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Abstract

Despite various payment innovations, today, cash is still heavily used to pay for low-value purchases. This paper develops a simulation model to test whether standard implications of the theory on cash management and payment choices can explain the use of payment instruments by transaction size. In particular, using diary survey data from Canada, France, Germany and the Netherlands, we test the assumption that cash is still the most efficient payment instrument, and the idea that people hold cash for precautionary reasons when facing uncertainty about their future purchases. The results of the simulations show that these two factors are significant determinants of the high shares of low-value cash payments in Canada, France and Germany. Yet, they are not so crucial in the Netherlands, which exhibits a significant share of low-value card transactions. We discuss how the differences in payment markets across countries may explain the differences in the performance of the model.

JEL classification: C61, E41, E47
Bank classification: Bank notes; Financial services; International topics

Résumé

En dépit des nombreuses innovations en matière de paiement, les espèces sont aujourd'hui encore très utilisées pour régler les achats de faible valeur. Dans cette étude, les auteurs élaborent un modèle de simulation pour déterminer si les modèles standard de la théorie sur la gestion des espèces et les choix des moyens de paiement permettent d'expliquer l'usage d'un instrument de paiement en fonction de la valeur de la transaction. Plus précisément, à l'aide de données issues d'enquêtes menées au Canada, en France, en Allemagne et aux Pays-Bas et comportant la tenue de journaux d'achats, ils testent l'hypothèse selon laquelle les espèces restent le mode de paiement le plus efficient et l'idée que les agents gardent une réserve d'argent pour des motifs de précaution afin de faire face à l'incertitude de leurs achats futurs. Les résultats des simulations montrent que ces deux facteurs expliquent en grande partie les parts élevées des espèces dans les achats de petits montants au Canada, en France et en Allemagne. L'incidence de ces facteurs est toutefois moins marquée aux Pays-Bas, où une part importante des transactions de faible valeur est réglée par carte de paiement. Les auteurs examinent de quelle manière les différences entre les marchés des paiements des pays à l'étude peuvent expliquer les performances du modèle.

Classification JEL : C61, E41, E47
Classification de la Banque : Billets de banque; Services financiers; Questions internationales

1 Introduction

Increasing the efficiency of retail payment systems is high on the agenda of every central bank. This objective is shared by the electronic payment systems promoting the use of debit and credit cards (Borzekowski et al., 2008), and the adoption of innovations such as prepaid cards (Shy and Tarkka, 2002) and contactless cards (Fung et al., 2012). However, despite the huge investments in promoting multiple technological innovations, cash is still the main payment instrument used to pay for low-value transactions in most developed countries. Jonker et al. (2012) find that 69 per cent of transactions up to €20 in the Netherlands were paid with cash in 2011. In Germany, 98 per cent of transactions up to €5 were settled in cash in 2011 (Deutsche Bundesbank, 2013).[1] In France, Bouhdaoui and Bounie (2012) find that the cash market share for transactions under €5 was about 90 per cent in 2011, a proportion that has not changed since 2005. To better understand the role of cash and alternative payment instruments in the payments ecosystem, it is crucial to study what determines their use at different transaction values.

In this paper, we develop a simulation model based on two standard rules on payments and cash withdrawals that are traditionally examined in the economics literature to explain the use of payment instruments for different transaction values. First, following Alvarez and Lippi (2009), we assume that an agent makes cash withdrawals even though his cash holdings are not zero; we define a "Minimum Cash Holdings" rule to mean that an agent withdraws cash when his cash balances drop below a given threshold. This rule has also been introduced in stochastic inventory models *à la* Eppen and Fama (1968, 1969) and Milbourne (1983), where cash balances are allowed to wander freely between a lower (non-zero) and an upper limit, beyond which a cash transfer occurs. Second, we assume that a consumer prefers to use cash whenever he has enough cash; otherwise, the consumer uses a payment card. This feature of cash as "burning" when it is on hand, called here "Cash First," has been examined empirically in Arango et al. (2014), Bouhdaoui and Bounie (2012), and Eschelbach and Schmidt (2013). All three studies confirm that higher cash holdings lead to greater use of cash in payments. This Cash First rule has also been formally considered in Alvarez and Lippi (2013). The authors show that if the level of

[1] Mooslechner et al. (2012) also show that, in Austria, 86.7 per cent of payments up to €20 were transacted in cash in 2011.

cash holdings is greater than the transaction amount, it is optimal to use cash and not a payment card.

We assess the validity of the "Minimum Cash Holdings" and "Cash First" rules in a dynamic shopping environment derived from Milbourne (1983), but adding the fact that consumption occurs randomly in discrete amounts of different sizes. We contrast the predictions of the model about cash payment shares at different transaction values with data from payment diaries in four countries, namely Canada, France, Germany and the Netherlands. Interestingly, we find that the two rules are operating in Canada, France and Germany, but to a lesser extent in the Netherlands. Indeed, in the Netherlands, a significant fraction of low-value transactions are paid with cards even though the public has enough cash on hand (which contradicts the Cash First rule). In addition, the Dutch have the lowest Minimum Cash Holdings compared to Canada, France and Germany, who hold more cash for various precautionary reasons. We document how the Netherlands have succeeded in reducing the use of cash for low-value transactions by implementing a set of strategies with the objective of decreasing the costs of the point-of-sale (POS) payment system as a whole. These strategies implied making changes to the payment infrastructure of retailers (reductions in retailer fees, etc.) and promoting card acceptance and usage among retailers and consumers. The Netherlands experience shows that retail payment systems can switch from a "Cash First" rule toward a "Card First" rule through adequate incentives and information campaigns, reaping the potential reductions in costs of a digital payments economy.

Our contribution to the payments literature is threefold. First, we develop an original framework that predicts the use of payment instrument for each transaction size. In the recent past, economists have tried to incorporate multiple payment instruments in a cash-management model. Most of this work is built on Baumol's view (Baumol, 1952) of a continuous and exogenous flow of consumption that is not equipped to analyze the use of payment instruments for specific transaction values. One interesting exception is Whitesell (1989, 1992). Given the respective costs of payment instruments, Whitesell shows that there are exclusive transaction domains for payment instruments: cash for low-value transactions, and other payment instruments (e.g., payment cards) for higher-value transactions. However, this approach is not fully consistent with the empirical fact that,

although cash is used more frequently for low-value transactions, there are no exclusive transaction domains, and cards and cash are used to pay for both low- and high-value transactions (Arango et al., 2014; Bouhdaoui and Bounie, 2012). Second, we assess the validity of our model across different economies, exploiting four detailed micro data sets based on surveys and payment diaries commissioned by central banks and card payment networks. This effort is significant in the field of payment economics, where public detailed data are scarce and hardly homogeneous for this type of comparison. Third, our results imply that our theoretical understanding of cash demand is still limited and should be rethought in the light of payment innovations that may significantly change the way consumers handle cash.

The remainder of the paper is structured as follows. In section 2, we present the simulation model and the methodology of the simulations. Section 3 describes the data and section 4 the results of the simulations. Section 5 concludes.

2 Simulation Model and Methodology

This section develops a simulation model based on two standard rules examined in the monetary and payments economics literature that explain the use of payment instruments for each transaction value. We first present the rules. We then describe the simulation methodology. Finally, we describe how we measure the model's performance.

2.1 The Minimum Cash Holdings and Cash First Rules

Recent research in monetary and payment economics provides strong predictions on cash management and payment choices.

The Minimum Cash Holdings rule

Refining standard inventory models on cash management *à la* Baumol (1952) and Tobin (1956), Alvarez and Lippi (2009) analyze how technological innovations such as ATM terminals have affected the demand for cash. In particular, introducing free and random withdrawal opportunities, they show that agents may withdraw cash even if they have some cash on hand; the randomness of opportunities, then, gives rise to a precautionary

motive for holding cash. Contradicting Baumol-Tobin's predictions that abstract from a precautionary motive, Alvarez and Lippi (2009) find that the model is consistent with stylized facts concerning households' cash management behavior. Using household data for Italy and the United States, they confirm the existence of a precautionary motive for holding cash. A similar cash management pattern applies for firms. Considering stochastic cash balance issues, Eppen and Fama (1968, 1969) and Milbourne (1983) discuss and provide optimal policy rules when cash balances are allowed to wander freely until they reach either a *non-zero* lower bound or an upper level (when the levels are reached, cash transfers are realized). As a consequence, they explicitly consider the case of positive cash balances to face daily transactions requirements. In line with this research, we assume that when the agent's level of cash holdings falls below some lower level $\underline{m}^{th}$, a cash withdrawal occurs. We call this the "Minimum Cash Holdings" rule.

The Cash First rule

Obviously, this cash management pattern affects the use of payment instruments. More precisely, several empirical studies have confirmed that higher cash holdings lead to higher use of cash in payments. This feature is presented in the economics literature on money and payments as "cash burning," meaning that an agent prefers to use cash when his cash holdings are sufficiently high. For instance, exploiting 2,351 payment diaries and 10,200 transactions realized by two access panels in Canada in 2009, Arango et al. (2014) estimate the probability of choosing cash for POS payments as a function of a set of demographic variables, payment attributes, perceptions and transactions characteristics. The authors find that higher initial cash holdings lead to a higher probability of paying with cash, and that this result holds even after controlling for the possible endogeneity of cash-holding decisions. Likewise, Bouhdaoui and Bounie (2012) exploit two surveys from 2005 and 2011 of two representative samples of 1,386 and 1,047 French individuals to test three payment choice models. The first two models assume that payment choices between cash and cards depend on transaction sizes, while the third model assumes that the choice depends on the level of cash holdings: agents pay cash whenever they have enough cash; otherwise, they use another payment instrument. In particular, Bouhdaoui and Bounie (2012) test how well each model replicates the observed shares of cash payments in the

French economy. They find that the cash holding model better fits the observed shares of cash payments than the two previous models, and conclude that "the payment behavior of the public is more driven by a cash holding rule than by a transaction size rule." Finally, Eschelbach and Schmidt (2013) exploit a unique sample of 2,801 transactions realized by 636 Germans in 2011 to investigate whether individuals withhold a certain amount of cash for precautionary reasons. They find that "the probability of a transaction being settled in cash declines significantly as the amount of cash available at one's disposal decreases." In addition, Alvarez and Lippi (2013) present a dynamic model of cash management and payment choices where "cash burns." They show that the optimal consumer policy is to use cash rather than cards whenever agents have enough cash on hand. This optimal payments policy gives support to our "Cash First" rule. The intuition of this result is simple: when the level of cash balances is positive, people have already faced a fixed cost to obtain cash. As a consequence, it is never optimal to use a payment card, since people incur a direct cost of using credit in transactions (time cost). In line with the latter research, we will assume in the sequel that people follow a "Cash First" rule.

In the next section, we develop a simulation model based on these two simple rules.

2.2 Simulation Model and Strategy

We assume that time is infinite and divided into discrete periods t. Each period is divided into two subperiods. In the first one, the representative agent decides whether to make a cash withdrawal. In accordance with the Cash Minimum Holdings rule, he only does so if the level of his cash holdings is lower than $\underline{m}^{th}$. In this case, the agent draws by chance an amount from a distribution of cash withdrawals observed in the economy. In doing so, we acknowledge that people have different withdrawal costs that give rise to different cash withdrawal amounts; the simulations take into account such heterogeneity, which is specific to each economy. We denote by $\mathcal{W}$ the support of the empirical distribution of cash withdrawals, and by $\pi^{\mathcal{W}}(w)$ the empirical density function of a cash withdrawal w.

Next, in the second subperiod, the agent is confronted with a transaction opportunity of size p. Departing from the standard assumptions in inventory models set up in continuous time and on exogenous consumption flows, we assume that transactions are discrete and uncertain but still exogenous. In other words, the agent is supposed to be well informed

of the different transaction sizes he can face, but cannot correctly anticipate their timing. Thus the agent draws by chance a transaction size from the observed distribution of transactions in the economy, and decides which payment instrument to use according to the Cash First rule. If the agent has enough cash on hand, he uses cash; otherwise, he uses a payment card.[2] We let $\mathcal{D}$ refer to the support of the empirical distribution of transactions, and $\pi^{\mathcal{D}}(p)$ to the empirical density function of the transaction size p.

At $t = 0$, the representative agent is initialized with zero cash balances. We let $\pi_t^{(a)}(m)$ and $\pi_t^{(b)}(m)$ refer to the probability that the agent holds a cash balance m at the period t at the beginning of the first and second subperiods, respectively. The Minimum Cash Holdings rule implies that the law of motion of $\pi_t^{(b)}$ as a function of $\pi_t^{(a)}$ is written as follows:

$$\pi_t^{(b)}(m) = \begin{cases} \pi_t^{(a)}(m) + \sum\limits_{w:\ m-w\leq \underline{m}^{th}} \pi^{\mathcal{W}}(w)\pi_t^{(a)}(m-w); & \text{if } m > \underline{m}^{th} \\ \sum\limits_{w} \pi^{\mathcal{W}}(w)\pi_t^{(a)}(m-w); & \text{if } m \leq \underline{m}^{th}. \end{cases} \tag{1}$$

Starting with the first case on the right-hand side, the first term, $\pi_t^{(a)}(m)$, refers to the case where the agent is holding the same cash balance m before the withdrawal opportunity, and does not make a cash withdrawal according to the Minimum Cash Holdings rule, since we have $m > \underline{m}^{th}$. The second term includes the case where the agent with initial cash holdings $m - w \leq \underline{m}^{th}$ makes a cash withdrawal and ends up with the cash balance m. Next, in the second case, since $m > \underline{m}^{th}$, the right-hand side refers only to the probability of ending up with m after making a cash withdrawal.[3]

Next, making use of the Cash First rule, we obtain the law of motion of $\pi_{t+1}^{(a)}$, referring to the probability distribution of cash holdings at the beginning of the period $t+1$, as a function of $\pi_t^{(b)}$:

$$\pi_{t+1}^{(a)}(m) = \sum_{p} \pi^{\mathcal{D}}(p)\pi_t^{(b)}(m+p) + \sum_{p>m} \pi^{\mathcal{D}}(p)\pi_t^{(b)}(m). \tag{2}$$

[2]To keep things as simple as possible, we assume that a payment card is always accepted in payments; we discuss this assumption in the conclusion.

[3]Conversely to the first case, we do not include the probability of holding m before the first subperiod, because cash withdrawals are mandatory in the second case, according to the Minimum Cash Holdings rule.

The first term on the right-hand side deals with the probability that the agent ends up with m after a cash payment, and the second term captures the probability of starting the second subperiod with cash holdings m and using a payment card. The cash holdings are therefore left unchanged.

In practice, after setting a value for $\underline{m}^{th}$, we perform an iterative recursion scheme based on equations (1) and (2) and starting with a zero cash balance initialization ($\pi_0^{(a)}(0) = 1$), until reaching a fixed point for the distributions of cash balances $\pi^{(a)}$ and $\pi^{(b)}$.[4]

Using the obtained distribution of cash balances $\pi^{(b)}$, we measure the share of cash payments by transaction size:

$$S^{th}(p) = \sum_{m \geq p} \pi^{(b)}(m). \tag{3}$$

We also calculate the average cash balance of agents before facing transactions:

$$M^{th} = \sum_{m} \pi^{(b)}(m) \cdot m. \tag{4}$$

2.3 Measuring the Performance of the Two Rules

In this subsection, we describe how we measure the performance or the deviation between the shares of cash payments by transaction size resulting from the simulations $S^{th}(p)$ and the observed shares of cash payments denoted by $S^{obs}(p)$. We define the indicator $G(\underline{m}^{th})$, which measures more precisely, for a given threshold $\underline{m}^{th}$, the percentage error between the predicted shares of cash payments and the observed shares of cash payments for all the transaction sizes of a given distribution. It is defined as follows:

$$G(\underline{m}^{th}) = \sum_{p \in \mathcal{D}} \hat{\pi}^{\mathcal{D}}(p) \cdot \mid S^{th}(p) - S^{obs}(p) \mid, \tag{5}$$

where $\hat{\pi}$ refers to the observed frequency of transactions of size p in the distribution.[5] The objective is then to find with simulations the value of the minimum cash holdings $\underline{m}^{th}$ that minimizes the indicator G.

[4] The iteration is interrupted when the variation of the distributions becomes sufficiently low: $\|\pi_{t+1}^{(a)} - \pi_t^{(a)}\| < 1e-04$ and $\|\pi_{t+1}^{(b)} - \pi_t^{(b)}\| < 1e-04$.

[5] The indicator $G(\underline{m}^{th})$ is quite natural, since it assigns a higher weight for transactions values that appear more frequently in the distribution.

This simulation strategy constitutes a simple structural way to introduce the Minimum Cash Holdings and Cash First rules in a transactional environment to estimate in a non-parametric way, $\underline{m}^{th}$, and see whether these two rules can account for the cash share distributions we observe in different countries.

3 Data

This section describes the data used in the simulations. We present the methodology of the surveys and cash payment and withdrawal patterns.

3.1 Surveys' Methodology

Based on the pioneering research of Boeschoten (1992), card payment schemes and central banks around the world have conducted surveys and shopping diaries to study individual payment patterns.

The surveys are all structured in two parts: a questionnaire and a shopping diary. First, the questionnaire focuses on the individual's personal finances, socioeconomic characteristics and payment methods. In particular, survey participants were asked about their cash management practices, such as the number of cash withdrawals per period of time and their average amount withdrawn. Second, the shopping diary allows respondents to record details of each purchase performed such as transaction values (transaction size), type of goods and services purchased and payment instruments available at the moment of the payment.[6] The number of days recorded in diaries varies according to the countries: three days for Canada, eight days for France, one day for the Netherlands and seven days for Germany.[7]

The surveys differ slightly in terms of content and emphasis, but provide the same data required for the simulations. They were also administered differently. In Canada, the sample was drawn from access panels (directories of people willing to participate in surveys on a regular basis) using stratified random sampling of 18- to 75-year-old Canadian residents. During the month of November 2009, a subsample of participants responded to

[6] Professional expenses and bill payments were excluded from all the diaries.

[7] A summary of the survey's descriptive statistics is provided in Table A1 in the appendix.

the questionnaire online and the rest were sent a paper version by mail. Online participants could opt out of the diary. The final data set includes nearly 6,800 survey questionnaires, 3,300 diaries, and 16,000 transactions.[8] In the French case, the survey was conducted in 2011 on a representative sample of 1,106, 18-year-old or older French individuals who had not participated in a survey before. The questionnaire was responded to during face-to-face interviews. Out of 1,106 respondents, 1,047 individuals completed the diaries, collecting close to 10,700 transactions. The German survey was conducted in autumn 2011. The sample population consisted of German-speaking individuals aged 18 years and above, residing in private households in Germany. Participants were drawn from a master sample of the Association of German Market Research Institutes (Arbeitskreis Deutscher Marktforschungsinstitute e.V. - ADM) using a three-stage selection procedure which yielded a representative random sample. It was possible to collect 2,098 questionnaire interviews together with a payment diary. The interviews were conducted face-to-face. The week-long payment diaries could be filled-in either electronically (online) or on paper. 2,081 respondents opted for paper, while only 17 respondents chose to keep an online diary. The diaries contain information on around 20,000 transactions.[9] Finally, for the Dutch case, the sample was drawn from consumer panels and is representative of the population over 12 years of age.[10] The survey was conducted during the month of September 2011 among 7,944 consumers who recorded a total of 13,712 transactions. From all respondents, 7,521 were recruited via the Internet and 423 via telephone. Of the latter, 243 answered the questionnaire online via an email, with a link to the questionnaire.[11]

3.2 Some Descriptive Statistics

Since the paper aims to study cash payments, we exclude transactions on the Internet, by phone or by mail where the cash option is not always proposed.[12] We lose 445 transactions (3.9 per cent) for France, 354 (2.3 per cent) for Canada, 463 (2.3 per cent) for Germany and 1,704 for the Netherlands (11.1 per cent).

[8] See Arango and Welte (2012) for a detailed description of the Canadian survey.

[9] For a more detailed description of the data, see Deutsche Bundesbank (2013).

[10] The sample is representative based on demographic aspects such as gender, age, ethnicity and education. Other items factored into the sample were region, country of origin and income bracket.

[11] For a more detailed description of this survey, see Jonker et al. (2012).

[12] In the case of the Netherlands and France, the data also exclude person-to-person payments.

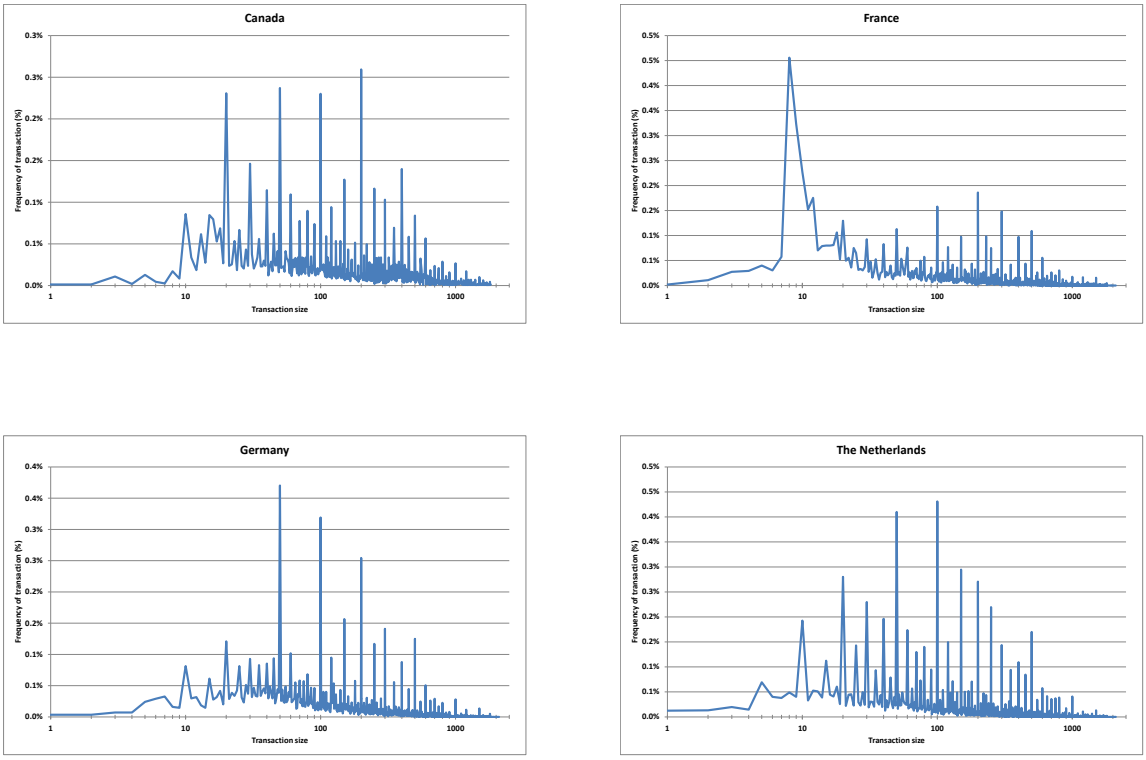

Figure 1: Distribution of the Frequency of Transactions as a Function of Transaction Size (Logarithmic Scale)

In the respective diaries, the average number of daily transactions per person ranges from 1.4 for Germany to 1.7 for Canada and the Netherlands. Likewise, the average spending per day and per person is worth €38.2 for France, €40.5 for Germany, €42.7 for the Netherlands and Can$65.7 (€43.0) for Canada.[13] The distribution of all transaction values reported in diaries is plotted in Figure 1.[14] The bulk of transactions are low-value purchases, especially in France and the Netherlands: 10 per cent of the lowest amounts (10th percentile) are below €1 for France and €2 for the Netherlands (€3 for Germany and Can$2.5 for Canada (€1.6)). Likewise, about half of the transaction values of the distribution (50th percentile) are equal to, or less than, €11.8 for France, €10.2 for the

[13]The Canadian dollar (Can$) is converted to euros for the year of the Canadian survey (2009): Can$1=€0.654; we use the PPP exchange rates from the OECD (PPPPRC: purchasing power parities for private consumption) available at http://www.oecd.org/std/pricesandpurchasingpowerparitiesppp.

[14]In all the figures shown, data are summed in 3-euro[dollar] brackets along transaction sizes.

Netherlands and Can$15 (€9.8) and €16.9 for Canada and Germany, respectively.

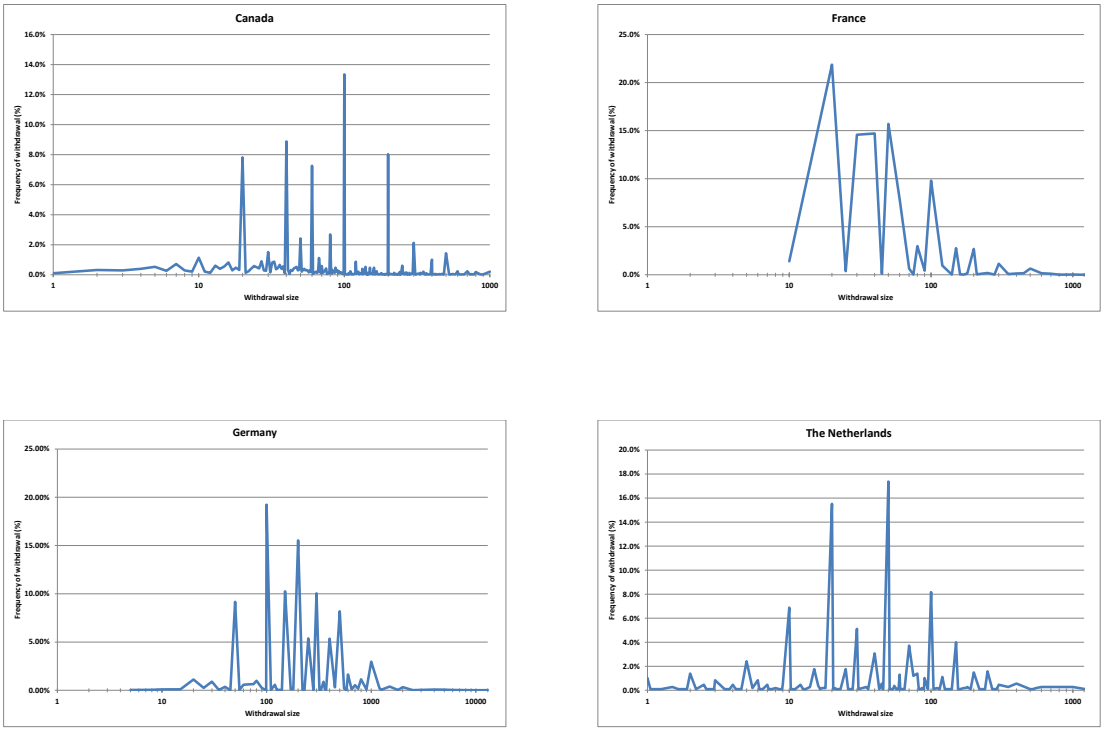

Figure 2: Distribution of the Frequency of Withdrawals as a Function of Withdrawal Amount (Logarithmic Scale)

Similar to transactions, we have information on individuals' cash management practices. For France, we have information on the number of cash withdrawals at ATMs and bank branches as well as information on average cash withdrawals. For Canada, the questionnaire focuses on various sources such as ATMs and bank branches, but also cash obtained from people, etc. For Germany and the Netherlands, there is information on withdrawals at ATMs, counters and cashbacks. The Canadians and Dutch, respectively, make about 0.17 and 0.18 cash withdrawals per day (i.e., 1.2 and 1.3 per week, respectively) and the French and the Germans around 0.11 and 0.12 per day (i.e., 0.8 per week), respectively. Germany has the highest average withdrawal amount with (€182.6), followed by Canada (Can$106.8 (€69.8)), the Netherlands (€65.2) and France (€63.2). Figure 2 shows the frequency of withdrawal as a function of withdrawal amount. We note that 13.3 and 19.2

per cent of the withdrawals occurred for an amount of Can$100 or €100 in Canada and Germany, while one out of five cash withdrawals occurred for values of €20 and €50 for France and the Netherlands, respectively.[15]

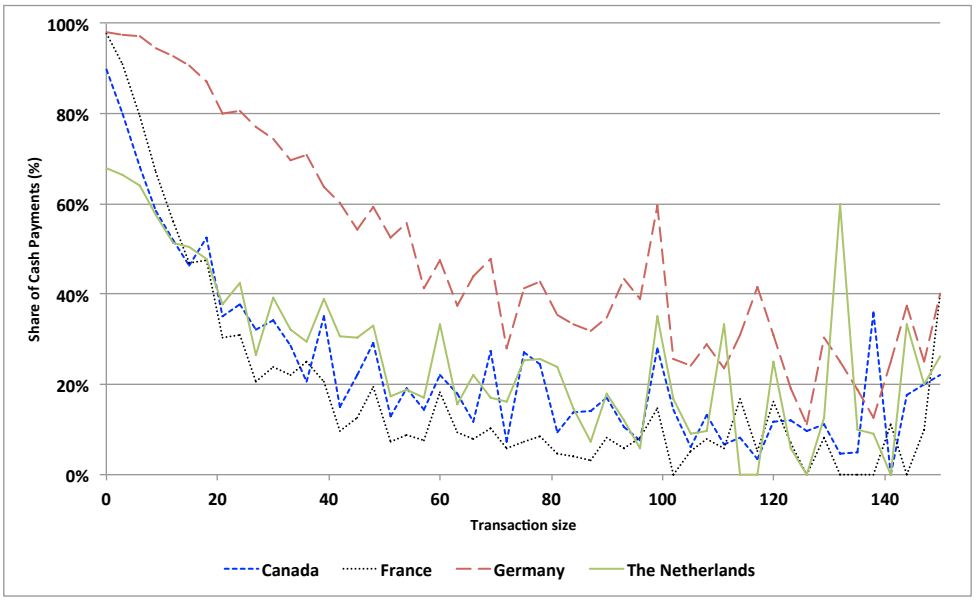

Figure 3: Observed Shares of Cash Payments as a Function of Transaction Size

Finally, we provide an overview of the shares of cash and other payments by transaction size in the respective countries. France, Canada and the Netherlands have similar cash payment shares, with 50.1 per cent for Canada, 52 per cent for the Netherlands[16] and 58 per cent for France;[17] Germany is an exception, with 81.0 per cent. As Figure 3 shows, the cash market share at the lower end of the transaction range in France, Germany and Canada is high: the cash market share of transactions below €3 exceeds 90 per cent. By contrast, the cash market share of transactions below €3 in the Netherlands is around 67 per cent. With the exception of Germany, the cash market share quickly decreases. The

[15]Note that the sharp spikes at certain values in the withdrawal distributions in Figure 2 reflect both consumers' withdrawal preferences and the fact that ATMs usually have preset withdrawal amounts, or allow withdrawals that are only multiples of a particular denomination value.

[16]These figures describe diary survey data and may differ from previously published ones based on other sources.

[17]Sample characteristics of the Dutch survey help explain differences in the share of cash payments with respect to countries with similar card acceptance rates, such as Canada. Unlike other countries in this study, the Dutch survey includes cash-intensive age groups such as children - between 12 and 18 years old - or elderly people - 75 years and older. These groups are responsible for an important share of transactions, of which the majority are cash payments.

market shares of cash and alternative payment instruments are equal when the transaction size is around €16 in France, Can$29 (€19.0) in Canada, €15 in the Netherlands and €54 in Germany. Beyond those transaction sizes, cards and other payment instruments are dominant. We finally observe in Figure 3 that all the distributions are rather irregular at the higher end of the transaction range.[18] This is due to the decreasing number of observations for higher-value transactions (the average number of observations by transaction size varies between 1.4 and 1.8 in the four countries).

4 Simulation Results

This section describes the performance of the Minimum Cash Holdings and the Cash First rules in replicating the payments of the public for each transaction size in the respective economies.

Before discussing in more detail the results of the simulations, we note that Figure 4 exhibits non-exclusive transaction domains for payment instruments; i.e., cash and other payment instruments are used for low- and higher-value transactions, respectively. This result contrasts with standard inventory models à la Whitesell, in which cash and alternative payment instruments are exclusively used for specific transaction domains.

Despite the differences in payment and cash management characteristics, we find that the French, German and Canadian payment patterns are globally well described by the two rules. Indeed, as can be seen in Table 1, the average deviation obtained in these countries with respect to the observed shares of cash payments ranges from 3.5 to 5 per cent. A large proportion of the deviation is related to low-value transactions that have the highest weights in the distribution. For instance, we note that for Canada, France and Germany, between 45 and 56 per cent of the total deviation is related to transactions below Can$20 or €20, whereas only about 11 per cent of the total deviation is related to transactions above Can$100 or €100. Therefore, the gaps between the predicted and the observed shares of cash payments shown in Figure 4 for higher-value transactions have a small impact on the global deviation. Yet, in the Dutch case, the model deviation from the empirical distribution at low-value transactions is significantly larger, reflecting the

[18] Graphics in Figure 3 are truncated to transactions below €150 or Can$150.

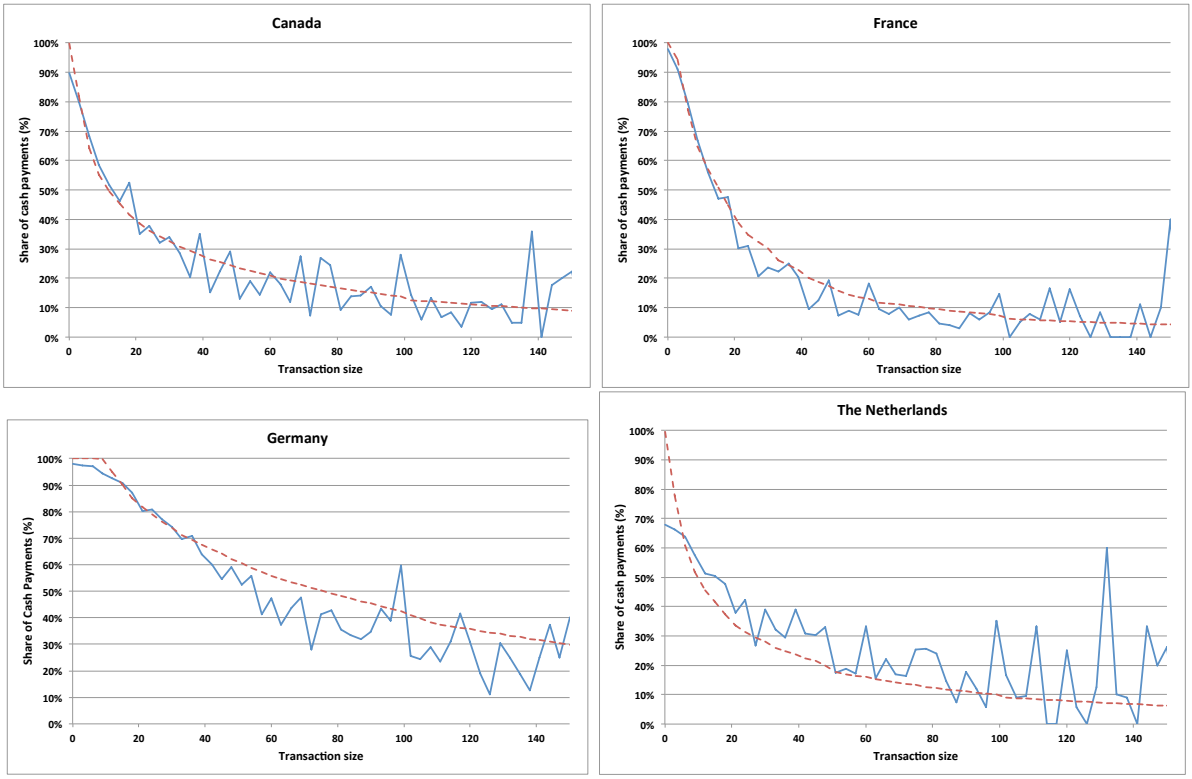

Figure 4: Observed S^{obs} (plain lines) and Theoretical S^{th} (dotted lines) Shares of Cash Payments as a Function of the Transaction Size

fact that, in the Netherlands, cards are used significantly more for micro payments than in the other countries. Indeed, as shown in Figure 4, there is a sharp difference between the share of cash payments at low-value transactions in the Netherlands, around 65 per cent at transactions below €5, and those of the other countries, which are higher than 80 per cent. As a result, the total deviation in the Dutch case amounts to 12.1 per cent, which is three times greater than that of France, for instance. Hence, a model that assumes that consumers would go "Cash First," when they have it on hand, seems to be partially invalidated by the Dutch data.

Turning to the cash holdings, three comments can be drawn from Table 2. First, the observed withdrawal thresholds, $\underline{m}^{obs}$, differ between Canada and Germany. This difference is probably related to the fact that cash payments in Germany are higher, on average, than in Canada (Figure 3), which would make German consumers replenish their cash holdings at a higher threshold. Yet, this difference could also be related to different costs for cash

Country (Can$/€)	[0-20]	]20-50]	]50-100]	>100	$G(\underline{m}^{th})$
Canada	2.8	1.0	0.6	0.5	5.0
France	1.6	1.2	0.4	0.4	3.5
Germany	1.7	0.6	1.0	0.5	3.8
The Netherlands	9.4	1.8	0.4	0.5	12.1

Table 1: The Performance of $G(\underline{m}^{th})$ for Classes of Transaction Size (in %)

withdrawals between the two countries. In Canada, for instance, banks charge a fee of about Can$1.5 (€0.98) for withdrawals made outside consumers' ATM network, whereas this fee is about €4 to €5 in Germany, which encourages cardholders to withdraw cash when they come across their bank's ATMs even if they hold enough cash. This theory may also explain the deviations obtained on the average cash holdings.

Second, the threshold minimizing $G(\underline{m}^{th})$ is positive and higher than zero for the four countries. In particular, we obtain the highest threshold for Germany ($\underline{m}^{th} =$ €10.9). This finding is in line with the data as well as with theoretical and empirical studies that confirm that a large number of agents hold cash for precautionary reasons. In our case, this result is particularly interesting, since the precaution springs from uncertainty on future purchases. In our model, agents face a series of random transaction sizes that are payable either with cash at a zero per-transaction cost or with a payment card which in some countries can imply higher costs.[19] Since agents do not want to run the risk of not having enough cash and face the cost of paying with cards, they hold a minimum amount of cash on hand.

Third, we observe for Canada and Germany, for which we have data, a gap between the estimated minimum cash holding thresholds, $\underline{m}^{th}$, and the observed average minimum cash holdings, denoted by $\underline{m}^{obs}$. In particular, the minimum cash holding thresholds predicted by the simulations are lower than the ones observed in the data (Table 2). A possible explanation is that the average is not a good statistical result for $\underline{m}^{obs}$. As suggested in Alvarez and Lippi (2009), some people face over time the possibility of withdrawing cash at random at no cost (for example, from their bank's ATM network), and therefore they could withdraw it even if they already carry it. Others may withdraw cash only in extreme events, where they find themselves out of cash, since it is the only payment instrument

[19] In the Netherlands, consumers do not pay additional fees for the use of debit cards.

universally accepted, but otherwise are comfortable with using a card for payment. This could also be the case among those cardholders with strong card rewards. In fact, about one-third of those participating in the Canadian survey declare that they do not have a Minimum Cash Holdings rule when withdrawing cash. Therefore, it is possible that the median is far below the mean at least in the Canadian case. A final explanation might be that, by relying on only one parameter m^{th} and two cash management and payment rules, the model finds it difficult to match other moments of the data. This is certainly an avenue for future development of this methodology incorporating other structural aspects of payment behavior.

Country	$\underline{m}^{th}$	$\underline{m}^{obs}$	M^{th}	M^{obs}
Canada (Can$)	2.8	21.9	50.2	84.2
France (€)	4.0	-	36.5	62.4
Germany (€)	10.9	34.0	139.5	103.1
The Netherlands (€)	2.6	-	50.1	44.8

Table 2: Minimum and Average Cash Holdings Thresholds[20]

To summarize, the results reveal the effect of heterogeneous payments systems in the sample. Although the Cash First and the Minimum Cash Holdings rules seem to replicate quite well the payments of consumers in Canada, France and Germany, they exhibit some limitations in the case of the Netherlands. A large proportion of very low-value transactions carried out by Dutch consumers are paid with cards, even though the consumers may hold enough cash on hand (since the Minimum Cash Holdings amount to €2.6; see Table 2). The Minimum Cash Holdings and the Cash First rules are therefore not fully supported in this case. The explanation corresponds to a number of strategies implemented in the Netherlands in order to reduce the costs of the payment system as a whole.[21] In 2005, banks and retailers in the Netherlands decided to join forces in encouraging consumers and merchants to use debit cards. As a result, banks agreed to offer a discount on merchants' fees and thus made debit cards more attractive to a larger number of Dutch retailers and

[20]It is worth noting that M^{obs} may not coincide with statistics in the survey reports of each country, due to differences in the subsamples used in the simulations.

[21]The objective was to reduce the social costs of the POS payment system by increasing debit card usage while reducing cash usage, given that the variable cost of a debit card transaction is often lower than that of transactions paid with cash.

businesses (Jonker, 2013). In 2010, acquiring fees in the Netherlands averaged 4 euro cents (NMa, 2010), one of the lowest compared to those applied in Europe (Börestam and Schmiedel, 2011).[22] Furthermore, Dutch banks offered special incentives for the acquisition of debit card terminals, offering low fixed monthly charges for small businesses processing a small amount of their sales using debit cards, as well as including a monetary incentive for the new acquirers of POS terminals (Jonker and Lammertsma, 2010).[23] Between 2005 and 2011, the POS terminal network increased around 36 per cent, corresponding to an average annual growth rate of 5.18 per cent.[24] Moreover, the increase of debit card usage was also achieved by promoting its acceptance and usage among retailers and consumers through a publicity campaign with TV commercials.[25] Finally, conversely to the other countries studied, consumers do not pay any transaction fees for cash withdrawals at an ATM. As a consequence, there is no need to hold a significant amount of cash on hand to avoid cash withdrawal surcharges.

Overall, these strategies have contributed to an increase in debit card usage and a reduction in the use of cash, invalidating in part the Cash First and the Minimum Cash Holdings rules for a fraction of the public in the Netherlands. However, as shown by Kosse and Jansen (2013), there are indications that groups such as first-generation migrants coming from cash-oriented countries (such as Germany, Turkey or Morrocco) are still more likely to use cash at the POS in the Netherlands.

5 Conclusion

This paper aims to test the validity of two standard rules on cash payments and withdrawals traditionally examined in the economics literature. The first rule, called "Minimum Cash Holdings," specifies the existence of a threshold of cash balances on hand below which

[22] As for Germany and Canada, there are no official statistics, but the system operator fees are estimated to be around 7 euro cents and 7 dollar cents (4.5 euro cents) per transaction, respectively.

[23] Other changes in the payment infrastructure included increased fees for retailers' cash withdrawals and cash depositions.

[24] The decrease in debit card costs had an effect in the reduction of the number of businesses applying a surcharge to small card payments, dropping from 22 per cent in 2006 to 2 per cent in 2011 (Bolt et al., 2010; HBD, 2012).

[25] Two different publicity campaigns were carried out: a first one with the slogan "Small amount, pin allowed" and a following one with the slogan "Pin? Yes please!"

the agent makes a cash withdrawal. The second one, "Cash First," means that the agent pays cash whenever he holds enough cash, or else uses card payment. In other words, it is always more convenient to pay with cash when it is on hand. We simulate the two rules using individual data on cash withdrawals and payments from four countries, namely Canada, France, Germany and the Netherlands.

The results of the simulations show that the "Cash First" rule accounts for a very large portion of cash payment shares by transaction value for Canada, France and Germany, but to a lesser extent for the Netherlands. More precisely, the average deviation obtained for France, Germany and Canada with respect to the observed shares of cash payments ranges from 3.5 to 5 per cent and amounts to 12 per cent for the Netherlands. These results indicate that cash is still perceived as less costly than cards by consumers in France, Germany and Canada. Yet, the case of the Netherlands suggests that a combination of easy access to cash and high acceptance of cards by merchants could induce consumers to use cards more intensively. Since the mid-2000s, the Netherlands has engaged in pricing strategies targeted at merchants to encourage the adoption of the payment card as well as to deter retailers from imposing a surcharge on low-value debit card payments. Other strategies have included marketing campaigns aimed at retailers and consumers in order to promote debit card usage. Retailers in turn have prompted consumers to use the card. As an illustration, Dutch survey respondents were asked to indicate in diaries whether they were able to use a payment card at the checkout; 98 per cent of those willing to pay with cards confirmed that they were able to do so. Finally, in contrast to Canada and Germany, cash withdrawals are usually free in the Netherlands, so people do not carry high cash balances. As a consequence, the public's payment pattern is gradually changing in the Netherlands from a Cash First toward a Card First rule and, today, a large proportion of low-value transactions are paid with cards.

These findings can be extrapolated to other countries. Amongst developed countries, as in the case of Canada, France, Germany and the Netherlands, cash withdrawal charges and card acceptance rates vary significantly. Compared with the Netherlands, the rate of payment card acceptance in Canada as measured in diaries amounts to 76.2 per cent and is much lower at low-value transactions. Similarly, in the case of Germany, consumers reported having a choice between cash and cards in only 60 per cent of their transactions.

We conjecture that the limited acceptance of alternatives to cash encourages the public to hold more cash for precautionary reasons and to use more cash in payments, especially for low-value transactions. Statistics on payments from other countries characterized by the high use of cash for low-value transactions, such as Australia (Bagnall and Flood, 2011) and Austria (Mooslechner et al. 2012), tend to confirm this conjecture. This is perhaps why our simulated model of cash management tends to underestimate the level of "Minimum Cash Holdings" consumers keep as a rule before making a withdrawal, given that the model does not account for uncertainty due to different card acceptance levels across economies.

Finally, the cross-country analysis of payments gives rise to a number of interesting questions for future research. For example, it is still puzzling why German consumers are substantially more cash oriented than those in other developed economies and why consumers in the Netherlands, even though apparently less restricted in their choices in terms of card acceptance, still tend to use cash as intensively as in Canada, and more so at medium- to higher-value transactions. The answer to these questions may help us differentiate between the wide acceptance of payment cards and other cash attributes that make consumers choose "Cash First" in their day-to-day transactions.[26]

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[26]See Bagnall et al. (2013) for recent work addressing some of these questions.

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A Appendix: Summary of the Surveys

	Canada	France	Germany	The Netherlands
Time of the survey	Nov. 2009	Sept. 2011	Oct. 2011	Sept. 2011
Sample frame (years)	18-75	≥ 18	≥ 18	12-95
Sample size (diaries)	3,283	1,047	2,098	7,944
Number of recorded days in diaries	3	8	7	1
Number of transactions in diaries	15,832	10,759	19,601	13,712
Share of cash payments	50.1	58.0	81.0	52.0
Percentiles of transaction amounts				
- 10th	2.5	1	3	2
- 50th	16.9	11.8	15	10.2
- 90th	80	52	63.7	67.5
Average number of daily transactions per person	1.7	1.5	1.4	1.7
Average of daily spending per person	Can$65.7 (€43.0)	€38.2	€40.5	€42.7
Average amount of a withdrawal	Can$106.8(€69.8)	€63.2	€182.6	€65.2
Average of daily withdrawals per person	0.17	0.12	0.11	0.18
Average cash holdings	Can$84.2 (€53.9)	€62.4	€103.1	€44.8

Table A1: Summary of Descriptive Statistics