technologies experienced a more rapid diffusion path, reducing the underestimation problem. But even in those cases, our arguments supporting the necessity to proxy for the technology gains through the intrafirm diffusion variable would stand. As it has been shown, the productivity gains stemming from adoption are related to the level of usage, whatever the diffusion speed of the technology studied is.

Thirdly, we provide some clues about the potential bias on the estimation of the productivity impact of innovation when no explicit control for endogeneity is included. The best alternative would be to model those factors influencing both the technology diffusion and the productivity of the firm. We employ a coarse grained approach to control for this endogeneity, which is to include firm fixed effects in the model. Since our intention is to assess the productivity effects of intrafirm diffusion instead of explaining the diffusion process, we find this approach more pragmatic. However, a reader interested on deepening in this issue can find a finer grained approach to the endogeneity problem in Crepon, Duguet and Mairesse (1998), who simultaneously model the decision of investing in R&D, the innovative output of that investment and the productivity impact of the innovation. Another methodology meant to cope with this issue is found in Kwon and Stoneman (1995), where the authors run three models allowing for different degrees of endogeneity.

Implications for future research

In this article we try to asses the productivity effects of the adoption of a new technology. We have sometimes referred to productivity as a performance measure. At this point, we think that it is important to underline a fundamental distinction between the concepts of productivity and profitability. Specifically, firm productivity is an internal characteristic. It is not directly affected by the actions of rivals. Therefore, when assessing the productivity impact of a technology, the main explaining factors should be internal. Other external factors could have some effect on this relationship. Learning externalities or pre-emption of complementary technical services would be two examples, but their effect should be just complementary to the influence of internal factors.

In contrast, firm profits are obtained as a consequence of the strategic interaction with competitors and the environment and, consequently, they are critically affected by external decisions and actions taken in the market. This difference is important when studying the consequences of technology adoption. As we have demonstrated, an increase in the level of usage of a technology may have a positive impact on productivity. However, it might have no direct effect on firm profitability. When studying the impact on profits the comparison in the *variation* of the level of usage of a firm and its competitors could be the driver of the benefits stemming from the innovation. In addition, external factors should be included on the regressions in order to control for environmental factors. Therefore, the study of the consequences of diffusion on profitability could require further attention and specific methodologies. Efforts on this line of research could be improved by taking into account the conclusions reached in this investigation.

As mentioned above, in this article all the firms are supposed to obtain the same benefits from the diffusion of the technology. In our model, we do not allow ATMs to be more productive for some entities than for others. This could be inaccurate, since firms differing in their absorptive capabilities (Cohen and Levinthal, 1990) might obtain different levels of advantage by using a technology. Given that we have observations for two decades at our disposal, a next step would be to determine whether permanent differences on the effects of technology adoption for different firms there exists. If those differences were significant and persistent through time it could be possible to estimate some kind of "proxy" for innovative or absorptive capacities. Once those capabilities were determined, it would be interesting (and possible) to study the factors affecting them. The estimation of those capabilities can be obtained using our approach to intrafirm diffusion, since it allows a higher degree of heterogeneity between firms in their intrafirm diffusion processes. However, the implicit homogeneity among technology adopters assumed in the other approaches (let it be by no distinguishing between adopters or between different intrafirm diffusion processes) makes either impossible or inaccurate to consider differences in productivity gains.

APPENDIX A: VARIABLES AND DESCRIPTIVE STATISTICS

The variables used in the empirical estimation are defined in the following lines. In 1992 there was a change in the presentation of financial statements that affected the savings banks. As a consequence, the headings were modified, which explains the differences in terminology before and after 1991.

- **Total production (*Q*):** for period 1986-1991 one calculates like the sum of the Credit Investments and Securities portfolio of the balance, whereas for the rest of the period (1992-2004) it is the sum of Loans, Obligations and Fixed-income securities, Securities and Shares, Participations and Group participation.
- **Labor (*L*)**: number of full-time employees of the savings bank i at moment t.
- **Fixed assets (*K1*)**: value of the fixed assets (non-financial assets) of the savings bank i at moment t. For the period 1986-1991 variable corresponds with the value of Non-financial assets. For the years 1992-2004 its value is the one of the Physical assets**.**
- **Liquid assets (*K2*):** For the first period its value corresponds to the sum of the Currency and Bank of Spain, Monetary assets and Financial intermediaries. For the second, one has calculated like the sum of Cash and deposits in central banks, Government Debt and Due from other banks.
- **Intrafirm Diffusion Index (IDI)**: This variable is the ratio number of ATMs/ number of branches. The number of ATMs installed by the savings banks and the number of branches belonging to the entity are provided by the Spanish Savings Banks Confederation (CECA).
- **ADOPTER:** Adopter is a dummy variable which takes the value "1" for those entities with an Intrafirm Diffusion Index Higher than 0.1 and "0" otherwise. With this restriction we try to avoid the distorting effects stemming from the small scale introduction meant to test the functionality of the new technology without providing real services for customers.
- **TIME:** Number of years elapsed from the first instalment of an ATM by the bank.

Table A. Descriptive statistics and correlations

	Obs.	Mean	Std. Desv.	log(K1it)	log(K2it)	log(Lit)	IDI	ADOPTER	TIME
log(K1it)	1062	10.480	1.309	1					
log(K2it)	1062	12.810	1.324	0.9299	1				
Log(Lit)	1062	6.763	1.093	0.9610	0.9285	1			
IDI	1062	0.811	0.491	0.4030	0.3675	0.3750	1		
ADOPTER	1062	0.967	0.179	0.1715	0.1474	0.1498	0.2849	1	
TIME	1062	11.091	6.005	0.4310	0.3905	0.4196	0.7219	0.2559	1

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