Competing Technologies for Payments and the Demand for Currency

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Abstract: The shift from paper-based towards electronic-based payment instruments is following a slow path in many developed countries which can be, at least partially, due to the over time overlapping objectives of banks in deploying ATMs and POS devices. We employ a unique database to explore these issues. The results suggest that the promotion of cards relative to cash is diminished by the co-existence of these two rival technologies. Additionally, POS devices and higher POS transactions are found to significantly reduce the demand for currency and to offset the effects that ATMs may have on the demand for currency (98 words).

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I. INTRODUCTION

Payment cards are considered as the main drivers of the shift from paper-based towards electronic-based payment instruments, which is commonly viewed as a significant socioeconomic and welfare improvement[1]. Payments systems are going through a period of rapid change with paper-based instruments increasingly giving way to electronic forms of payment. A common feature in banking systems all over the world is the deployment, in parallel, of both automated teller machine (ATM) and point of sale (POS) devices. The coexistence of both trends may be diminishing the substitution rate of cash by electronic payments in developed countries[2]. However, the relationships and interactions between these two technologies remain largely unexplored. These relationships are not trivial and, most importantly, may pose different implications for the substitution of cash for electronic payments. On the one hand, banks typically expand ATM networks to allow cardholders to easily withdraw cash. At the same time, they also spread out their POS devices to offer cardholders a cashless method of payment at the point of sale. Banks play a key role in the payment card markets for various reasons. Firstly, banks are the main card issuers in most financial markets. Secondly, card services are usually offered as part of a set of banking products which, in turn, are frequently interrelated, in terms of costs, revenues and prices. Finally, the majority of transactions take place at ATMs and POS machines which are principally provided by banks and determine a significant proportion of card network externalities.

[1] Based on a panel of 12 European countries during the period 1987–1999, Humphrey *et al.* (2006) estimate that a complete switch from paper-based payments to electronic payments could generate a total cost benefit close to 1% of the 12 nations' aggregate GDP.
[2] According to the data of the Bank for International Settlements, the growth rate of the real value of transactions at POS in the ten member countries of the Committee for Payment and Settlement Systems (CPSS) was 24.6%. However, the real value of cash withdrawals at ATMs was growing at an annual rate of 18.0% in the same year. The CPSS members are Belgium, Canada, France, Germany, Hong Kong, Italy, Japan, Netherlands, Singapore, Sweden, Switzerland, United Kingdom and United States.

The aim of this paper is to analyze the adoption and interaction patterns of ATM and (debit and credit) POS transactions using bank-level data and their effect on the substitution of cash by cards and on the demand for currency. In order to achieve this goal, the empirical analysis incorporates a number of demand and supply factors that may influence these relationships, as well as the bilateral market structure of card (two-sided) markets. The paper is structured as follows: Section 2 analyzes the intensity of adoption and the diffusion of ATM and debit and credit POS technologies. The empirical methodology is presented in Section 3. The adoption process of ATM and debit and credit POS transactions is estimated as a continuous hazard rate model while the diffusion process is estimated using Gompertz curves. The results of the adoption and diffusion processes are shown in section 4. Section 5 analyzes the effects of ATMs and POS diffusion on the demand for currency using a Baumol-Tobin model of the demand for currency. The paper ends with a brief summary of results and conclusions in Section 6.

II. THE INTENSITY OF ADOPTION AND DIFFUSION PATTERNS OF PAYMENT TECHNOLOGIES

The diffusion of technological innovations is a central issue in the literature of the economics of technical change. The seminal works of Griliches (1957) and Mansfield (1961) gave rise to numerous empirical studies that have analyzed the determinants of industry- and firm-specific technology adoption and diffusion[3]. However, there are only few empirical studies examining the interaction of different technologies in the adoption and diffusion processes and, in particular, the adoption of competing and likely incompatible innovations in network industries (Katz and Shapiro,

[3] See Stoneman (2001) for a comprehensive survey of the main theoretical and empirical approaches.

1986; Church and Gandal, 1993; Colombo and Mosconi, 1995; and Miravete and Pernías, 2006).

The adoption patterns of electronic payments delivery channels were first studied by Hannan and McDowell (1987) using a standard hazard rate (of failure-time) estimation procedure. They show that ATM innovation by rivals increases the conditional probability that a decision to adopt ATMs is made by a certain bank. The subsequent studies have largely identified ATM and payment cards diffusion as an epidemic trend mainly explained by rival precedence (Ausubel, 1991; Humphrey *et al.*, (2000; Snellman *et al,* 2000; and Rysman, 2007). However, the intensity of the adoption of the main driver of the substitution of cash for electronic payment nowadays –the POS machine- has not yet been specifically explored and its relationship with ATM adoption remains largely unknown. In many developed countries, consumers added debit cards to their wallets during the 1980s as devices to access cash at ATMs. At that time, banks aimed to move some front-desk customer services away from branches in order to increase efficiency and service. During 1990s banks also aimed to foster the use of cards at the point of sale for purchase transactions, installing POS card payment devices. However, the consumer adoption and merchant acceptance patterns of cards have been relatively slow in many countries and the usage and diffusion of cards at the ATM and at the POS have somehow overlapped. Humphrey *et al.* (1996) estimated a system of demand equations for five payment instruments (check, electronic or paper giro, credit card, and debit card) for 14 countries between 1987 and 1993 and found that although POS terminals and ATMs were strongly positively related to debit card usage, all payment instruments except debit cards substitute for cash. This result suggests that the use of debit cards for ATM withdrawals and POS transactions may impose some restrictions on the substitution of cash for cards. Similarly, Amromin and Chakravorti

(2009) study changes in transactional demand for cash in 13 OECD countries from 1988 to 2007, showing that ATM withdrawals decrease with greater debit card usage at the POS.

Studies by Humphrey and Berger (1990) or Humphrey *et al.* (2000) have shown that efficient payment instrument pricing induces greater use of electronic payment, as it is cheaper than paper-based payment. Nevertheless, the cost advantages of cards are highly dependent on the type of card employed. In particular, Humphrey and Berger (1990) show that debit cards are significantly cheaper than cash, while credit cards are relatively expensive payment instruments. The latter deserve specific attention because their characteristics are not identical to those of debit cards. Therefore, in substituting cash by cards, the distinction between debit and credit card transactions is essential. As for debit cards, enabling consumers to use debit cards is not sufficient to increase their diffusion and usage. As noted by Amromin and Chakravorti, in most economies debit cards are first added –for the most part unknowingly- to consumers' wallets as a device to access cash at ATMs. With the adoption of POS machines by merchants, debit cards can be alternatively used to make purchases. Hence, the final usage of debit cards will depend on consumers' attitudes as well as on the availability of POS and ATMs. Bank branches also play a role. A higher banking branch network may also reduce the use of cards at the POS since branches –together with ATMs- are the main distributors of cash.

As for credit cards, they may not be directly related to rivalry between ATM and POS card transactions but they may pose some significant indirect effects on the demand for cash since credit cards may increase consumers debt and/or permit them to move their liquidity (cash) constraints forward in time (Wright, 2004). Not surprisingly, the adoption of credit cards has been found to significantly reduce currency holdings (Boeschoten, 1992). Consumers perceive credit cards as a low-cost delayed payment substitute for cash settlements. Moreover, Brito and Hartley (1995) demonstrate that although borrowing on credit cards may appear irrational, due to the usually higher prices paid, such cards also provide liquidity services by allowing customers to avoid some of the opportunity costs of holding money.

In our analysis, we put together –for the first time to our knowledge- four different ingredients to explore the adoption of ATM and POS technologies at banks. The first of these ingredients is separating the influence of demand-driven and technology-driven influences in order to infer how the adoption process evolves. A second ingredient is the estimation of adoption patterns using a continuous hazard rate model. This methodology permits analyzing the not just the adoption of the technological device (ATMs and POS machines) but the intensity of this adoption (the relative amount of ATM or debit/credit POS transactions over total bank transactions). A third feature refers to the industry structure itself since card payments function as networks and, therefore, the value of a network increases with every new consumer who uses cards at the own ATM or POS terminals and any other bank that accepts them at their ATMs or POS terminals. These networks are generally organized as two-sided markets. In these markets, two (or more) parties interact on a "platform", and the interaction involves network externalities. In the two-sided card market, the value of a network increases with every new consumer who uses cards, every merchant that accepts them at their point of sale and any other bank that accepts them at their ATMs (Hannan *et al.*, 2003). A fourth final ingredient is the inclusion of market power in the analysis since a pattern of diffusion will not be appropriately defined unless the ability of the providers to set prices above the marginal costs of both delivery services (ATMs and POS) is controlled for. As a consequence, the two-sided structure requires considering prices at both sides (Rochet and Tirole, 2002 and 2003). Therefore, the prices should consider all sources of card revenues including annual cardholders fees, merchants' discount fees and interchange fees (paid by acquiring banks to issuing banks for the use of the issuers' cards at ATM and POS devices) and to separate the fees that are specific of ATM transactions from those of POS transactions (Rochet and Tirole, 2003).

III. ADOPTION AND DIFFUSION RATES: DETERMINANTS AND MAIN INTERACTIONS

III(i). A continuous hazard rate model for the intensity of ATM and POS adoption

The first empirical step is the definition of a hazard rate model that distinguishes between demand-driven and technology-driven factors in the adoption of ATM and POS distribution services. The relationship follows:

$$h_i(t) = \exp(X_t^{'}\beta) \qquad (1)$$

where $h_i(t)$ is a continuous 'hazard rate' and denotes the conditional probability that bank i will adopt the innovation during t; $X_t^{'}$ denotes a vector of explanatory variables relevant to period t adoptions; and β represents a vector of coefficients. Since the hazard rate is continuous rather than discrete, it is not actually a probability because it can be greater than 1. A more accurate description is that the continuous hazard rate is the unobserved rate (intensity of ATM or POS adoption in our case) at which events occur:

$$h_i(t) = \lim\ pr\frac{(t, t+s)}{s} \qquad \text{with } s \to 0 \qquad (2)$$

Because the hazard rate is continuous rather than discrete, the probability is divided by s, the length of the interval. s becomes smaller until the ratio reaches a limit. This limit is the continuous hazard rate, denoted by $h_i(t)$. In our continuous hazard rate model, we do not look at which banks have deployed the first ATM/POS machine.

Rather, we examine how intense the adoption of these devices is taking place in those banks. In particular, our dependent variable is defined the total value of ATM (alternatively, POS) transactions divided by the sum of the total value of bank assets, ATM transactions and POS transactions. Importantly, debit and credit POS transactions are also distinguished. A first set of explanatory variables consists of demand parameters (ATM and POS transactions in *t-1*), proxies of rival precedence (rival's ATM and POS adoption in *t-1*), parameters showing own and indirect network effects ("card growth x own ATMs"; "competitors' ATMs x own card issuance", "card growth x own POS terminals" and "competitors' POS terminals x own card issuance"). Similarly we report the results employing a mark-up indicator of market power, the Lerner index (the ratio "price-marginal costs/price") applied to ATM and POS services. This involves the estimation of the marginal costs of ATMs and POS[4]. As for the computation of prices, the price of ATM transactions comprises the total revenue for ATM transactions (including ATM surcharges and fees) divided by ATM transaction value. In the case of the POS the two-sided nature of the market is considered so that prices are the sum of consumer and merchant fees while marginal costs are the sum of the estimated consumer and merchant marginal costs. As Emch and Thomson (2005) note, the "two-sidedness" of the POS transactions does not refute the basic logic of the hypothetical monopolist test of the traditional measurement of market power, and thus the total price of cards (for both cardholders and merchants) should be employed to calculate market power. In our analysis we also studied another type of market power indicator, the market share of ATM and POS[5]. Finally, the there is a set of control

[4] Furthermore, the cost function employed needs to be sufficiently flexible to reflect the non-linear shape of the different marginal costs estimated. Following Pulley and Braunstein (1992), we employ the fairly flexible composite cost function to estimate the marginal costs of ATMs and POS.

[5] See footnote 8.

variables (growth of bank ATMs; growth of bank POS terminals; total bank assets; bank branches; bank average wage; regional GDP) and a time trend.

III(ii). The diffusion processes of ATM and POS transactions: logistic and Gompertz curves

Since the hazard rate model identifies the intensity of ATM and POS transactions as a diffusion (epidemic) process we use both logistic and Gompertz curves to consistently estimate the speed of ATM and (debit and credit) POS transactions diffusion rates over time. The linearly-transformed logistic and Gompertz models for the probability of adoption (p_t) follow, respectively:

$$\ln[p_t/(L-p_t)] = -\ln\alpha + \beta t + \varepsilon_t \qquad (3)$$

$$\ln[-\ln/(p_t/L)] = \ln\alpha - \beta t + \varepsilon_t \qquad (4)$$

where L is the limit for the adoption measure, pt, and is assumed to be 100%[6]. In these linear models, the estimated β proxies the speed of diffusion. Both curves are estimated using least squares with fixed effects.

III(iii). Data

The data corresponds to bank-level information from the all the Spanish savings banks on ATM and POS transactions and prices. The sample consists of all savings banks operating in Spain from 1997:1 to 2007:4, constituting 1,980 panel observations[7]. The Spanish case is representative, since Spain is one of the world's largest ATM and

[6] A principal difference in the two S-curve models from a forecasting standpoint is that the Gompertz model is asymmetric about its inflection point, whereas the logistic curve is symmetric.
[7] These savings banks belong to two of the three competing networks in Spain (Servired and Euro6000) and are involved in approximately 60% of total card payment transactions.

POS industries[8]. All variables employed in the empirical models are described in the Appendix along with the corresponding sources of data.

IV. RESULTS

IV(i). Results of the continuous hazard rate model

The hazard rate model is estimated using a maximum likelihood routine with fixed effects and the results are shown in Table 1 for ATMs, debit POS transactions and credit POS transactions. Overall, the intensity of adoption is mainly driven by rival precedence (positively), network effects (positively) and market power (negatively for ATMs and positively for POS), while the influence of demand-driven factors is negligible. The case of market power is particularly interesting since it suggests that increasing margins in the ATM side -thereby increase cardholders' ATM and/or annual fees- has a negative impact on the intensity of ATM adoption, while increasing the margins in the POS side does not seem to reduce (but to augment) the adoption of these devices.[9] The patterns of the intensity of adoption of debit and credit POS are similar with one main difference. In particular, the growth of ATM devices seems to negatively affect the intensity of adoption of debit POS technologies but not credit POS adoption. The deployment of POS terminals, however, does not seem to affect the intensity of ATM adoption.

[8] According to the figures contained in the Blue Book on Payment and Securities Settlement Systems (European Central Bank) and the Red Book on Payment and Settlement Systems (Bank for International Settlements) in 2004 there were 55,399 ATMs and 1,055,103 POS machines in Spain. Only the United States showed a higher absolute number of ATMs and POS terminals that year.

[9] The bank market share of ATMs and POS was also introduced as a measure of competition in card markets. The coefficients of these variables were not found to be statistically significant (not shown).

IV(ii). The diffusion curves: main results and interactions

The diffusion curves of ATM and credit and debit POS transactions are explored in Table 2. By extrapolating the α and β estimates in Table 2, In the logistic and Gomperz curves the speed of diffusion is found to be higher for ATMs than for POS over the entire estimation period. These results seem to be consistent even when the diffusion variable was interacted with four dummies -shown in rows (2) to (5) in Table 2- distinguishing the over the median and below the median observations of rival precedence, own network effects, indirect network effects and market power. Interestingly, the speed of diffusion seems to increase when these factors are accounted for excepting own network effects. The speed of diffusion seems to be also higher for credit than debit cards. These conclusions hold when estimation biases are controlled for using bootstrapped confidence intervals (Corradi and Swanson, 2005).

The diffusion parameters in Table 2 may be estimated at the bank level. These estimates can be viewed as the average bank-level diffusion rates for the estimated period. As a robustness check, we evaluate the impact of the rival precedence, network effects, competition and posited control factors on the estimated bank-level diffusion rates of the ATM, debit POS and credit POS. The results are shown in Table 3 and suggest that diffusion rates are mostly industry-driven with rival precedence and network effects playing a major role. Again, while market power seems to reduce the speed of adoption of ATMs, its effect on POS diffusion is positive.

V. DIFFUSION AND THE DEMAND FOR CURRENCY

Previous studies have analyzed the impact of currency holdings for monetary control purposes and, in particular, the distortions related to the efficient management of cash balances for consumers' transaction purposes when a (nominal) interest-bearing asset is available , using a Baumol-Tobin model of the demand for currency[10] (e.g. Avery *et al.*, 1986; Mulligan, 1997; Mulligan and Sala-i-Martin, 2000). Attanasio et al (2002) have even considered the adoption of new transaction technologies on the demand for currency and, in particular the effects of ATM transactions. In these models, the demand for deposits -in terms of both amounts held and interest rates paid- represents the natural interest bearing asset to be considered alternative to currency. The general econometric specification of the demand for currency in the Baumol-Tobin framework is:

$$\text{In}\,(m) = \alpha - \beta t + \chi(t^2) + \delta \ln(R) + \gamma \text{In}(c) + \varepsilon \qquad (5)$$

where *m* is the demand for currency, *t* is a time trend, *R* are the deposit interest rates and *c* is the consumption in nondurable goods. In these models, the effects of new technologies is based on comparisons between users and non-users of the technology or simply introduced as a control variable. Some studies have used aggregated data (Avery *et al.*, 1986) to estimate the demand for currency while some other used survey household or firm-level information (Mulligan, 1997). One of the main lines of inquiry in this context is the analysis of the elasticity of the demand for currency to nominal interest rates. As noted by Attanasio *et al.* (2002) interest rates on deposits and the demand for currency overall display a remarkable degree of regional variation that can be exploited to estimate the relevant elasticity of currency.

To our knowledge, these studies have considered neither the effects of debit and/or credit POS transactions nor the interaction between ATM and POS transactions in the demand for currency[11]. In order to achieve this goal, our dataset is transformed into a regional dataset. In particular, in a first step, the demand for currency, deposit

[10] See Baumol (1952) and Tobin (1956).
[11] We assume that cash is the main alternative to cards while the role of checks is negligible. According to the Blue Book of Payments of the European Central Bank only 4.4% of total retail payment transactions in Spain were made by checks in 2007, and mainly for real state purchases.

interest rates and nondurable consumption in equation (5) are computed as weighted averages of the different banks in that region using the distribution of assets as a weighting factor. In a second stage, these variables are re-computed at the consumer level as ratios of the number of depositors of the banks operating in these territories[12]. Since the available data only permit to analyze consumers holding deposits accounts at each bank, our estimations of the demand for currency are restricted to depositors while non-depositors are not considered[13]. Additionally, when averaging the variables we consider that, on average, all depositors make ATM and debit and credit POS transactions. The variables are computed on an annual basis for the 17 administrative regions in Spain which yields 187 panel observations.

The demand for currency is computed in each region as the sum of three consumer-level variables: demand deposits, ATM withdrawals and one half of the consumption divided by the average number of deposit withdrawals[14]. The sum of demand deposits proxies the minimum amount of currency for cash withdrawals while cash withdrawals are represented by the consumption ratio and ATM withdrawals.[15] The mean and over time evolution of the different variables is shown in Table 4. All variables shown in Table 4 are annual averages excepting (demand for) currency which reflects the average currency holdings per person. All the monetary variables are deflated using the regional consumer price index. Overall, the main trends show a

[12] Consumer-level variables are computed from savings bank data only. This may be a limitation that overstates the results of the demand for currency since savings banks' depositors are likely to make higher withdrawals than commercial banks' depositors. However, the regional variability in the demand for currency is likely to be better captured from savings banks data since most of savings bank information can be clearly identified at the regional level while most commercial banks operate nationwide and it is difficult to identify the source of regional variation from commercial banks data.

[13] According to the Eurobarometer published by the European Commission in 2004, 10% of Spanish households do not have a deposit account.

[14] This is an assumption in this type of studies, following the standard inventory model of cash management in which the determination of the optimal level of cash holdings involves a trade-off between the cost of a cash shortage and the cost of holding non-interest bearing cash.

[15] Data on consumption is obtained from the Spanish Statistical Office while the average number of deposit withdrawals is obtained from savings banks information.

decrease in currency holdings. Table 4 shows that currency holdings (724 euros in 2007) are similar to international standards (Humphrey *et al*., 1996; Carbó *et al*., 2003) and it decreases over time. Deposit interest rates also decrease while consumption increases during the sample period.

The main estimations of equation (5) are shown in Table 5. The logarithm of ATMs, POS devices, bank branches[16] and regional GDP are included as control variables. ATM and POS transaction are included in a second specification while debit and credit POS transactions are considered separately in a third specification. Additionally, a fourth specification controls for the intensity of cash (or alternative, cards) usage across sectors. The latter distinction is relevant since there is significant variability in the use of cash and cards across merchants sectors. For example, the average share of cash payments in grocery stores is 92.3% while the average share of card payments in department stores is 70.9%.

The equations are estimated using a random effects panel data routine, where the regional unobservable effects are considered to be part a composite error term and are not necessarily fixed over time. This specification also includes time dummies. The Hausman test of random vs. fixed effects specification suggests employing a random effects procedure. Additionally, the structure of equation (5) requires an intercept which the random effects model offers while the fixed effects model suppresses. In the first specification (column I), the elasticity of currency to deposit interest rates (-.473) and consumption (.202) are significant and their values are in line with the theoretical and empirical results of previous studies based on inventory models of cash management. Importantly, the deployment of ATM devices seems to increase the use of currency, although the estimated elasticity (0.009) is significantly lower compared to the negative

[16] As in Amromin and Chakravorti (forthcoming), bank branches is a proxy for cash access, in particular for non-ATM dispenses notes and coins.

elasticity of the deployment of POS devices (-.462). The opening of bank branches also affects the demand for currency positively and significantly (0.349). The average number of ATM and POS transactions is included in a second specification in Table 5 (column II). The elasticity of interest rates (-.316) and the elasticity of consumption (.199), decrease in absolute terms. Importantly, average ATM transactions affect positively and significantly the demand for currency (.144) while POS transactions exhibit a negative and significant effect (-.351) that almost triple that of ATM transactions. However, the results suggest that as long as banks continue to deploy ATMs and POS terminals, the substitution rate of cash by cards will be diminished. As for the distinction between POS debit and credit card transactions in column III, although debit POS transactions appear to have a higher negative marginal effect on the demand for currency (-.391), credit POS transactions also affect currency demand negatively and significantly (-0.284) suggesting that differing payments and increasing cardholders debt also reduce currency holdings significantly.

Finally, column IV shows the results where the intensity of the use of cards and cash across merchant sectors are controlled for. As noted, *inter alia*, by Whitesell (1992) and Amromin and Chakravorti (forthcoming), the choice of a payment instrument for consumption purposes (and, hence, the demand for currency) is highly dependent on merchant's acceptance. In particular, the effects of card payments on the demand for cash (for purchases) in certain merchant sectors may *per se* be invariably conditional on merchant's acceptance (related, for example, to idiosyncratic reasons and the size of payments) in that sector. In order to analyze these effects, the variables showing average ATM and POS transactions are redefined. In particular, the "the average POS transactions" variable for a certain region is computed as a weighted average of the POS transactions, using the relative weight of sectors with a high card usage as a weighting factor. Similarly, average ATM transactions are computed using the reciprocal of the same weighting factor in order to show the likelihood of cash usage in sectors where cash is expected, *per se*, to show a higher usage.[17] The sectors where cards are found to be used to a significant larger extent than cash[18] are hotels, restaurants & travel agencies; department stores and boutiques; and entertainment. The results when these variables are applied are shown in the third column of Table 5. The positive and significant effect of ATM transactions on the demand for currency seems to be higher when the composition of the non-durable consumption expenditure across merchant sectors is considered (.266). Similarly, the negative and significant effect of average POS transactions -corrected for the relative weight of sectors with a high card usage- is also found to augment in absolute terms (-.585). These results suggest that the margin to reduce the demand for currency is limited in certain sectors where the use of cash is expected to be higher. Similarly, POS transactions may help reduce the demand for currency to a larger extent in those sectors where the average transaction size or the characteristics of the sector themselves make card payments more willing to occur. This may also explain why many card issuers are trying to develop specific card products for small value payments (e.g. store-value-cards or pay-as-you-go cards).

VI. CONCLUSIONS

The empirical results of this study show that the diffusion of ATMs and POS is found to be mostly driven by supply factors. Additionally, the growth of ATM transactions is found to negatively interfere with POS diffusion. This behavior seems to be a kind of "horse race" where banks have been typically deploying ATMs to move

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[17] The sector information is obtained from the regional consumption expenditure database of the Spanish Statistical Office

[18] According to a supplementary database also provided by the Spanish Savings Banks Confederation the use of cards in these sectors is above 65% while the median value of all sectors is 39% (not shown, available upon request).

certain front-desk customer services away from branches although this may also have fostered cash use, thereby negatively affecting the use of cards at the merchants' point of sale. Our results suggest that this behavior is also connected with two different pricing structures for ATM and POS in which increasing market power in the POS side does not reduce (but augment) the diffusion of these technologies while the opposite seems to occur in the case of ATMs. The results also show that the deployment of POS devices and higher POS transactions may reduce the use of currency and offset the positive effects that ATMs and ATM transactions may have on the demand for currency.

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APPENDIX. VARIABLE DEFINITION AND DATA SOURCES

VARIABLES FOR THE ESTIMATION OF THE BANK-LEVEL DIFFUSION AND ADOPTION PATTERNS	
	Variable definition
Dependent variables	
ATM adoption	The total value of ATMs transactions divided by the sum of the total value of bank assets, ATM transactions and POS transactions.
POS adoption	The total value of POS transactions divided by the sum of the total value of bank assets, ATM transactions and POS transactions.
Demand	
Log(ATM transactions$_{t-1}$)	Demand for ATM transactions at the beginning of the period
Log(POS transactions$_{t-1}$)	Demand for POS transactions at the beginning of the period
Rival precedence	
Log(rival's ATM adoption$_{t-1}$)	Rivals' precedence in the ATM market
Log(rival's POS terminal adoption$_{t-1}$)	Rivals' precedence in the POS market
Network effects	
Log [(card growth) x (own ATMs)]	Direct ATM network effects
Log[(competitors' ATMs) x (own card issuance)]	Indirect ATM network effects
Log [(card growth) x (own POS terminals)]	Direct POS network effects
Log[(competitors' POS terminals) x (own card issuance)]	Indirect POS network effects
Competition	
Lerner index ATM transactions	The difference between price and marginal cost of ATM transactions divided by the price. Prices are computed as total ATM (surcharge and fee) revenues over total ATM transactions while marginal costs are estimated using a composite function with five outputs (loans, other earning assets, deposits, ATMs and POS) and three inputs (deposit funding, physical capital and labor) as in Carbó *et al.* (2006).
Lerner index POS transactions (two-sided)	The difference between price and marginal cost of POS transactions divided by the price. Prices are computed as the sum of the prices at both sides of the POS transactions (merchant discount fee and annual fee) while marginal costs are the sum of the estimated marginal costs at each one of the sides using a composite function with five outputs (loans, other earning assets, deposits, POS acquirer transactions and POS issuer transactions) and three inputs (deposit funding, physical capital and labor) as in Carbó *et al.* (2006).
Control factors	
Log(growth of bank ATMs)	Average growth of ATMs in the market.
Log(growth of bank POS terminals)	Average growth of POS terminals in the market.
Log(total bank assets)	Bank's balance sheet growth
Log(bank branches)	Branching network growth
Log(bank average wage)	Average employment costs
Log(regional GDP)	Regional GDP in constant terms
VARIABLES FOR THE CROSS-REGIONAL ANALYSIS OF THE DEMAND FOR CURRENCY	
	Variable definition
Dependent variable	
Demand for currency	Computed in each region as the sum of three consumer-level variables: demand deposits, ATM withdrawals and one half of the consumption divided by the average number of deposit withdrawals
Depositor level	
Deposits interest rates (R)	Computed as the average ratio of interest expenses to total customers' deposits of banks operating in the region.
Non-durable consumption (c)	Regional consumption in nondurable goods
Average ATM transactions	Average number of ATM transactions in the region
Average POS transactions	Average number of POS transactions in the region
Regional level controls	
Log(ATMs)	Log of total ATMs in a given region.
Log(POS)	Log of total POS terminals in a given region.
Log(bank branches)	Log of total bank branches in a given region
Log(regional GDP)	Log of regional GDP in constant terms.

DATA SOURCES: All bank variables were obtained from reports provided by the Spanish Savings Banks Confederation. GDP and non-durable consumption were obtained from the Spanish Statistical Office.

TABLE 1. DETERMINANTS OF THE CONDITIONAL PROBABILITY OF THE INTENSITY OF ADOPTION OF ATMs AND POS (CONTINUOUS HAZARD MODEL)

ML estimation. Standard errors in parentheses (1,980 observations)

	ATM adoption	***POS adoption (debit)***	***POS adoption (credit)***
Constant	-.0628 (.04)	-.0557 (.03)	-.0599 (.07)
Demand			
Log(ATM transactions$_{t-1}$)	-	.0209 (.02)	.0047 (.02)
Log(POS transactions$_{t-1}$)	.0385 (.02)	-	-
Rival precedence			
Log(rival's ATM adoption$_{t-1}$)	.4432*** (.05)	-	-
Log(rival's POS terminal adoption$_{t-1}$)	-	.4723*** (.05)	.4930*** (.08)
Network effects			
Log [(card growth) x (own ATMs)]	.0526*** (0.01)	-.0863*** (0.01)	-.0721** (0.01)
Log[(competitors' ATMs) x (own card issuance)]	.0018*** (.01)	.00558*** (.01)	.0065*** (.01)
Log [(card growth) x (own POS terminals)]	-.0192*** (.01)	.0602** (.01)	.0599*** (.01)
Log[(competitors' POS terminals) x (own card issuance)]	-.0084** (.01)	-.0077*** (.01)	-.0062** (.01)
Competition			
Lerner index ATM transactions	-.8028** (.09)	-	-
Lerner index POS transactions (two- sided)	-	-.1644** (.04)	-.1156 (.10)
Control factors			
Log(growth of bank ATMs)	-	-.0286*** (.01)	-.0129 (.01)
Log(growth of bank POS terminals)	.3086 (0.02)	-	-
Log(total bank assets)	-.2516*** (.05)	-.1934* (.04)	-.1118** (.05)
Log(bank branches)	-.2071** (.04)	-.5104*** (.06)	-.4122** (.05)
Log(bank average wage)	.7216** (.06)	.3970* (.04)	.3671* (.03)
Log(regional GDP)	.1658** (.01)	.1952** (.01)	.1503** (.01)
Time	.0726** (.01)	.0418*** (.01)	.0398** (.01)
χ^2	17.63***	18.03***	16.56***
*, **, *** Indicates p-value of 10%, 5% and 1%, respectively.			

TABLE 2. ESTIMATING FORECASTING CURVES FOR ATM AND POS DIFFUSION

Least squares estimates with bank fixed effects
Confidence intervals from bootstrapped standard errors in parentheses (1,980 observations)

		Diffusion ATM		*Diffusion POS (debit)*		*Diffusion POS (credit)*	
		Logistic	***Gompertz***	***Logistic***	***Gompertz***	***Logistic***	***Gompertz***
(1)	α	1.3397** (1.29,1.35)	1.1856** (1.10,1.33)	1.7104** (1.64,1.79)	1.5662* (1.42,1.66)	1.6102** (1.54,1.76)	1.6051* (1.51,1.72)
	Β (Time)	.0916*** (.07,.10)	.0518** (.04,.07)	0.0622*** (.05,.07)	0.0599*** (.05,.08)	0.0715*** (.06,.09)	0.0599*** (.05,.08)
	R^2	.87	.84	.80	.81	.88	.81
(2)	α	2.0125** (1.95,2.26)	1.9128* (1,76,2.09)	1.5290* (1.44,1.63)	1.2741** (1.19,1.33)	1.2420** (1.21,1.30)	1.0141** (.90,1.18)
	Β (Time X rival precedence)	.1552*** (.14,.16)	.1015** (.09,.11)	.0751** (.06,.09)	.0741** (.06,.09)	.0880** (.08,.10)	.0663*** (.06,.08)
	R^2	.90	.84	.83	.90	.87	.88
(3)	α	.6029*** (.58,.65)	.7355*** (.62,.88)	2.1315* (2.07,2.26)	1.9128** (1.82,2.02)	2.2759* (1.99,2.46)	1.8725** (1.68,1.98)
	β (Time X own network effects dummy)	.0890*** (.07,.10)	.0778*** (.06,.09)	0.0982*** (.08,.11)	.0665*** (.05,.08)	0.1643** (.15,.18)	.0662** (.06,.08)
	R^2	.72	.71	.61	.62	.53	.62
(4)	α	2.2281* (2.35,2.96)	1.6236* (1.55,1.72)	3.9055** (3.71,4,63)	1.4415** (1,36,1.62)	3.0326** (2.88,3,15)	1.4408** (1,35,1.63)
	Β (Time X indirect network effects dummy)	.1016*** (.08,.11)	.0920*** (.08,.10)	.1329*** (.12,.15)	.0721*** (.06,.08)	.0817** (.06,.11)	.0772*** (.06,.09)
	R^2	.70	.72	.78	.68	.74	.71
(5)	α	3.4332** (3.02,4.13)	2.0118** (1.95,2.05)	5.2250* (4.90,5.39)	1.6084** (1.51,1.72)	3.7521** (3.51,3.95)	2.0285** (1.94,2.22)
	β (Time X Lerner index dummy)	.1365** (.11,.15)	.0885* (.07,.10)	.1442*** (.13,.16)	.0957** (.08,.11)	.1028*** (.09,.12)	.0956*** (.08,.11)
	R^2	.72	.74	.72	.74	.75	.78

*, **, *** Indicates p-value of 10%, 5% and 1%, respectively.

TABLE 3. ESTIMATING THE DETERMINANTS OF BANK-LEVEL DIFFUSION OF ATMs AND POS TRANSACTIONS

Least squares estimates from Gompertz curve bank-level β_i
Explanatory variable of each bank have been averaged over 44 quarters
Standard errors in parentheses (45 observations)

	β_i *(Time)*		
	ATM	*POS (debit)*	*POS (credit)*
Constant	.0311* (.01)	.0308** (.01)	.0214** (.01)
Demand			
Log(ATM transactions$_{t-1}$)	.1327 (.02)	-	-
Log(POS transactions$_{t-1}$)	-	.0914 (.08)	.0715 (.08)
Rival precedence			
Log(rival's ATM adoption$_{t-1}$)	.2712*** (.02)	-	-
Log(rival's POS terminal adoption$_{t-1}$)	-	.1601** (.01)	1554** (.02)
Network effects			
Log [(card growth) x (own ATMs)]	.0228** (.01)	-.0223** (.01)	-.0153** (.01)
Log[(competitors' ATMs) x (own card issuance)]	.0481** (.01)	.0780* (.01)	.0391* (.01)
Log [(card growth) x (own POS terminals)]	-.0782* (.02)	.0802*** (.01)	.0928** (.02)
Log[(competitors' POS terminals) x (own card issuance)]	-.0331** (.01)	-.0221*** (.01)	-.0767** (.01)
Competition			
Lerner index ATM transactions	-.6061*** (.02)	-	-
Lerner index POS transaction (two-sided)s	-	-.4421** (.01)	-.0119 (.02)
Control factors			
Log(growth of bank ATMs)	-	-.2976** (.01)	-.0442 (.03)
Log(growth of bank POS terminals)	.2226 (.03)	-	-
Log(total bank assets)	-.6221** (.02)	-.5104** (.01)	-.3602* (.01)
Log(bank branches)	-.1591*** (.01)	-.1629*** (.01)	-.0845** (.02)
Log(bank average wage)	.6362* (.04)	.2703* (.03)	.2819* (.01)
Log(regional GDP)	-.0996** (.01)	-.0641** (.01)	-.0629** (.01)
R^2	.92	.95	.88
*, **, *** Indicates p-value of 10%, 5% and 1%, respectively.			

TABLE 4. EVOLUTION OF MAIN VARIABLES OF THE MODEL OF THE DEMAND FOR CURRENCY

	1997	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*
DEPOSITOR LEVEL											
Currency holdings (euros)	783	771	818	807	802	793	761	754	743	732	724
Deposits interest rates (%)	2.28	2.06	2.02	2.00	1.91	1.74	1.66	1.56	1.84	1.78	1.75
Non-durable consumption (euros)	17,075	17,324	17,032	17,392	18,080	18,391	18,950	19,046	19,116	19,225	19,306
Average ATM transactions (per card and year)	24	25	26	26	28	29	29	30	31	31	32
Average POS transactions (per card and year)	7	9	11	12	14	17	20	22	25	27	28
REGIONAL LEVEL											
Log(ATMs)	2.96	3.31	3.41	3.52	3.63	3.69	3.71	3.96	4.21	4.44	4.76
Log(POS)	4.52	4.56	4.59	4.62	4.64	4.71	4.75	5.16	5.54	5.87	6.05
Log(bank branches)	2.94	3.06	3.18	3.21	3.28	3.31	3.35	3.69	3.98	4.12	4.26
Log(bank average wage)	4.28	4.31	4.34	4.39	4.42	4.46	4.47	4.49	4.52	4.55	4.56
Log(regional GDP)	10.53	10.56	10.59	10.61	10.64	10.67	10.69	10.76	10.88	10.91	10.93

Note: All variables are shown as annual averages excepting currency which reflects the “amount of currency usually held at home”. The table reports averages values from sample information. Nondurable consumption and currency are deflated by the consumer price index and then converted to euros.

TABLE 5. DETERMINANTS OF THE DEMAND FOR CURRENCY

Panel data fixed effects estimation .Standard errors in parentheses. The errors are clustered at the regional level (187 observations)

	(I)	(II)	(III)	(IV)
Constant	.721** (.020)	.703* (.019)	.707** (.018)	.696** (.018)
Time (t)	-.122*** (.008)	-.125*** (.010)	-.122*** (.010)	-.118*** (.009)
Time² (t²)	.007** (.001)	.009* (.001)	.008** (.001)	.010* (.001)
Deposits interest rates (R)	-.473*** (.014)	-.316** (.013)	-.285* (.012)	-.216** (.012)
Non-durable consumption (c)	.202*** (.017)	.199*** (.016)	.208*** (.015)	.198** (.021)
Log(ATMs)	.009** (.005)	.008*** (.006)	.005** (.003)	.007*** (.005)
Log(POS)	-.462** (.023)	-.452*** (.020)	-.418** (.019)	-.405*** (.015)
Log(bank branches)	.349*** (.017)	.358*** (.018)	.361*** (.017)	.397** (.018)
Log(regional GDP)	-0.018** (.004)	-.014** (.005)	-.015*** (.008)	-.017** (.008)
Average ATM transactions	-	.144*** (.010)	.129** (.008)	-
Average POS transactions	-	-.351** (.015)	-	-
Average POS debit transactions	-		-0.391** (0.010)	-
Average POS credit transactions	-		-0.284*** (0.009)	-
Average ATM transactions (corrected for the relative weight of sectors with a high cash usage)	-	-	-	.266*** (.014)
Average POS transactions (corrected for the relative weight of sectors with a high card usage)	-	-	-	-.585** (.013)
R^2	.73	.80	.83	.82
*, **, *** Indicates p-value of 10%, 5% and 1%, respectively.				