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TECHNOLOGICAL CHANGE AND THE DEMAND FOR CURRENCY: AN ANALYSIS WITH HOUSEHOLD DATA

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Abstract

Advances in transaction technology allow agents to economize on the cost of cash management. We argue that accounting for the impact of new transaction technologies on currency holding behaviour is important to obtain theoretically consistent estimates of the demand for money. We modify a standard inventory model to study the effect of withdrawal technology on the demand for currency. An empirical specification for households' demand schedule is suggested, in which both the level of currency holdings and the interest rate elasticity of demand depend on the withdrawal technology available to agents (e.g. ATM card ownership or a high/low density of bank branches, ATMs). The theoretical implications are tested using a unique panel of Italian household data (on currency holdings, deposit interest rates, consumption, development of banking services, etc.) for the period 1989-2004.

JEL Classification: E5.
Keywords: money demand, inventory models, technological change.

Contents

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1 Introduction*

A quantitative assessment of the parameters of the money demand function is important for answering key questions in macroeconomics. Information on the interest elasticity of money demand is helpful in evaluating the distortion induced by inflation upon the holdings of non-interest bearing assets, a centerpiece in the analysis of the welfare costs of inflation (e.g. Bailey, 1956; Lucas, 2000). The income elasticity is crucial in establishing the money growth rate consistent with price stability (Friedman, 1969).

Yet the wide range of empirical results available in the literature may foster skepticism about the stability of money demand and the possibility to provide conclusive answers to those fundamental questions. It is often conjectured that volatile estimates of the parameters of money demand may be due to compositional changes in expenditures and the evolution of financial practices. For instance, Teles and Zhou (2005) show that banking deregulation in the United States blurred the traditional distinction between monetary aggregates (e.g. M1 and M2) since it allowed previously illiquid savings accounts to be used for settling transactions. Some of these institutional complications can be avoided by focusing on currency, whose definition is less controversial. Even currency, however, is affected by advances in payment and withdrawal technologies, e.g. by the diffusion of bank branches, electronic points of sale and the ATM network. Such developments confound the linkage between currency, consumption and interest rates, further challenging the identification of the money demand schedule.

We contribute to this debate by presenting a model that accounts for the effect

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of developments in the withdrawal technology on the demand for currency. To this end, we modify a standard inventory model by introducing a role for the diffusion of bank branches and ATMs withdrawal points on agents' cash holding choices. The key difference with respect to the classic Baumol - Tobin framework, where all withdrawals are assumed to be costly, is that in our setup agents are occasionally given the opportunity to withdraw at basically no costs, for example when they meet an ATM terminal during a shopping trip. We show that in such an economy both the level and the interest elasticity of the demand for currency decrease as the number of withdrawal opportunities increases. Our dataset shows that the density of bank branches and ATM terminals has a large cross-sectional and time-series dispersion. Thus, accounting for the type of withdrawal technology that is accessible to the households in different regions or periods is potentially important in the estimation of the demand for currency.

The theoretical framework suggests a modified empirical specification of the demand for currency, namely one that augments the standard specification with an index of the withdrawal technology and its interaction with the interest rate. We test this specification on a panel of Italian household data over 1989-2004, a period characterized by a widespread heterogeneity in the diffusion of bank branches and ATM terminals. The database includes information on household currency holdings, interest rates on deposit and consumption paid in cash. It also includes information on the households' access to banking services and the diffusion of the bank branch and ATM networks. An important feature of our investigation is that the data on money holdings, interest rates and expenditures are close counterparts to their theoretical notions. In particular, we use consumption paid with cash as the scale variable for the money demand. This is important because it allows us to isolate the inventory problem (how to finance a given stream of cash consumption expenditure) from the choice of *the proportion* of total expenditures to be financed in cash. The latter is influenced by developments in other transaction technologies, such as credit cards or points of sale, which transcend the scope of this paper.

The paper is organized as follows. The next section revisits the money demand estimates of Attanasio, Guiso and Jappelli (2002) using a dataset that almost doubles their sample size. The estimation shows that the interest elasticity of money demand changes significantly compared to their results. Section 3 discusses a modification of the inventory model that is used in Section 4 to revisit the household demand for currency. Section 5 discusses the results and offers some comments on related literature. Section 6 presents some evidence on the money demand effects of changes in the banking structure using an aggregate Italian time-series that covers most of the 20^{th} century. A final section summarizes our findings.

2 Revisiting previous evidence

We begin our analysis by replicating the estimation exercise of Attanasio, Guiso and Jappelli (2002) (AGJ henceforth) over a sample that is about twice as large than the one they used. The data, as in their case, are taken from the *Survey of Household Income and Wealth* (*SHIW*), an investigation of the economic behaviour of about 8,000 Italian households that is run every two years by the Bank of Italy (see Appendix A). AGJ use four surveys, covering the 1989-1995 period. We benefit from the following four ones, about the 1998-2004 period.

A key premise of the estimation method followed by AGJ is that there are significant differences in households' access to deposit accounts and withdrawal technologies. In particular, households differ in whether they own a deposit account (the relevant margin for the currency to deposit substitution) and in whether they possess an ATM card (a feature that is likely to affect the marginal cost of withdrawals).[1]

[1]Updated summary statistics on Italian households' money holding behaviour and access to deposit accounts and ATM cards are given in Appendix A, Table 6.

They argue that heterogeneity in the access to these banking services is likely to be endogenous, affected by factors that also influence money holding behaviour. This instance of endogenous sample selection may give rise to inconsistent estimates of the money demand coefficients if the shocks that affect the household decision to open a bank account or to have an ATM card are correlated to the shocks of the demand for currency. Based on this premise, AGJ estimate a currency demand equation controlling for sample endogeneity by means of Heckman's (1979) two step methodology.[2] The baseline specification for the currency demand equation, derived from McCallum and Goodfriend's (1987) extension of the Baumol-Tobin inventory model (see their Section 3), is the following:

$$\log m_{i,t} = \frac{1}{1+\beta}\log\beta + \frac{1}{1+\beta}\log w_{i,t}A_{i,t} - \frac{1}{1+\beta}\log R_{i,t} + \frac{\beta+\gamma}{1+\beta}\log c_{i,t} \qquad (1)$$

where m denotes deflated currency holdings, β and w A are parameters of the transaction technology, R is the nominal interest rate and c measures the real consumption expenditure.

Our updated replication of AGJ estimates over a much larger sample is presented in Table 1. For ease of comparison, we use the same specification and the same variables they selected. In particular, the equation includes a measure of the interest rate paid on the household deposit account that is disaggregated by year and province,[3] the value of nondurable consumption (measured at household level from *SHIW*), a linear and a quadratic trend that are intended to proxy for technological progress (the term $w_{i,t}$ $A_{i,t}$ in equation (1)) and several demographic controls.

[2]In this particular case Heckman methodology implies the estimation of two probits. First, a probit for having a bank account is estimated on all the observations. Then a probit for having an ATM card, conditional on having a bank account, is estimated. This allows them to obtain the two variables (Mills' ratios) that are necessary to correct OLS estimates of the currency demand equation (see AGJ Section 4 for details).

[3]In Italy there are around 100 provinces. A province is comparable to a U.S. county. Descriptive statistics on the historical evolution of the mean and the dispersion of interest rates on deposits are available in Appendix A, Table 6.

Table 1: Demand for Currency: 1989-2004. Heckman's two step methodology.

	Probit		Demand for currency	
	Bank account	ATM card	Bank account holders without ATM card	Bank account holders with ATM card
	(1)	(2)	(3)	(4)
log(consumption)	0.301 (0.023)	0.729 (0.016)	0.470 (0.016)	0.488 (0.020)
log(interest rate)	-0.163 (0.050)	-0.134 (0.031)	0.081 (0.024)	0.023 (0.021)
Time	-0.157 (0.008)	0.157 (0.006)	-0.036 (0.005)	-0.009 (0.007)
Time squared	0.003 (0.001)	-0.008 (0.001)	0.003 (0.001)	0.001 (0.001)
Less than elementary school	-0.834 (0.062)	-1.406 (0.042)	-0.333 (0.031)	-0.727 (0.057)
Elementary schooling	-0.656 (0.058)	-0.937 (0.025)	-0.328 (0.026)	-0.422 (0.026)
Junior high school	-0.305 (0.059)	-0.361 (0.024)	-0.186 (0.022)	-0.122 (0.016)
High school	0.027 (0.061)	-0.055 (0.024)	-0.097 (0.021)	-0.056 (0.014)
Male head	-0.006 (0.021)	0.068 (0.015)	0.101 (0.010)	0.071 (0.011)
Living in rural areas	0.138 (0.043)	-0.179 (0.030)	...	...
Living in suburbs	0.048 (0.023)	0.106 (0.016)	...	...
Living in semicenter	0.072 (0.025)	0.107 (0.016)	...	...
Log (financial wealth)	0.730 (0.007)	0.036 (0.004)	...	...
Number of ATMs in the province	1.861 (0.057)	1.077 (0.034)	...	...
Mills ratio:				
Bank account	...	...	-0.519 (0.015)	-0.730 (0.028)
ATM card	...	...	0.512 (0.029)	0.875 (0.038)
Constant	-6.427 (0.244)	-8.129 (0.165)	1.416 (0.161)	-0.200 (0.237)
R^2	0.55	0.25	0.20	0.15
Sample size	62,957	53,819	27,749	26,070

Note: Standard errors in parenthesis.- The equations are estimated using Heckman's two-step procedure. The dependent variable in the probit regression for the ownership of a bank account (ATM card) equals one if the household has at least one account (ATM card), zero otherwise. The regressions also include the number of children, number of adults, age, age squared number of income recipients and dummies for employed, self employed and retired heads.

The first stage probits, respectively for the deposit account and the ATM card adoption, are reported in columns (1) and (2) of Table 1. The estimated coefficients show that higher levels of consumption, financial wealth, educational records and ATM withdrawal points increase the probability of adoption of both a bank account and an ATM card. The estimated parameters do not substantially differ from those obtained by restricting the sample to 1995, with the only exception of the negative effect of the (log) interest rate on the adoption of both.

The currency demand estimates concern households who possess a deposit account. Two separate demand equations are estimated, one for the households without an ATM card and one for those who possess an ATM card. The estimates are shown in columns (3) and (4) of Table 1, respectively. These indicate values for the coefficients of consumption and the demographic variables which are broadly in line with the ones of AGJ. The point estimate of the consumption elasticity is close to 0.5, the value predicted by the classical Baumol - Tobin model.

Different results from the ones of AGJ emerge instead for what concerns the estimated interest rate elasticity. Column (3) shows a positive (statistically significant) elasticity for the households without ATM card, which compares to a negative (statistically significant) value of -0.27 found by AGJ. For the households with ATM card, column (4) reports an interest elasticity that is not statistically different from zero. This compares to a point estimate of -0.59 found by AGJ over the 1989-1995 sample.

The positive (albeit small) interest rate coefficients that appear in the full sample estimates, and the large differences between those and AGJ estimates, suggest a misspecification problem.[4] Three possible sources of misspecification are considered next. First, the linear quadratic trend used to proxy for technological progress in the withdrawal technology may impose too much of a structure over a long time

[4]Restricting the estimation to their sample period allows us to replicate their results.

period.[5] Second, the sizable heterogeneity of the micro data (witnessed by the low values of the fit statistics) signals the presence of other unobserved factors affecting money demand. Systematic year or regional distribution of these factors, as is likely the case for the level of petty crime or the diffusion of economic activities that rely on cash (e.g. street markets, the black economy), may give rise to an omitted variable problem. Based on these considerations, the regressions presented below use year and province dummies to remove unobserved time and regional factors affecting currency demand.[6] Third, the functional form of the demand for currency rather than obeying a constant interest rate elasticity (as implied by the log-log specification in (1)) may feature a different functional form, such as constant semi-elasticity (log-lin).

These issues are tackled by the regressions presented in Table 2. In the first set, shown in columns (1) and (4), the trend and its square are replaced by year and province dummies. The estimation results show that this specification delivers a near zero interest elasticity for both types of households, although the point estimates of the interest rate coefficient remain positive. Note, moreover, that the consumption coefficients for both types of households become much smaller (we discuss the properties of the scale variable below).

In the regressions of columns (2) and (5) the logarithm of the interest rate is replaced by the level, thus stipulating that the elasticity varies with the interest rate. This modification does not solve the puzzling finding of a positive interest elasticity. Additional experiments with alternative functional forms, including polynomial specification as well as Box-Cox transformations, do not deliver any sensible improvement in the fit of the model or the sign of the interest rate elasticity (not reported in the table).

[5]Note that in a sample that includes four periods, a linear and a quadratic trend work "almost" like time dummies.

[6]A robustness exercise discussed in Section 4 estimates the currency demand equation by removing all unobserved factors at the household level using fixed effects.

Table 2: Demand for Currency: Alternative specifications.

	Bank account holders without ATM card			Bank account holders with ATM card		
	(1)	(2)	(3)	(4)	(5)	(6)
log(consumption)	0.307 (0.016)	0.310 (0.016)	...	0.146 (0.022)	0.151 (0.023)	...
log(cash consumption)	...	...	0.430 (0.014)	...	...	0.313 (0.011)
log(interest rate)	0.028 (0.038)	...	-0.109 (0.044)	0.051 (0.034)	...	0.044 (0.036)
interest rate	...	0.069 (0.018)	...	...	0.057 (0.025)	...
Mills ratios						
Bank account	-0.578 (0.015)	-0.578 (0.015)	-0.472 (0.020)	-0.647 (0.028)	-0.649 (0.028)	-0.502 (0.031)
ATM card	-0.091 (0.033)	-0.087 (0.033)	-0.280 (0.059)	-0.225 (0.054)	-0.212 (0.055)	-0.339 (0.073)
Province and Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.26	0.26	0.26	0.21	0.21	0.21
Sample size	27,749	27,749	17,339	26,070	26,070	22,512

Note: Standard errors in parenthesis. The equations are estimated using Heckman's two-step procedure. The coefficients of the first stage probit regression are reported in Table 8. The other variables included in the second stage regressions are as in Table 1. Equations (3) and (6) are estimated over the sample period 1993-2004, the remaining equations over the sample 1989-2004.

Lastly, we analyze the role of the scale variable. The measure used above aggregates non durable consumption and service purchases irrespective of the way the agents pay for it. The large diffusion of debit and credit cards networks occurred throughout the period is likely to make this variable inappropriate for the estimation of the cash inventory model (the low consumption elasticities detected in (1) and (4) may be a consequence of this). A more appropriate scale variable, the household expenditures done in cash, is available from *SHIW* since 1993. The regressions that use the cash consumption variable are presented in columns (3) and (6). The consumption coefficients increase substantially, although they remain below one half. A small and negative interest rate elasticity is detected for the households without ATM card (at -0.1); the one for agents with ATM remains small and not significantly different from zero.[7]

Altogether, the currency demand regressions presented above yield estimates of the interest rate elasticity that are small and scattered around zero, in the -0.1 to 0.1 range. Our preferred specification, which controls for unobserved time and provincial effects and uses cash consumption as a scale variable (columns 3 and 6 of Table 2), eliminates the puzzling finding of a positive interest rate coefficient. However, the estimated interest elasticities remain small (-0.1 for agents without ATM and zero for the others) compared to previous estimates and to the predictions of inventory models such as Baumol-Tobin or Miller-Orr (which are equal to, respectively, -1/2 and -1/3).[8] The rest of this paper investigates the possibility that the developments in withdrawal technology occurred in Italy over the period considered, namely the strong diffusion of bank branches and the ATM terminals, may contribute to explain the low and unstable interest rate coefficients detected above. To this end, the next section discusses the consequences of such developments for standard inventory models of the demand for currency.

3 A theoretical framework

This section presents a modification to the standard inventory model that investigates the relation between the withdrawal technology and the demand for currency. The distinguishing feature of the model is to account for the currency demand effect

[7]Note, for comparability, that estimates of equations (3) and (6) using non-durable consumption over the 1993-2004 period yield an interest rate elasticity of -0.05 for households without ATM card, of 0.06 for households with ATM card.

[8]The possibility of a low interest elasticity at low interest rates is discussed by Mulligan and Sala-i-Martin (2000). In their model agents must pay a fixed cost to have a deposit account, which is shut down when its return falls below the cost (agents with little savings or low return will close it first). They show that this effect may lower the interest elasticity estimated on *aggregate* data. Note however that our households data are not affected by this effect as we only use data for the agents who do possess a deposit account (taking into account the sample selection problem). Moreover, as shown in Appendix A, Table 6, no clear signs of a reduction in the number of agents who possess a deposit account emerge from the data over time.

of the diffusion of cash dispensers (ATM terminals or bank branches). We consider the steady state problem of an agent who uses cash to finance an exogenous stream of consumption expenditure equal to c. Shopping takes place in one of several locations of the economy, which may be endowed with a cash dispenser that allows the agent to withdraw cash without incurring a time cost. By contrast, a withdrawal done at a location without cash dispenser entails a cost b, as in the Baumol-Tobin model, as the agent wastes some resources to walk to the bank.

Let $T(M, c)$ be the number of costly withdrawals from the bank that are necessary to finance a consumption flow c when the average money balances are M. We assume that T is decreasing in M, so that higher balances allow the agent to finance consumption with less withdrawals, and that T is convex in M, so the minimization problem is well behaved. The money demand solves the minimization problem:

$$\min_{M} \; R\, M + b\, T(M, c) \tag{2}$$

where R is the net nominal interest rate. The optimal choice of M balances the impact on the cost due to forgone interest with the effect on the cost of withdrawals.

To analyze the effect of technological change in T on the money demand we present two comparative static results, one about the level of money demand and the other about its interest rate elasticity. Consider two withdrawal technologies T_i and the associated money demand schedules, M_i for $i = 1, 2$. Note that the first order condition of problem (2) and the assumption that T is convex in M yield:

Result 1. *If the marginal cost of withdrawals is higher then the money demand is lower. Formally, if* $T_2'(M) \geq T_1'(M)$ *for all* M *then* $M_2 \leq M_1$ *for all* $R \geq 0$.

The second result relates the interest rate elasticity to the curvature of the cost function T. In particular, the first order condition of problem (2) and its total differential imply:

$$-\frac{R}{M}\frac{\partial M}{\partial R} = 1 \ / \ \left(M \frac{T''}{-T'} \right) \tag{3}$$

The expression $-M \ T''/T' \geq 0$ is a measure of the local curvature of the cost function T. It is also the elasticity of the marginal cost T'. Thus equation (3) says that if the marginal cost is more sensitive to M, then the money demand is less sensitive to interest rate changes. This yields:

Result 2. *If the interest rate elasticity of the marginal cost of withdrawals is higher, the interest rate elasticity of the money demand is smaller. Formally, assume that at a given R:*

$$M_2 \frac{T_2''(M_2)}{-T_2'(M_2)} \ \geq \ M_1 \frac{T_1''(M_1)}{-T_1'(M_1)} \ , \textit{ then } \ -\frac{R}{M_2}\frac{\partial M_2}{\partial R} \leq -\frac{R}{M_1}\frac{\partial M_1}{\partial R}$$

where M_1 and M_2 denote, respectively, the demand for currency implied by technology T_1 and T_2 when the interest rate is R.

We now use these results to analyze the effect of technological progress in T on money demand for two alternative withdrawal technology specifications.

3.1 Example 1: Baumol-Tobin with free withdrawals

We consider a Baumol - Tobin setup and assume that in every period the agent has p contacts with the financial intermediary (opportunities to withdraw) which come for free. Withdrawals in excess of p are costly. To think of an application, imagine an agent who passes by a bank branch once a week on her way to the ball game. This case can be represented by a technology T_p saying that she has one free withdrawal a week, or $p = 1$. Now suppose that an ATM is installed on the way to her job and that she works six days per week. This "technological change" can be represented by an increase in p, so that she gets seven free withdrawals a week. The above setup is described by the following technology:

$$T_p(M,c) = \max\{\frac{c}{2\ M} - p, 0\}. \tag{4}$$

where T_p denotes the number of costly withdrawals and the parameter p gives the number of free withdrawals per unit of time.

Setting $p = 0$ in (4) stipulates that all trips are costly, as in the Baumol-Tobin model:[9] $T_0(M,c) = \frac{c}{2\ M}$. Note that T_0 has a marginal cost function T_0' with constant elasticity equal to 2, which implies the well known result that the interest elasticity of the money demand is 1/2. The interpretation of the $p > 0$ case is that the agent has p free withdrawals, so that if the total number of withdrawals is $c/(2\ M)$, then she pays only for the excess of $c/(2M)$ over p.

The money demand for a technology with $p \geq 0$ is given by

$$M_p(R) = \begin{cases} \sqrt{\frac{b\ c}{2\ R}} \text{ for } R \geq R^* \\ \sqrt{\frac{b\ c}{2\ R^*}} \text{for } R < R^* \end{cases} \tag{5}$$

where

$$R^* \equiv (p)^2\, 2b/c\ . \tag{6}$$

When $p = 0$ the forgone interest cost is small at low values of R, so agents economize on costly withdrawals and choose a large value of M. Now consider $p > 0$. In this case there is no reason to have less than p withdrawals per unit of time, since these are free. Hence, for $R < R^*$ agents choose the same level of money holdings, namely, $M_p(R) = M_p(R^*)$, since they are not paying for any withdrawal but they are subject to positive forgone interest rate costs.

Note that improvements in the particular technology described in (4) produce

[9] An agent with consumption flow c withdraws $2\ M$, which last $2M/c$ periods, has average balances M and makes $(c/2M)$ trips to the bank.

a money demand that is lower in level and has a smaller interest rate elasticity (in between zero and one-half) because it indeed satisfies the assumptions for results 1 and 2 presented above. To see this, consider two technologies indexed by $0 \leq p_1 < p_2$. These technologies satisfy the following three properties:

(i) A greater value of p represents technological progress, because T_p is decreasing in p. Formally $T_{p_2}(M, c) \leq T_{p_1}(M, c)$ (with strict inequality for $M < c/(2p_1)$).

(ii) a higher value of p increases the marginal cost T'_p, hence decreases money demand by result 1, at least for some values of M. In particular, $0 = T'_{p_2}(M, c) > T'_{p_1}(M, c)$ over the range: $c/(2\ p_2) < \ M \ < c/(2\ p_1)$, and equal otherwise.

(iii) A greater value of p increases the curvature of T_p, hence decreases the interest elasticity by result 2. To see this notice that T_{p_2} can be obtained by the following transformation $T_{p_2}(M, c) = g(T_{p_1}(M, c))$ for $g(\tau) = \max\{\tau - (p_2 - p_1), 0\}$. As the transformation is increasing and convex in τ, it follows that technologies indexed by a higher value of p have more curvature.

3.2 Example 2: A random matching model

This section studies the effect of bank branch (ATM terminals) diffusion on currency demand using a random matching framework. We consider an economy with two locations: the shopping center and the financial district. The agent incurs a time cost b whenever she visits the financial district to withdraw money. Let c be the agent daily consumption and $p \in (0, 1)$ be the probability that the agent is offered an opportunity to withdraw for free in the shopping center (e.g. from an ATM). Note that a withdrawal of $2M$ allows her to finance at least $2M/c$ consecutive days in the shopping center (i.e. without having to go to the financial district). The probability that the agent is not matched with a cash dispenser during this period is $(1-p)^{\frac{2M}{c}}$, that for small p can be approximated by $e^{-\frac{2M\ p}{c}}$. This probability gives the fraction of total trips ($\frac{c}{2\ M}$) which are costly. This yields the following transaction technology:

$$T_p\left(M,c\right)=\frac{c}{2\ M}e^{-\frac{2M\ p}{c}} \tag{7}$$

where T_p denotes the average number of costly withdrawals for an agent who withdraws $2M$ and consumes c.[10]

As for the case discussed in Section 3.1 it is immediate to show that the technology in (7) has the following features: (i) T_p is decreasing in p, so that higher values of p represent technological progress; (ii) the marginal cost T_p' is increasing in p which, by result 1, implies that the level of money demand decreases as the technology improves; (iii) the curvature of the cost function, as measured by $\left(M\frac{T''}{-T'}\right)$, is increasing in p which, by result 2, implies that the interest rate elasticity of the money demand is smaller for better technologies.[11]

4 Estimation results

The theory discussed in the previous section shows that the level and the interest elasticity of the demand for currency depend on the type of withdrawal technology that is available to agents. In particular, it suggests that technological improvements, i.e. reductions in the cost of withdrawals, lower the level of the money demand and its interest elasticity (in absolute value). Based on these insights, we construct a proxy for the level of the withdrawal technology faced by the household

[10] The use of equation (7) in problem (2) assumes that the ratio between the average withdrawal and the average balance is equal to 2. This is only an approximation, as the exact computation must take into account that the money holding profile is not saw-tooth, and that with random matches some withdrawals occur before a zero balance is reached. See Alvarez and Lippi (2006) for such an extension.

[11] Some algebra shows that $\left(M\frac{T''}{-T'}\right)=2+\frac{(2pM)^2}{c(2pM+c)}$ which is increasing in p. Result (iii) is alternatively established by noting that, given $p_2>p_1$, T_{p_2} can be obtained by applying the following increasing and convex transformation to T_{p_1}:

$$g\left(\tau\right)=\left(\tau\right)^2\frac{c}{2M}.$$

and estimate a specification of the demand for currency that includes this variable both in level and interacted with the interest rate.

We proxy for the level of the withdrawal technology faced by agents by using the number of bank branches per capita measured at city level (around 300 cities per year). This indicator, whose year averages and standard deviations are reported in Table 7 of Appendix A, highlights the ongoing diffusion of bank services across the territory over the past fifteen years as well as its large cross section dispersions.[12]

To make the results comparable with those described in Section 2 the currency demand estimates presented in the next Table use the same set of regressors of Table 2. All regressions feature cash-expenditure rather than non-durable consumption as a scale variable, and use year and province dummies in the place of the linear-quadratic trend.[13]

Our first set of results, that controls for endogeneity in the access to bank services, is presented in Table 3. The Heckman second step regressions reported in columns (1) and (2) concern agents without ATM card. This is the group for which our measure of withdrawal technology - the number of bank branches per capita at the city level - is most appropriate.

The specification in column (1) integrates the technology measure in level. In line with the predictions of the theory, a greater diffusion of bank branches reduces currency holdings and the interest rate enters the equation with a negative and statistically significant coefficient.

Column (2) considers a specification which allows the technology index to affect both the level and the interest elasticity of the demand for currency, as the theory

[12]Until the early nineties commercial banks faced restrictions to open new bank branches in other provinces. A gradual process of liberalization has occurred since then, which has led to a sharp increase in the number of bank branches and a reduction of the interest rate differentials across different areas (see Casolaro, Gambacorta and Guiso (2006) for a review of the main developments in the banking industry during the past two decades).

[13]None of these choices is really key for the results that follow. Qualitatively similar estimates are obtained by using alternative methods (see Table 4) or by removing demographic controls.

Table 3: The Demand for Currency and Withdrawal Technology

	Bank account holders without ATM card		Bank account holders with ATM card	
	(1)	(2)	(3)	(4)
log(cash expenditure)	0.431 (0.014)	0.426 (0.014)	0.315 (0.011)	0.314 (0.011)
log(interest rate)	-0.103 (0.044)	-0.175 (0.046)	0.048 (0.036)	0.058 (0.038)
log(interest rate) · Bank branches per capita[a]	...	0.107 (0.020)	...	-0.015 (0.020)
Bank branches per capita[a]	-0.127 (0.033)	-0.133 (0.033)	-0.147 (0.030)	-0.150 (0.030)
Mills ratios				
Bank account	-0.477 (0.020)	-0.475 (0.020)	-0.514 (0.031)	-0.512 (0.031)
ATM card	-0.266 (0.059)	-0.292 (0.059)	-0.305 (0.073)	-0.314 (0.074)
Province and Year dummies	Yes	Yes	Yes	Yes
R^2	0.26	0.26	0.21	0.21
Sample size	17,339	17,339	22,512	22,512

Note: Standard errors in parenthesis. The equations are estimated using Heckman's two-step procedure. The coefficients of the first stage probit regression are reported in Table 9. The other variables included in the second stage regressions are as in Table 1.
[a] Number of bank branches per capita measured at the city level.

predicts. The estimates confirm the findings of column (1) that a greater diffusion of bank branches reduces currency holdings and that the interest rate (log) level enters the equation with a negative coefficient. Moreover, the interaction between the interest rate and the diffusion term enters significantly with a positive coefficient. This suggests that the interest elasticity of the demand for currency varies across households, with lower values for households who face more a superior technology (a greater diffusion of bank branches). The comparison of (1) and (2) shows that omitting the interaction term from the estimation yields an estimate of the *average* interest rate elasticity that neglects an important layer of heterogeneity. In quantitative terms, the estimates imply that agents faced with less developed technology, e.g. a diffusion value of 0.1 (the 5th percentile), have an interest elasticity of about -0.2. The interest elasticity falls to -0.1 for the median agent (the median of the diffusion indicator is around 0.5) and is basically nil for the households facing the highest levels of development.

The regressions in columns (3) and (4) concern households who possess an ATM card. We attempt this estimation exercise even though we are aware of the fact that our index for the development of the withdrawal technology - the diffusion of bank branches per capita at the city level - is not the most appropriate measure of diffusion for this type of household.[14] The estimation results should thus be taken with a grain of salt, as they may be subject to a greater amount of measurement error than the ones concerning the households without ATM.

In both regressions the level of currency holdings is negatively related to the diffusion of bank branches, with a coefficient magnitude comparable to the one detected for the agents without ATM card. Instead, the interest rate coefficients (both levels and interactions) are not significantly different from zero. In principle, a zero interest elasticity for agents who face a more advanced withdrawal technology can be explained by the models outlined in Section 3. For instance, the Baumol-Tobin model with free withdrawals predicts that the interest rate range over which the demand for currency has a zero interest elasticity expands with technological advances.

We conclude this section by exploring the robustness of the estimates. The results for the households without ATM card are shown in Table 4.[15] For all regressions, we compute the coefficients' standard errors by accounting for the possibility of heteroschedasticity and cross correlation of the shocks within a province in a given year.[16] We begin by assessing whether the estimated coefficients were affected by

[14]Unfortunately information on the diffusion of ATM terminals, the natural diffusion measure for the ATM card holders, is not available to us at the city level but only at the province level (about 100 datapoint per cross section).

[15]The corresponding results for the households with ATM card are reported in Appendix C (Table 10).

[16]The standard errors presented in Tables 2 and 3 do not control for heteroschedasticity and cross correlation because of comparability with AGJ (2002).

the choice of the Heckman estimation method. The identification of the currency demand coefficients in the presence of sample endogeneity hinges on the specification of the probit selection equation. In particular, if the first and the second stage OLS have a large set of variables in common, a collinearity problem may occur as the Mills ratio is approximately a linear function of these variables over a wide range of values (see Puhani, 2000).[17] To assess the impact of multicollinearity on the baseline results of column (2) of Table 3 we present a plain OLS estimate of the demand for currency in column (1) of Table 4. The results show that coefficients on cash consumption and the interest rate are similar to those estimated in Table 3.

Table 4: The Demand for Currency and Withdrawal Technology: Robustness.

	Bank account holders without ATM card		
Estimation method	*Ordinary Least Squares* (1)	*Instrumental Variables*[a] (2)	*Household Fixed Effects* (3)
log(cash expenditure)	0.486 (0.018)	0.487 (0.018)	0.393 (0.025)
log(interest rate)	-0.180 (0.092)	-0.236 (0.135)	-0.334 (0.088)
log(interest rate) · Bank branches per capita[b]	0.109 (0.036)	0.103 (0.062)	0.098 (0.046)
Bank branches per capita[b]	-0.113 (0.058)	-0.159 (0.127)	-0.399 (0.135)
Province dummies	Yes	Yes	No
Year dummies	Yes	Yes	Yes
R^2	0.23	0.23	0.08
Sample size	17,371	17,371	17,371

Note: Robust standard errors in parenthesis. The other regressors are as in Table 1. -[a] The instruments used for the deposit interest rate and the number of bank branches at the city level are the interest rate lagged value and the number of firms and employees per resident at the city level. -[b] Number of bank branches per capita measured at the city level.

We consider next the possibility that some of the regressors are not exogenous

[17]The Montecarlo evidence surveyed in Puhani (2000) shows that, based on standard evaluation criteria, OLS is often superior to limited information maximum likelihood in the case of multicollinearity. In our case a suspect multicollinearity problem is signalled by the fact that the regression of the Mills ratio of the ATM adoption on the other regressors of the second stage OLS yields an R^2 statistic of 95 per cent.

with respect to the currency demand shocks. This issue might arise both for the number of bank branches per city and the deposit interest rate at the province level, which might move in response to currency demand shocks that are common to all households of a given city or province. To this end we study the sensitivity of the results in Table 3 instrumenting the interest rates with the previous-year value and the number of bank branches with the number of firms in the area. The results, reported in column (2) of Table 4, do not show significant differences with respect to the benchmark estimates of Table 3.[18]

Finally, column (3) of Table 4 presents results obtained by a fixed effect estimate, which controls for household-specific unobserved factors. The estimated coefficients of the consumption, interest rate and bank branch diffusion are statistically significant and maintain the expected sign. The point estimates of the direct (negative) effect of bank branch diffusion on currency holdings and the average interest elasticity (about -0.3) are somewhat larger than the values reported in columns (1) and (2). The coefficient of the interaction term is unaffected, confirming the previous estimate of the marginal effect of technological advances on the interest rate elasticity.

5 Discussion and related literature

The evidence on the households money demand discussed in the previous section is consistent with the theory presented in Section 3, which predicts that the level and interest elasticity of money demand decrease with developments in the withdrawal technology.

Other studies, based on cross-section or time series data, have analyzed the effects

[18]The fact that the estimates obtained through OLS and IV are very similar provides evidence in support of a limited relevance of endogeneity problems, an hypothesis confirmed by standard exogeneity tests on the three variables (not reported).

of financial innovation on the level of the money demand. Duca and Whitesell (1995), who follow a cross-sectional approach based on US household survey data, find that credit card ownership is associated with lower money holdings. AGJ highlight, based on Italian survey data, that ATM users hold significantly lower cash balances than non-users. Similarly, Stix (2004) offers evidence concerning Austrian individuals showing that the demand for purse cash is significantly smaller for ATM users. Overall, the evidence consistently indicates that innovations in withdrawal (ATM cards) and payment instruments (credit cards) reduce the level of money balances that agents hold.

Concerning the interest elasticity of the demand for currency, our estimates indicate a value in the -0.3 to -0.1 range for the median household without ATM card. A basically zero elasticity is found for agents with an ATM card. These values are within the range of theoretically plausible elasticities predicted by the models of Section 3.

The estimated interest elasticity for the households without ATM is close to the one detected by AGJ, which is -0.27. A stark difference emerges instead for the households with ATM card, whose interest elasticity was estimated at -0.59 based on the 1989-1995 surveys, but turns out to be essentially nil using the full sample period. In our view the latter finding is to be preferred to the high elasticity found over the smaller sample, not just because of the greater amount of information upon which it is based but also because it is consistent with the theoretical prediction that agents with more developed withdrawal technologies (e.g. ATM card holders) are expected to have a smaller interest elasticity.[19]

The findings concerning the elasticity with respect to the scale variable (non-

[19] This proposition, which holds true for the models discussed in Section 3, is also consistent with the McCallum-Goodfriend model that underlies AGJ formulation. That model can be written in terms of problem (2) by defining the transaction technology: $T(M, c) = Ac^{\gamma}\left(\frac{c}{M}\right)^{\beta}$ where A, β and γ are technological parameters and c denotes consumption. A smaller interest elasticity requires a larger value of the parameter β. A greater value of this parameter corresponds to technological development as it reduces the cost of withdrawals provided $c/M < 1$.

durable consumption or cash-expenditure) that emerge from the various specifications indicate values that are close, sometimes a little below, one-half. These estimates, which are essentially based upon the cross-sectional variation (due to our use of year dummies), differ from the near-unit elasticity that emerges by the analyses of long time-series, e.g. Lucas (1988, 2000) and Meltzer (1963), and is predicted by many theoretical models. The issue is of interest in the debate on the optimality of the Friedman rule (e.g. De Fiore and Teles, 2003). A simple reconciliation between the long-run unit elasticity of consumption and the smaller values detected over the cross-sectional household data is that the cost of a trip to the bank, b, is linked to the consumption (income) variable in the long-run but less so in the cross-section (or the short-run). It is reasonable to presume that the b cost is related to the wages in the banking sector which, over a long time period, is proportional to aggregate wages and consumption. Formally, assuming a proportionality relation between b and c yields a unit income elasticity if one maintains the reasonable assumption that the transaction technology $T(M, c)$ in problem (2) is homogenous of degree zero in M and c (as in the example economies discussed in Section 3).[20] The next section presents estimates of the demand for currency in Italy based on a centennial time-series (yearly data), from 1890 to 1998 (the last year before the euro was introduced). The unit elasticity is strongly supported by the time-series evidence. The estimated interest elasticity is about -0.3, a value that is consistent with the estimates that were found above.

6 Time series evidence from the 20^{th} century

This section investigates the robustness of the results based on disaggregated data using a long time-series for aggregate Italian data. We estimate a specification of the

[20]The proof follows immediately from the first order condition of problem (2): $-R = b\,T'(M, c)$. Note that the homogeneity zero of $T(M, c)$ implies $T'(\lambda M, \lambda c) = \lambda^{-1} T'(M, c)$.

demand for currency that accounts for developments in withdrawal technology, as proxied by the diffusion of bank branches. The evidence is based on annual Italian data from 1936 to 1998.[21] The results are reported in Table 5.

Table 5: Currency Demand in Italy : 1936-1998.

	Dependent variable: log(real currency holdings)			
	Levels			First differences
	(1)	(2)	(3)	(4)
log(real GDP)	0.878 (0.058)	1.032 (0.071)	1.065 (0.073)	0.749 (0.141)
log(interest rate)	-0.217 (0.075)	-0.283 (0.058)	-0.505 (0.241)	-0.377 (0.188)
log(interest rate) · Bank branches per capita			0.833 (0.767)	0.819 (0.500)
Bank branches per capita		-1.202 (0.423)	-3.021 (1.676)	-2.944 (1.769)
Number of observations	63	63	63	62

Newey-West standard errors in parenthesis. - All regressions include a year dummy for the war year 1944.

In column (1) we report the results of the estimation of a baseline money demand equation relating real currency holdings to GDP and the nominal interest rate. The estimates detect a near-unit income elasticity, in line with previous results based on long time-series and theoretical models (see e.g. Lucas, 1988, Lucas, 2000 and Meltzer, 1963). The interest rate elasticity, although significantly below one-half, is comparable to the one found by previous studies. In the regression of column (2) the baseline money demand equation is augmented with a proxy for the development of the withdrawal technology, namely the ratio between the number of bank branches and population. This variable enters the equation significantly and with a negative sign, suggesting that a greater diffusion of bank branches reduces currency holdings,

[21] The sample size is constrained because data on the number of bank branches are available only from 1936. The GDP data is from Fenoaltea (2005) and the national statistical institute (ISTAT), the price level from ISTAT, currency in circulation and interest rates from De Mattia (1967), the number of bank branches from Banca d'Italia (1977).

as predicted by the theory. Compared to the estimates of column (1) both the income and the interest rate elasticity increase, although the latter remains below one-half.

In column (3) we present our preferred specification for the currency demand equation, which includes the interaction between the (log) interest rate and bank-branch diffusion. The point estimates suggest an income elasticity not significantly different from one and a lower bound for the interest rate elasticity equal to one-half.[22] Moreover, the signs of the financial diffusion variable (both for the level and the interaction with the interest rate) are in line with the theoretical predictions of Section 3. The point estimates suggest that over seventy years the interest rate elasticity in Italy declined from around -0.4 to -0.1. Note that the interaction term is not statistically different from zero. This is likely due to a multicollinearity problem, as suggested by the high level of the condition number and by the fact that the regression of the interaction term on the interest rate and of financial diffusion yields an R^2 above 98 per cent. A tentative assessment of the effects of multicollinearity on the estimated parameters is provided in column (4) where we present results based on first-differenced variables.[23] These estimates confirm sign and magnitude of the financial diffusion coefficients detected in the level regressions (the p-values for the interaction and level terms of financial diffusion are both equal to ten per cent).

7 Concluding remarks

This paper contributes to the quest for accurate quantitative estimates of the parameters that govern the money demand function. We argue that accounting for technological development is important to identify theoretically consistent estimates of

[22]The lower bound is reached for a near zero level of financial diffusion.

[23]We are aware that first differencing, even if it is often suggested as a remedy for multicollinearity problems is not a panacea. See, for example, Burt (1987).

the demand schedule. We base our analysis on an original household level database that provides us with empirical observations that closely match their theoretical counterpart over the 1989-2004 period.

The analysis is guided by a theoretical framework on the money demand effect that are caused by advances in the withdrawal technology. The main theoretical implication of the model is that technological development has an effect on average money holding and on the interest elasticity of money demand. The latter prediction is the novel implication of this paper. These insights are tested by augmenting a standard money demand equation with a proxy for the technology level faced by households (the number of per capita bank branches) and its interaction with the interest rate.

Our results, which are robust to different estimation methods, suggest that the money demand is significantly affected by advances in the withdrawal technology. In particular, for the households that do not have an ATM card, the density of bank branches and its interaction with the interest rate enter the money demand equation with the sign predicted by the theory. The estimates suggest that the interest elasticity of money demand lies in between 0.2, for households who face the least developed withdrawal technology, and zero, for the ones facing the highest one. The micro evidence upon which our results are based is drawn from the 1993-2004 period. The analysis of an aggregate Italian time-series for a much longer period covering most of the 20^{th} century confirms the impact of financial development on the level and interest elasticity of the demand for currency.

Appendix

A Currency and financial development: the data

Our analysis relies on a dataset drawn from the *Survey of Household Income and Wealth* (*SHIW*), a periodic survey conducted by the Bank of Italy since 1965 on a rotating sample of Italian households. The survey collects information on several social and economic characteristics of the household members, such as age, gender, education, employment, income, real and financial wealth, consumption and saving behavior. Each survey is conducted on a sample of about 8,000 households. We focus on the surveys conducted from 1989 to 2004 because they include a section dedicated to the household cash management. This contains data on the average amount of cash held by the household and information on the household access to various means of withdrawal and deposit. Annual sample means of some variables related to the household currency management are reported in Table 6.

Table 6: Italian household: currency management

Variable	1989	1991	1993	1995	1998	2000	2002	2004
Fraction with a checking account	0.88	0.86	0.84	0.85	0.85	0.85	0.86	0.86
Fraction using ATMs	0.15	0.29	0.34	0.40	0.49	0.52	0.56	0.58
Average currency holdings	705	581	417	466	407	393	394	400
No bank account	694	609	382	463	395	416	521	550
With bank account	707	577	423	467	409	389	373	376
No ATM card	697	601	448	506	444	448	425	422
With ATM card	754	530	386	423	382	352	345	354
Nondurable consumption	1,644	1,544	1,572	1,632	1,537	1,600	1,633	1,705
Cash consumption	...	...	1,025	1,036	910	923	889	871
Total number of observations	8,274	8,188	8,089	8,135	7,147	8,001	8,011	8,012

Source: Bank of Italy - *Survey of Household Income and Wealth.* Entries computed using sample weights. - Nominal variables are deflated and expressed in euro (base: 2004). - Nondurable and cash consumption are averages per month.

The first line shows that about 15 per cent of the households did not hold a checking account in 2002, a value that is near that recorded in 1989. During the same period, the fraction of households who possess an ATM card increases sharply, from 15 to 55 per cent. Concerning real currency holdings, the average amount held by the household almost halves during the last 15 years. The reduction, which is common across households with different withdrawal technologies, is largest for those who own an ATM card.

Table 7 reports summary statistics on the supply of bank services, such as the diffusion of bank branches, ATM terminals, and on the interest rate paid on deposits.[24] Note that interest rates paid on deposits record a substantial reduction

[24]These data are drawn from the *Supervisory Reports to the Bank of Italy* and the *Italian*

since 1989, although they maintain a relatively large cross-sectional variation even in more recent years (this is important to estimate the interest elasticity).

Table 7: Financial development and interest rates

Variable	1989	1991	1993	1995	1998	2000	2002	2004
Bank branches[a]	...	0.35	0.41	0.44	0.49	0.53	0.54	0.57
		(0.19)	(0.23)	(0.24)	(0.24)	(0.27)	(0.31)	(0.31)
ATM points[b]	0.10	0.22	0.32	0.39	0.51	0.57	0.65	0.65
	(0.07)	(0.13)	(0.18)	(0.19)	(0.22)	(0.22)	(0.23)	(0.22)
Interest rate[c]	6.90	6.69	6.07	5.18	2.14	1.13	0.77	0.33
	(0.48)	(0.52)	(0.45)	(0.32)	(0.22)	(0.21)	(0.15)	(0.12)

Entries computed using sample weights. - Standard deviation in parenthesis. - [a] Per thousand residents; individual observations disaggregated at city level. [b] Per thousand residents; individual observations disaggregated at provincial level. [c] Individual observations disaggregated at provincial level (source: Central credit register).

Central Credit Register (See Miller (2000) for a detailed description of this database). Information is available for each year and province. Italian provinces were 95 until 1995 and became 103 afterwards. The size of a province is broadly comparable to that of a U.S. county).

B Additional evidence

Table 8: Probit (first stage analysis for Table 2)

	Probit for equations (1) and (4)		Probit for equations (2) and (5)		Probit for equations (3) and (6)	
	Bank account	ATM card	Bank account	ATM card	Bank account	ATM card
log(consumption)	0.301 (0.023)	0.729 (0.016)	0.304 (0.024)	0.727 (0.016)		
log(cash expenditure)					-0.092 (0.023)	0.197 (0.013)
log(interest rate)	-0.163 (0.050)	-0.134 (0.031)			-0.271 (0.095)	0.129 (0.055)
interest rate			-0.123 (0.039)	0.066 (0.031)		
Province and Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.55	0.25	0.58	0.27	0.61	0.21
Sample size	62,957	53,819	62,957	53,819	46,756	39,851

Note: The dependent variable in the probit regression for the ownership of a bank account (ATM card) equals one if the household has at least one account (ATM card), zero otherwise. The other regressors are as in Table 1.

Table 9: Probit (first stage analysis for Table 3)

	Probit for equations (1) and (3)		Probit for equations (2) and (4)	
	Bank account	ATM card	Bank account	ATM card
log(cash expenditure)	-0.092 (0.023)	0.197 (0.013)	-0.092 (0.023)	0.196 (0.013)
log(interest rate)	-0.271 (0.095)	0.129 (0.055)	-0.250 (0.110)	0.019 (0.068)
log(interest rate) · Number of bank branches in the city			-0.057 (0.151)	0.245 (0.089)
Number of bank branches in the city	0.373 (0.238)	0.281 (0.142)	0.364 (0.239)	0.306 (0.142)
Province and Year dummies	Yes	Yes	Yes	Yes
R^2	0.61	0.21	0.61	0.21
Sample size	46,756	39,851	46,756	39,851

Note: Standard errors in parenthesis. The dependent variable in the probit regression for the ownership of a bank account (ATM card) equals one if the household has at least one account (ATM card), zero otherwise. The other regressors are as in Table 1.

Table 10: The Demand for Currency and Withdrawal Technology: Robustness.

	Bank account holders with ATM card		
Estimation method	*Ordinary Least Squares* (1)	*Instrumental Variables*[a] (2)	*Household Fixed Effects* (3)
log(cash expenditure)	0.356 (0.012)	0.358 (0.012)	0.261 (0.014)
log(interest rate)	0.076 (0.080)	0.047 (0.124)	0.050 (0.063)
log(interest rate) · Bank branches per capita[b]	0.001 (0.038)	0.000 (0.056)	-0.098 (0.039)
Bank branches per capita[b]	-0.137 (0.046)	-0.002 (0.096)	-0.356 (0.124)
Province dummies	Yes	Yes	No
Year dummies	Yes	Yes	Yes
R^2	0.19	0.19	0.06
Sample size	22,620	22,620	22,620

Note: Robust standard errors in parenthesis. The other regressors are as in Table 1. - -[a]The instruments used for the deposit interest rate and the number of bank branches at the city level are the interest rate lagged value and the number of firms and employees per resident at the city level. -[b] Number of bank branches per capita measured at the city level.

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