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Cash management and payment choices: a simulation model with international comparisons

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Cash Management and Payment Choices: A Simulation Model with International Comparisons



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Cash Management and Payment Choices: A Simulation Model with International Comparisons*

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Abstract

Despite various payment innovations, today, cash is still heavily used to pay for low-value purchases. This paper proposes a simulation model based on two optimal cash management and payment policies in the payments economics literature to explain cash usage. First, cash is preferred to other payment instruments whenever consumers have enough balances at hand. Second, it is optimal for consumers to hold a stock of cash for precautionary reasons. Exploiting survey payment diaries from Canada, France, Germany and the Netherlands, the results of the simulations show that both optimal policies are well suited to understand the high shares of low-value cash payments in Canada, France and Germany. Yet, they do not perform as well in the case of the Netherlands, overestimating the share of low-value cash payments. We discuss how the differences in payment markets across countries may explain the limitations of the two optimal policies.

Key Words: Cash management, Payment Choices, International Comparison.

JEL Classification: C61, E41, E47.

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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 large investments in fostering 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.

The payments economics literature provides two optimal cash management and payment choice policies to explain the use of cash in transactions. First, households make cash withdrawals even though their cash holdings are not zero; in other words, they follow a "Minimum Cash Holdings" policy. This optimal policy has been derived in cash management models à la Eppen and Fama (1968, 1969) and Milbourne (1983), among others, where, facing uncertainty about income flows and expenses, it is optimal to allow cash balances to wander freely between a lower (non-zero) and an upper limit, beyond which a cash transfer occurs to keep balances within bounds. More recently, a similar optimal policy is found by Alvarez and Lippi (2009). The authors find that it is always optimal for consumers to withdraw cash at zero cost even if they have some cash on hand.

Second, consumers prefer to use cash whenever they have enough cash on hand; otherwise, consumers use a payment card. This feature of cash as "burning" when it is on hand, called here "Cash First," has been formally derived as an optimal policy by Alvarez and Lippi (2015). It has also been examined empirically in Arango et al. (2014), Bouhdaoui and Bounie (2012), and Eschelbach and Schmidt (2013). All three studies confirm that consumers are more likely to

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

choose cash than other payment instruments the higher their cash holdings.

The objective of this paper is precisely to explore whether the "Minimum Cash Holdings" and the "Cash First" optimal policies are relevant to explain the use of cash and cards in transactions. More precisely, we develop a dynamic shopping environment where consumers face random cash withdrawal opportunities of different withdrawal costs and shop around for purchasing opportunities of different random and discrete transaction values. The model therefore enables us to study the shares of cash and card payments by *transaction values*. In line with previous studies, we assume that it is optimal for consumers to go "Cash First" and to follow a "Minimum Cash Holding" policy. In other words, we hypothesize that cash is faster than cards at the point-of-sale when at hand and that paying with cards may imply a per-transaction cost (e.g. interests on credit or time cost) or be prohibitively costly due to lack of acceptance. Also, it is optimum for consumers to follow a "Minimum Cash Holding" policy as an insurance against the likelihood of not having enough balances in a purchase and, hence, facing the extra cost of paying with cards.

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. Our results shed light on the potential that policy measures have in achieving a shift in payment behavior. Although cash has been traditionally used for small payments, our paper shows that this does not necessarily need to be the case. Interestingly, we find that the two optimal policies 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 policy). In addition, the Dutch have the lowest Minimum Cash Holdings compared to Canada, France and Germany, which hold more cash for various reasons (precautionary, etc.). 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 retail 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. These efforts may account for cards becoming actually less costly than cash in terms of speed and increasing satisfaction among users not willing to deal with coins and change. The Netherlands experience shows that retail payment systems can

switch from a "Cash First" policy toward a "Card First" policy through adequate incentives and information campaigns, reaping the potential reductions in costs of a digital payments economy.

Our contributions to the payments literature are threefold. First, we develop an original framework that predicts the use of payment instruments by transaction size. Even though economists have tried to incorporate multiple payment instruments in a cash-management model (Alvarez and Lippi, 2015), 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.² Departing from Alvarez and Lippi (2015), our model allows for the possibility that cards can be used to pay even when consumers have some cash at hand (just not enough) due to the discrete arrival of payments of different size. In their model, the optimal cash policy implies using cards only if the consumer has no cash at hand. Second, we assess the validity of the two optimal policies 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 show that the Netherlands have been able to make paying with debit at low-value transactions the cheapest and most convenient. Just increasing acceptance is a big reduction in the implicit cost to consumers of carrying and using a debit card.³

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.

²One 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).

³Between 2005 and 2011, the number of active point-of-sale terminals in the Netherlands increased in a 35 per cent, which in combination with a set of promotion strategies translated into a 71 per cent increase of debit cards transactions (http://www.pin.nl/wp-uploads/2012/08/p_uk_key_figures_pinnen.pdf).

2 Simulation Model and Methodology

The monetary and payments economics literature characterizes two optimal cash management and payment policies to explain cash usage. In this section, we first present these optimal policies and then present a model and a simulation strategy to explore whether these policies are consistent with observed cash payments in various countries.

2.1 Optimum Cash Holdings and Payment Choices

Recent research in monetary and payments economics provides strong predictions about household cash holdings (and withdrawals) and payments. First, it is optimal for people to hold a positive stock of cash to face transactions and, second, they prefer to use cash instead of cards whenever they have enough cash on hand. We review both optimal cash holdings and payment policies, which we use as a benchmark in our simulation model.

Optimal Minimum Cash Holdings

[Baumol \(1952\)](#) and [Tobin \(1956\)](#) - hereafter BT - provide the first inventory models to explain cash management. In their setting, an agent finances a continuous and deterministic consumption flow c by making n cash withdrawals. Cash balances decrease until they hit zero and consumers only withdraw when they have depleted their stock of cash. Hence, in the BT model, the size of each withdrawal is $W = c/n$, half of average cash balances $W/M = 2$, and there is no precautionary motive for holding cash.

[Alvarez and Lippi \(2009\)](#) refine the BT model by introducing free and random withdrawal opportunities, p ($p = 0$ in BT). They find that it is always optimal for agents to withdraw cash at zero cost even if they have some cash on hand, giving rise to a precautionary motive for holding cash. The ratio between cash holdings at the time of a withdrawal (\underline{M}) and average currency holdings (M) captures the strength of this precautionary motive. The model predicts that \underline{M}/M is 0 when $p = 0$ (BT model) and goes to 1 as p increases. Moreover, it is shown that the number of withdrawals, n , increases in p , and the average withdrawal size W decreases, and, therefore, W/M ranges between zero and two (whereas the ratio is 2 in BT).⁴ Using household data for Italy

⁴It is worth noting that previous theoretical research have shown similar cash management patterns for firms facing uncertain cash flows ([Miller and Orr, 1972](#); [Eppen and Fama \(1968, 1969\)](#); [Milbourne \(1983\)](#)). In this settings,

and the United States, [Alvarez and Lippi \(2009\)](#) document that \underline{M}/M is about 0.4, confirming therefore the existence of a precautionary motive for holding cash.

This cash management pattern has recently been confirmed in various other countries. For instance, exploiting data from payment surveys between 2009 and 2012 in Australia, Austria, Canada, France, Germany, the Netherlands and the United States, [Bagnall et al. \(2014\)](#) find that the median of \underline{M}/M is always positive and about 0.20 for CA, 0.25 for Austria, 0.32 for Germany and 0.73 for US. These findings therefore strongly support the existence of a precautionary motive for holding cash.

Following [Alvarez and Lippi \(2009\)](#) and empirical results, we take this optimal cash holdings policy as a benchmark. For the sake of simplicity, we will assume in the simulation model that when the household's cash holdings fall below some lower level \underline{m}^{th} , a cash withdrawal occurs. We call this the "Minimum Cash Holdings" optimal policy.

Cash-first optimal choice

The level of cash holdings obviously determines whether the agent uses cash or credit. In a very recent contribution, [Alvarez and Lippi \(2015\)](#) propose a model that characterizes the relationship between optimal dynamic cash management and the choice of payment instruments. In line with [Alvarez and Lippi \(2009\)](#), consumers face a continuous flow of consumption denoted here by e and cash holdings are assumed to have an opportunity cost of R per-dollar per-unit of time. Households can pay with cash or credit at any time and if they pay with credit they incur a flow cost of γe per-unit of time. The authors show that the optimal payment policy is to use cash rather than cards whenever agents have cash on hand; in this case, cards are only used when the stock of cash is exhausted. The intuition of this result is simple: when the stock of cash is positive, people have already faced the fixed cost of obtaining cash, either the time cost involved in a cash withdrawal or the monetary cost in case of facing withdrawal fees, with a zero marginal cost of paying with it; the agent pays only the opportunity cost, R . In this case, according to the authors, it is never optimal to use a payment card, since people incur a direct cost of using credit in transactions (plus the debt-funding interest cost).

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 in and out of a bank account are realized).

Several empirical studies have confirmed that agents prefer to use cash when their cash holdings are sufficiently high. For instance, [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." Likewise, [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." Finally, [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 by exploiting 2,351 payment diaries and 10,200 transactions realized by two access panels surveyed in Canada in 2009. 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.

Again, following [Alvarez and Lippi \(2015\)](#) and empirical studies, we take this optimal payment policy as a benchmark. We will assume in the sequel that people follow a "Cash First" policy, meaning that consumers prefer to use cash whenever they have enough cash on hand; otherwise, they use a payment card.

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 Minimum Cash Holdings policy, 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 W the support of the empirical distribution of cash withdrawals, and by $\pi^W(w)$ 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 optimal choice. If the agent has enough cash on hand, he uses cash; otherwise, he uses a payment card.⁵ We let D refer to the support of the empirical distribution of transactions, and $\pi^D(p)$ 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 period t at the beginning of the first, a, and second, b, subperiods, respectively. The Minimum Cash Holdings policy implies that the law of motion of $\pi_t^{(b)}$ as a function of $\pi_t^{(a)}$ is written as follows:

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

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 policy, 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 $m \leq \underline{m}^{th}$, the right-hand side refers only to the probability of ending up with m after

⁵To keep things as simple as possible, we assume that a payment card is always accepted in payments; we discuss this assumption in the conclusion.

making a cash withdrawal.⁶

Next, making use of the Cash First policy, 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 $\pi_t^{(b)}$:

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

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), 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 $\pi^{(b)}$.⁷

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

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

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

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

2.3 Comparing the Predicted and Observed Shares of Cash Payments

In this subsection, we describe how we measure 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 $G(\underline{m})$, which measures more precisely, for a given threshold \underline{m} , the percentage error between the predicted shares of cash payments and

⁶Conversely 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 policy.

⁷The iteration is interrupted when the variation of the distributions becomes sufficiently low: $\|\pi_{t+1}^{(a)} - \pi_t^{(a)}\| < 1e - 04$ and $\|\pi_{t+1}^{(b)} - \pi_t^{(b)}\| < 1e - 04$.

the observed shares of cash payments for all the transaction sizes of a given distribution. It is defined as follows:

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

where $\hat{\pi}$ refers to the observed frequency of transactions of size p in the distribution.⁸ The objective is then to find with simulations the value of the minimum cash holdings denoted \underline{m}^{th} that minimizes the indicator G .

This simulation strategy constitutes a simple structural way to introduce the Minimum Cash Holdings and Cash First policies in a transactional environment to calibrate \underline{m} for the different economies studied, and see whether these two policies can account for the cash share distributions we observe in data.

3 Data

This section describes the survey data from Canada, France, Germany and the Netherlands 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. 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. 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

⁸The indicator $G(\underline{m})$ is quite natural, since it assigns a higher weight for transactions values that appear more frequently in the distribution.

instruments available at the moment of the payment.⁹ 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.¹⁰

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 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 16,000 transactions.¹¹ In the French case, the survey was conducted in 2011 on a representative sample of 1,106 French individuals, aged 18 years and older, who had not participated in a survey before. The questionnaire was conducted 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. 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.¹² The interviews were conducted face-to-face.¹³ The diaries contain information on around 20,000 transactions.¹⁴ Finally, for the Dutch case, the sample was drawn from consumer panels and is representative of the population over 12 years of age.¹⁵ The survey was conducted during the month of September 2011 among 7,944 consumers who recorded a total of 13,712 transactions.¹⁶

⁹Professional expenses and bill payments were excluded from all the diaries.

¹⁰A summary of the surveys' descriptive statistics is provided in Table A1 in the appendix.

¹¹Out of the close to 6,800 survey participants, 3,300 fill out a 3-day diary. For a detailed description of the Canadian survey, see [Arango and Welte \(2012\)](#).

¹²Participants were drawn from a master sample of the Association of German Market Research Institutes (Arbeitskreis Deutscher Marktforschungsinstitute e.V. - ADM)

¹³The week-long payment diary 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.

¹⁴For a more detailed description of the data, see [Deutsche Bundesbank \(2013\)](#).

¹⁵The 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 brackets.

¹⁶From 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. For a more detailed description of this survey, see [Jonker et al. \(2012\)](#).

3.2 Some Descriptive Statistics

Since the paper aims to study cash payments at the point-of-sale,¹⁷ we exclude transactions on the Internet, by phone or by mail where the cash option is not always proposed. 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).

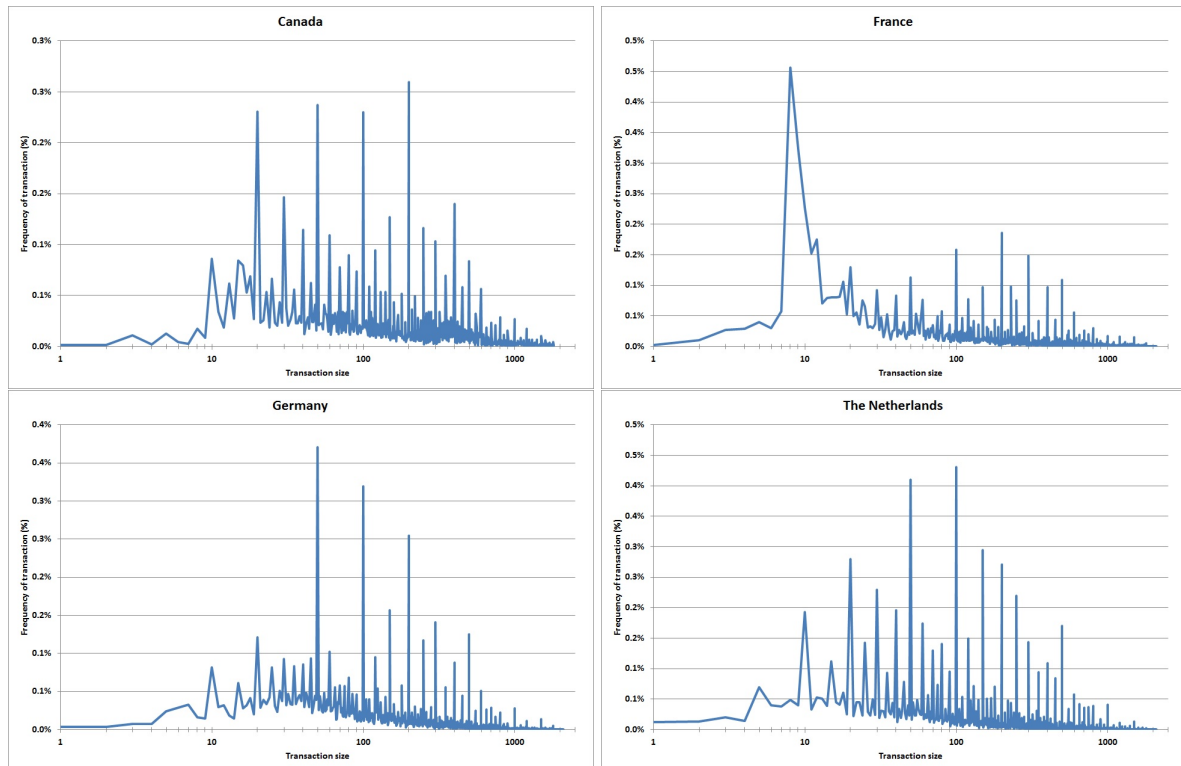


Figure 1: Distribution of the Frequency of Transactions as a Function of Transaction Size (Logarithmic Scale)

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.¹⁸ The distribution of all transaction values reported in the

¹⁷Diary data from Canada and Germany also consider person-to-person transactions.

¹⁸To compare Canada to France, Germany and the Netherlands, the Canadian dollar (Can\$) is converted to euros for the year of the Canadian survey (2009): Can\$1=€0.654; to do that, we use the PPP exchange rates from the OECD which are the rates of currency conversion that equalize the purchasing power of different currencies by eliminating the differences in price levels between countries; available at <http://www.oecd.org/std/prices-ppp/>.

diaries is plotted in Figure 1.¹⁹ The bulk of transactions are low-value purchases. 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 Netherlands and Can\$15 (€9.8) and €16.9 for Canada and Germany, respectively.

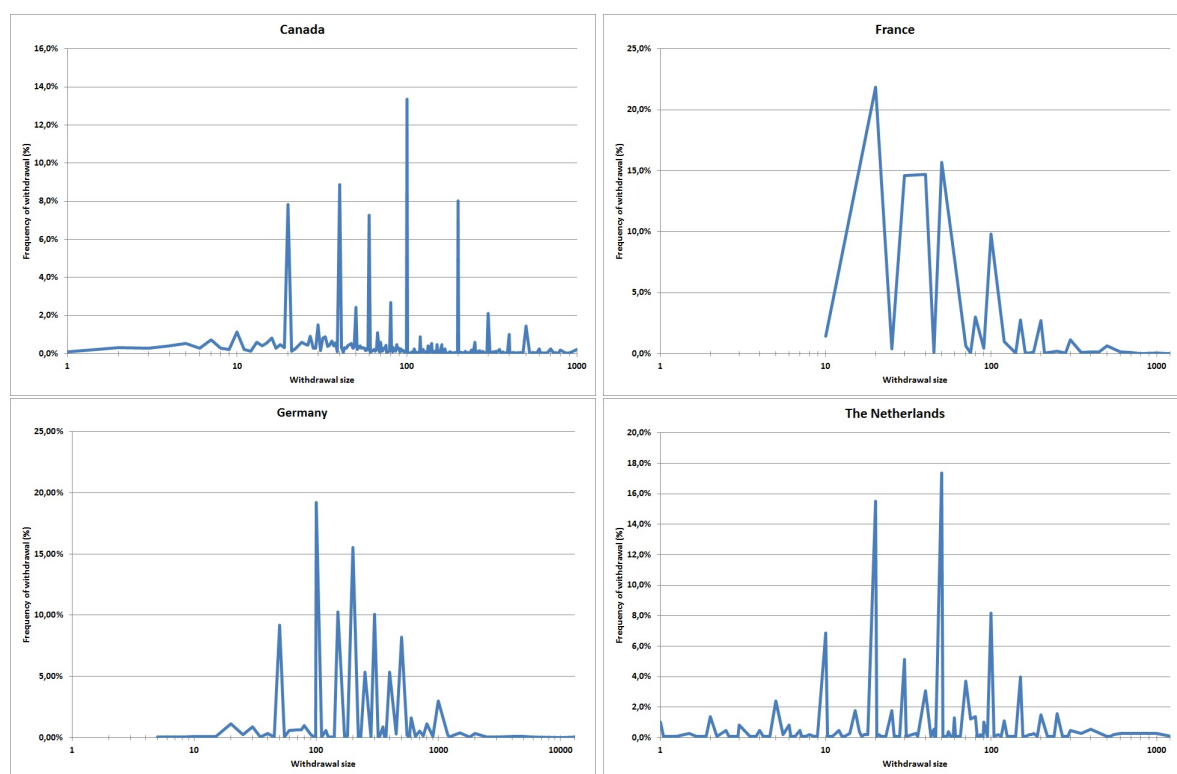


Figure 2: Distribution of the Frequency of Withdrawals as a Function of Withdrawal Amount (Logarithmic Scale)

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 1.2 and 1.3 cash withdrawals per-week and the French and the Germans around 0.8 per-week. Germany has the highest average withdrawal amount with (€182.6), followed by Canada (Can\$106.8 (€69.8)), the Netherlands

¹⁹In all the figures shown, data are summed in 3-euro[dollar] brackets along transaction sizes.

(€65.2) and France (€63.2). Figure 2 shows the frequency of withdrawals 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 and €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.²⁰ These differences in the distributions of cash withdrawals reflect differences in the ATM network and fee structure to access cash in the economies studied. These features directly affect the levels of cash holdings and therefore the use of cash in transactions. For instance, as depicted in Figure 2, the distribution of cash withdrawals in Germany is more skewed to the right compared to that of the other countries, which implies higher households' cash holdings and higher cash shares in Germany.

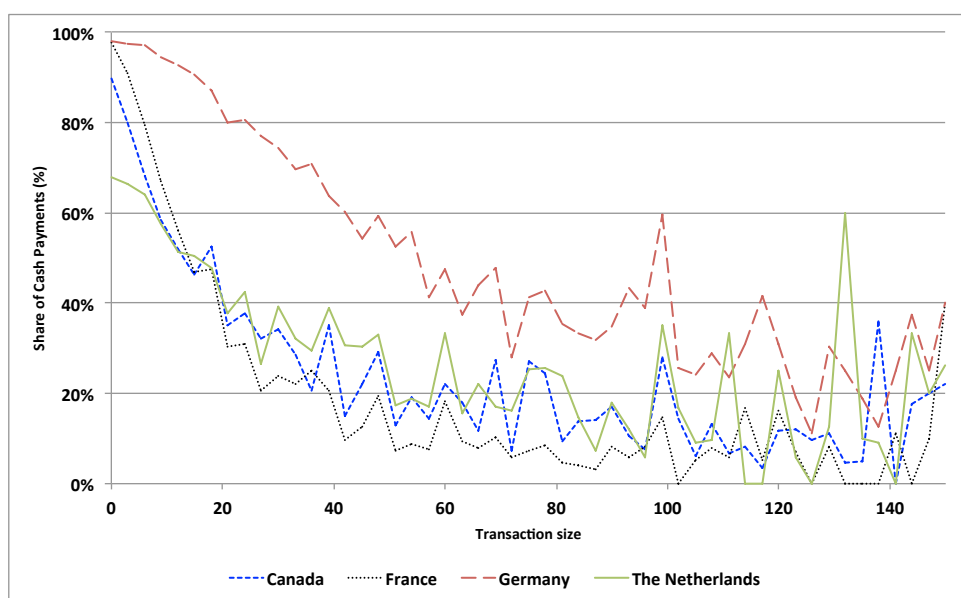


Figure 3: Observed Shares of Cash Payments as a Function of Transaction Size

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 per cent for Canada, 52 per cent for the Netherlands²¹ and 58 per cent for France;²² Germany is an exception, with 81 per cent. As Figure 3 shows, the cash market

²⁰Note 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.

²¹These figures describe diary survey data and may differ from previously published ones based on other sources.

²²Sample characteristics of the Dutch survey help explain differences in the share of cash payments with respect

share at the lower end of the transaction range in France, Germany and Canada is high with the cash market share of transactions below €3 exceeding 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 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.²³ 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 relevance of the cash management and payment policies in replicating the payments of the public for each transaction size in the respective economies.

Figure 4 shows that, despite the differences in payment and cash management characteristics, the French, German and Canadian payment patterns are globally well described by the "Cash First" and the "Minimum Cash Holdings" policies. As can be seen in Table 1, the average deviation of the simulations in the first three countries with respect to the observed shares of cash payments ranges from 3.5 to 5 per cent, indicating that the cash-first optimal choice fits well consumers' payment behaviour towards low value transactions in these countries. Yet, in the Dutch case, the model deviation from the empirical distribution at low-value transactions is significantly larger, reflecting the fact that in the Netherlands, cards are used significantly more often 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,

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.

²³Graphics in Figure 3 are truncated to transactions below €150 or Can\$150.

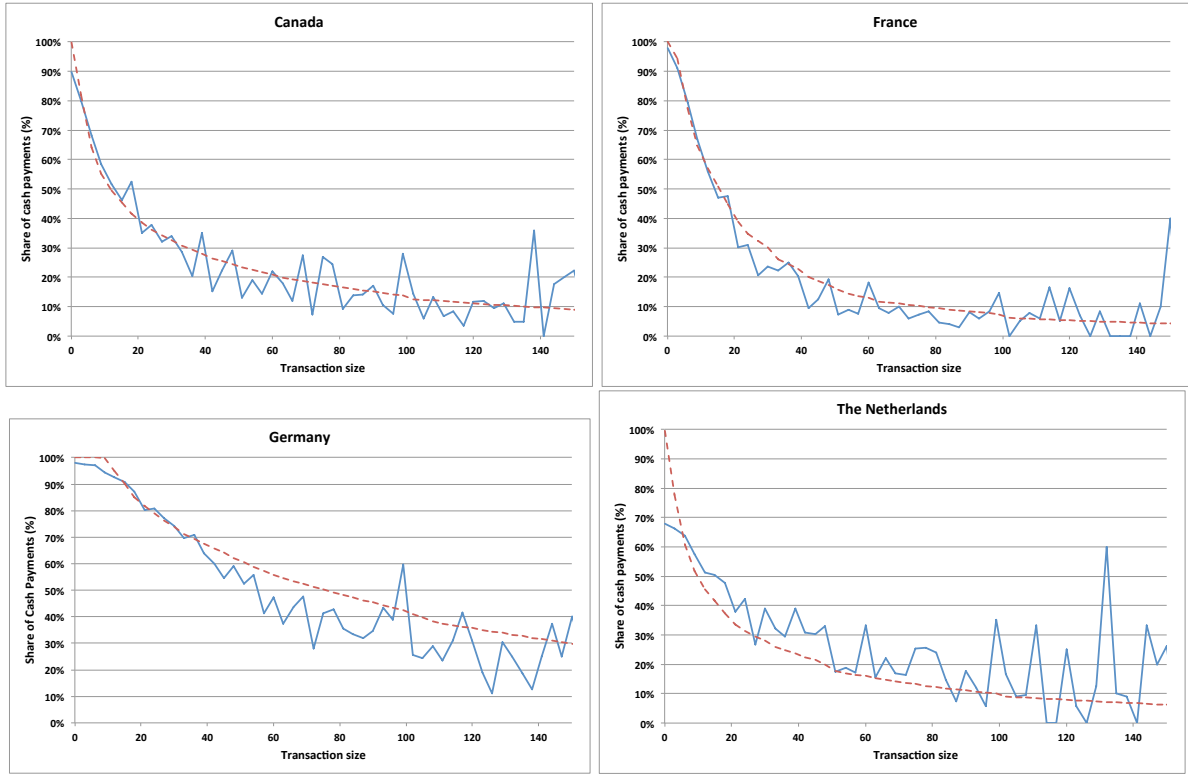


Figure 4: Observed S^{obs} (plain lines) and Theoretical S^{th} (dotted lines) Shares of Cash Payments as a Function of the Transaction Size

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, shedding light on the effect of policy measures targeting an increase of card usage among consumers and card acceptance among retailers.

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

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 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 difference may also explain the deviations obtained on the average cash holdings.

Second, the threshold \underline{m}^{th} minimizing $G(\underline{m})$ is strictly positive for the four countries. In particular, we obtain the highest threshold for Germany ($\underline{m}^{th} = \text{€}10.9$). 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.²⁴ 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). Two possible explanations can be advanced. First, our model does not include any uncertainty related to merchant card acceptance; in other words, cards are supposed to be always accepted in transactions. Now, cards are not always accepted and consumers have always to hold a positive stock of cash to either avoid missing transactions, paying unexpected withdrawal costs (foreign withdrawal fees paid by consumers when they withdraw cash at banks that are not their own) or facing the extra cost of paying with cards. Indeed, the impact of card acceptance on cash usage has been explored in detail recently finding that it is a major factor explaining why cash is still being used extensively in developed economies (Huynh et al, 2014; Arango et al, 2015). A second 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

²⁴In the Netherlands, consumers do not pay additional fees for the use of debit cards.

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 universally accepted, but otherwise are comfortable with using a card for payment. In fact, about one-third of those participating in the Canadian survey declare that they do not have a Minimum Cash Holdings policy 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 \underline{m}^{th} and two cash management and payment policies, 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 Thresholds²⁵

To summarize, the results reveal the effect of heterogeneous payments systems in the sample. Although the Cash First and the Minimum Cash Holdings policies 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 policies 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.²⁶ In 2005, banks and retailers in the Netherlands decided to join forces in encouraging consumers and merchants to use debit cards.

²⁵It 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.

²⁶The 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.

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 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).²⁷ 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).²⁸ Between 2005 and 2011, the POS terminal network increased around 36 per cent, corresponding to an average annual growth rate of 5.2 per cent.²⁹ 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.³⁰ 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 reduce the cost of using cards with respect to cash and therefore impacted households cash management and payment choices.

Finally, our results do not conflict with previous studies that emphasize the role of consumers' characteristics in payment patterns. In contrast with our aim to explain the aggregate distribution of payment shares, those studies, for instance, reveal that consumers that are more apprehensive about security issues related with cards, those that see in cash a way to commit to budgetary measures and those that are first generation of migrants from cash-oriented countries are more likely to use cash at the point-of-sale (Kosse, 2013; Hernandez et al, 2014; Von Kalckreuth et al, 2014; Arango et al, 2015).

²⁷As 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.

²⁸Other changes in the payment infrastructure included increased fees for retailers' cash withdrawals and cash depositions.

²⁹The 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).

³⁰Two 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!"

5 Conclusion

This paper aims to evaluate the validity of two cash management and payment choice policies traditionally derived as optimal in the payments economics literature. The first policy, called "Minimum Cash Holdings," specifies the existence of a threshold of cash balances on hand below which 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 a card. In other words, it is always more convenient to pay with cash when it is on hand. We simulate the two optimal policies using individual data on cash withdrawals and payments from four countries, namely Canada, France, Germany and the Netherlands and compare the theoretical and the observed shares of cash payments for each transaction size.

The results of the simulations show that the "Cash First" policy 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 prepared to accept the payment card. As an illustration, the number of active POS terminals among retailers increased in 35 percent in the first six years after banks and retailers agreed on a set of strategies in order to increase debit card usage and acceptance. 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 policy 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 (Huynh et al. 2014). 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.³¹

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³¹See Bagnall et al. (2014) 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

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