Cash is Alive: How Economists Explain Holding and Use of Cash*

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Abstract

Research on holding and use of cash involves many aspects such as: reasons for holding and hoarding cash, transactional demand for cash, cash management, type of spending paid with cash, type of consumer who pays cash, merchant acceptance, how consumers get cash, currency denominations, legal aspects, cash substitutes, and cost of cash. The purpose of this article is to introduce the reader to some of the research economists do on consumer holding and use of cash.

Keywords: Paying with cash, getting cash, holding and hoarding cash, cash management, cost of cash, cash substitutes, currency denominations.

JEL Classifications: D11, D12, E41, E42.

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1. Introduction

For the purpose of this article, *cash is defined as "tangible" currency notes (paper or polymer) and metal coins that are issued only by sovereign governments*. Cash is considered to be *money* because it serves as a medium of exchange, unit of account, and store of value. Cash is also a component of a broader class of money M1 that includes funds that are readily accessible for spending. Currency notes are often referred to as *banknotes* although they are no longer issued by commercial banks. In this article, currency notes, banknotes, or just notes, are used interchangeably.

1.1 Why is economic research on cash needed?

Why is economic research on cash needed? A short and simple answer to this question is that cash does not seem to be going away. All earlier predictions about the disappearance of cash in the form of tangible notes and coins turned out to be either wrong of premature. Who knows? Moreover, different countries seem to be going in different directions. The transaction demand for cash decreased substantially in China, Norway, and Sweden relative to other countries such as France, Germany, and the U.S.

For many years, economists have been researching issues related to the use and holding of cash by all agents in the economy: consumers, merchants (retailers), financial institutions (banks) and governments (finance ministries and central banks). This article reviews this literature while placing a heavier emphasis on issues related to the consumer side. These issues include: reasons for holding and hoarding cash, transactional demand for cash, cash management, type of spend-

ing paid with cash, type of consumer who pays cash, merchant acceptance, how consumers get cash, currency denominations, legal aspects, cash substitutes, and cost of cash.

Although cash use is trending down, the use of cash continues to be strong in both developing and developed countries. However, the use of cash varies among countries. Authorities in some countries, such as China, Norway, and Sweden, struggle with the fast pace in which merchants (stores and service providers) become cashless. In the U.S., where the use of cash remains strong, some cities and states started banning cashless stores. While cash payments are declining, the demand for large-denomination currency notes keeps rising. This means that more cash is being hoarded. In addition, some cash is shipped abroad and some of it may be used for illegal activities and tax evasion purposes. The latter has led the European Central Bank in 2018 to stop issuing the €500 currency note thereby leaving the €200 currency note to be the largest denomination in the euro area.

From consumers' perspective, cash has some unique features that make cash different from other payment methods such as checks, debit cards, credit cards, prepaid cards, and bank account transfers:

(i) Cash is circulated for free (although consumers may encounter time cost and fees for bank teller and ATM withdrawals).

(ii) Cash is transferable in both directions among individuals and among buyers and sellers.

(iii) Use of cash results in an immediate and final settlement since there is no need for clearing via banks or any other third party.

(iv) Cash transactions preserve the anonymity of the transacting parties because they are not recorded on any server.

(v) Cash transactions can be made "offline" during power outages and natural disasters.

(vi) Cash payments can be made and received without the need to open and use bank accounts.

(vii) Cash is still a widely accepted form of payment although it is limited to in-person transactions. That is, both parties to a cash transaction must be physically present. Cash payments in parking garages and vending machines require only one party to be present.

There are several drawbacks of using cash: (a) cash can be stolen or lost; (b) cash does not have

any record-keeping capability in which consumers can trace back their payments. This feature is a direct consequence of the anonymity property. For that reason, some consumers may actually dislike anonymity if they want to keep a traceable record of every transaction. In addition, anonymity permits money laundering, illegal trade, and tax evasion which are harmful from a social perspective.

1.2 Cash as a medium of exchange in historical perspective

As a medium of exchange, the purpose of cash is to reduce transaction costs relative to transactions conducted in the absence of cash, such as barter trade and debt negotiations. Under barter trade, buyers and sellers face enormous challenges with getting matched in pairs with the exact opposite needs, commonly referred to as *double coincidence of wants*. For example, if person A has extra apples and person B has extra wagon wheels, they must agree on a rate of exchange that would make both of them better off, and then physically meet in order to exchange the goods.

1.2.1 Emerging needs for cash from a technological perspective

Whereas barter trade has always existed, recent research in economic anthropology and economic archaeology has found that barter was not the only way in which trade was conducted before coins emerged as a medium of exchange. As noted in Dalton (1982), "moneyless exchanges and payments which are not barter are now very well documented." First, within closed communities, a large amount of trade was based on reciprocity in the form of frequent gift giving. Note that gift givings are not considered barter because they do not involve formal rates of exchange (such as two apples for one orange), and also because they do not necessarily take place at the same time. Second, anthropologists, archaeologists, and historians have identified thousands of decorative and useful objects such as shark teeth or woodpecker scalps as special means of commercial or noncommercial payment methods that were used for exchange in primitive, peasant, and archaic societies all over the world. Third, Graeber (2012) provides evidence that debt existed long before coins were used as media of exchange. The author argues that a significant share of trade was conducted by having buyers issue an "I owe you" to the seller anticipating that, sometime in the future, an opportunity will arise when the buyer will be able to sell something back to the seller,

thereby completing the trade.

Surveying the history of cash is beyond the scope of this review article. Briefly, several museums around the world display coins that were minted in Lydia (today, western Turkey) during the 7th century BC. Therefore, Lydia is commonly viewed as the birthplace of coins; see Howgego (1995). The coins were made of electrum, which is an alloy of gold and silver with traces of copper6 and other metals. Since then, the use of coins spread throughout the world. According to Velde (1998), the quantity of money was not under the control of any authority and coins were minted according to price incentives that determined the money supply.

Fiat money in the form of printed documents was developed in China during the Tang dynasty (618–907), see Goetzmann and Rouwenhorst (2005). These were needed to replace the heavy copper coins that were not suitable for intercity trade or other commercial travel. The documents were called *flying cash* because they allowed merchants to sell goods in the capital city and then deposit their profits in their provinces. In 1661, Sweden became the first European country to introduce paper money. Ironically, China and Sweden that were the first to introduce paper money are rapidly switching to cash alternatives via mobile apps and central bank digital currency.

1.2.2 Counterfeiting

Counterfeiting currency notes and coins plays a role in the history of cash similar to the role credit card fraud and cyber attacks play in today's world of digital money. Finlay and Francis (2019) provide a brief history of counterfeiting with a focus on Australia. Basically, every form of cash, whether it is coins, currency paper notes, or older cash in the form of cowrie shells, clam shells, or bones, has been subjected to counterfeiting.

Counterfeiting paper money has started during the first-known introduction of paper notes in China and was always tied to advances made in color printing technologies. To reduce the amount of counterfeiting, governments have always tried to improve the security features by adopting more advanced coloring techniques, unique markings, polymer notes, and frequent replacements of old currency notes with newer ones (demonetization). Metal coins were commonly counterfeited with coins made from less-valuable metal, or by shaving off the edges of silver coins that gradually reduced their weight. Rhodes (2012) describes the history of counterfeiting in the

U.S. starting from 1776 when the British printed and circulated counterfeited Continental currency to destabilize the economy of the American colonies. Lambert and Stanton (2001) describe counterfeiting during the free banking era and the establishment of the Secret Service as a Treasury bureau to guard against counterfeiting activities.

Over the past 30 years a growing number of countries switched to banknotes made from polymer. For the list of countries see https://en.wikipedia.org/wiki/Polymer_banknote. Polymer banknotes last significantly longer than paper notes and therefore reduce their environmental impact and the cost of replacements. Polymer banknotes are significantly more secure because they are harder to counterfeit. In 1988 Australia was the first country to issue polymer banknotes and now uses polymer exclusively. Bouhdaoui, Bounie, and Van Hove (2013) develop an analytical framework to assess whether changing the manufacturing material would be beneficial. Applied to the U.S., the authors find that a complete adoption of polymer notes could save $140 million per year because it would cut by half the annual replacement cost of banknotes. By denomination, the benefit would be the highest by replacing the $1 bill whereas the benefit from replacing the $100 is small, suggesting that a partial adoption of polymer seems reasonable.

1.3 Scope and organization of this survey

I have been doing research on payment methods for over 20 years. When we started, we were convinced that cash was about to disappear in a few years, primarily because of the emergence of electronic cash cards, see section 8.2 which reviews this literature. We were wrong! Cash continues to be alive and is actually doing well in most countries. However, we do observe some changes in the motivation for holding cash. The use of cash for transaction purposes is declining in some countries whereas holding cash for other purposes, such as store of value, is increasing.

I tried my best to review most of the literature (266 references to be exact) on a wide variety of related topics, including the theoretical and empirical literature on money demand, payer and payee characteristics, the unique characteristics of cash relative to other means of payment, and more. However, I may have unintentionally missed some important papers. In particular, to reduce repetitions of stating similar results in section 4.2, I had to select only a representative sample from the vast literature that characterizes the demographics of cash users and the type of

payments made with cash. In addition, this review focuses primarily on holding and use of cash in developed economies and less on cash holding and use in the developing countries.

Section 2 reviews the literature on cash holding, cash management, and the welfare cost of inflation. Section 3 reviews the literature on cash hoarding (domestic and foreign) and policy measures to reduce illegal activities. Section 4 analyzes the characteristics of cash payers, payees, cash transactions, price incentives, and the benefits from paying cash. Section 5 reviews the literature on how people get cash and the effects of Covid-19 on the use of cash. Section 6 surveys the literature on optimal denominations of currency notes and coins. Section 7 reviews cost studies. Section 8 reviews past and present attempts to replace cash. Section 9 concludes. Lastly, the data and R-code used for the graphs and tables presented in this article are available for downloading from https://github.com/ozshy/cash.

2. Cash holding: Theory, empirical testing, and welfare analysis

2.1 Theory of cash management

The transaction demand for cash holding is motivated by two basic needs:

(i) to bridge the gaps in time between receiving money (say, income) and spending;

(ii) to reduce liquidation costs of yield-bearing assets in order to meet spending opportunities.

The first need implies it is not necessary to hold cash if receipts of money and spending are synchronized to occur at the same time. However, even if receipts and spending are not synchronized, cash holding may still not be needed if yield-bearing assets can be costlessly liquidated each time the consumer must pay for goods and services. Thus, the second need implies that consumers must restrict the number of cash withdrawals if they bear liquidation costs. These facts have motivated the use of *cash-in-advance models* to describe consumers' cash holding behavior. The cash-in-advance constraint imposes two costs on consumers: (a) the transaction cost of bank fees (such as ATM fees) plus the value of time spent on each cash withdrawal and (b) the opportunity cost of holding money such as inflation and forgone interest.

The literature surveyed in this subsection develops analytical models that incorporate both costs. Because consumers bear a cost for each liquidation of an asset, consumers often choose

to hold a large amount cash (inventory) in order to able to pay for multiple transactions over a certain period of time.

2.1.1 The Baumol-Tobin inventory model

Baumol (1952) and Tobin (1956) integrate inventory theory with consumer decision making on how much cash to withdraw from interest-bearing accounts or investments in order to be able to meet consumer spending needs. Baumol and Tobin (1989) attribute the original idea for this framework to Allais (1947). Let S denote the total dollar amount a consumer or household spends over one year in a steady stream. The parameter ϕ denotes the pecuniary and non-pecuniary costs of withdrawing money, which include withdrawal fees such as ATM fees and loss of value of time associated with each cash withdrawal.

The consumer has to decide on the amount of cash per withdrawal, c, which determines the number of cash withdrawals in the course of a year, $n_w = \frac{S}{c}$. For example, if a consumer spends \$5200 each year, the consumer can meet all payments by withdrawing $c = \$100$ each week, which would necessitate $n_w = \frac{5200}{100} = 52$ weekly withdrawals each year. Alternatively, withdrawing $c = \$200$ would necessitate $n_w = \frac{5200}{200} = 26$ withdrawals in a year (one withdrawal every two weeks). Note that the number of withdrawals n_w is a positive integer. However, in order to simplify, the number of cash withdrawals n_w derived in the model will be approximated by a positive real number.

Assuming that a consumer withdraws cash each time she runs out of cash, the consumer's average cash holding is $\frac{c}{2}$. Let r denote the annual rate of interest which reflects the opportunity cost of holding one dollar. Therefore, the consumer chooses the amount to withdraw c to solve

$$\min_c \left(\phi \frac{S}{c} + r \frac{c}{2} \right). \tag{1}$$

The first term in (1) equals the total annual cost of withdrawing cash, which is the fee per withdrawal multiplied by the yearly number of withdrawals. The second term is the interest opportunity cost of holding the average balance throughout the year. Solving (1) yields the cost-minimizing amount of cash c obtained from each withdrawal and the number of yearly with-

drawals n_w:

$$c = \sqrt{\frac{2\phi S}{r}} \quad \text{and} \quad n_w = \frac{S}{c} = \sqrt{\frac{rS}{2\phi}}. \tag{2}$$

The above expressions assume that r, S, ϕ are positive and that the withdrawal cost (fee) is sufficiently low to satisfy $\phi < \frac{rS}{2}$. Expressions (2) imply that both the amount of cash withdrawn and the number of withdrawals increase with $\sqrt{S}$, which is the square root of total yearly spending. In addition, the amount withdrawn c increases and the number of yearly withdrawals n_w decreases with $\sqrt{\frac{\phi}{r}}$, which is the square root of the ratio of the fee for each withdrawal to the interest rate. The above result in which c (the transaction demand for cash) increases proportionally to the square root of total spending S can be interpreted as if there are some economies of scale in holding cash. That is, an increase in spending is financed partly by withdrawing larger amounts and partly by making more frequent withdrawals. This is because n_w also increases proportionally to the square root of total spending S, which could be interpreted as an increase in velocity.

Figure 1 provides additional intuition for the consumers' optimization problem of how much cash to hold. Suppose the consumer spends S dollars between $t = 0$ and $t = 1$. Let $s_t = S(1-t)$ be the remaining unspent amount in each instant $t \in [0, 1]$. In each instant t, the consumer allocates her money between interest-bearing bonds b_t and cash holding c_t. Hence, the remaining amount she intends to spend satisfies $s_t = b_t + c_t$, where b_t and c_t are nonnegative.

Insert Figure 1 about here

The step function b_t in Figure 1 depicts the amount of money the consumer optimally holds in interest-bearing assets, call it bonds for this discussion. The figure corresponds to a case where the optimal number of withdrawals is $n_w = 4$. Therefore, the consumer always waits until she runs out of cash and then withdraws cash in $t \in \{t_1^w, t_2^w, t_3^w, t_4^w\}$. The shaded areas in Figure 1 measure the value of bond holding multiplied by the time interval the bonds are held by the consumer. For example, the shaded rectangle on the left measures the value of bond holding multiplied by the $\frac{1}{4}$ time interval these bonds are held. The second shaded rectangle measures the same after the second cash withdrawal.

The sum of the three shaded areas in Figure 1 measures the value of interest-earning assets:

$B_4 = \left(\frac{1}{4} - 0\right)\frac{3}{4}S + \left(\frac{1}{2} - \frac{1}{4}\right)\frac{1}{2}S + \left(\frac{3}{4} - \frac{1}{2}\right)\frac{1}{4}S = \frac{3}{8}S$, where subscript 4 denotes a consumer who makes 4 withdrawals. This sum can be generalized to $B_{n_w} = \frac{n_w - 1}{2n_w}S$ for a consumer who makes n_w withdrawals during this period. This consumer chooses the number of withdrawals n_w to solve

$$\max_n \left(rB_n - \phi n\right) = \left(r\,\frac{n-1}{2n}\,S - \phi n\right). \tag{3}$$

Therefore, the consumer chooses the number of withdrawals n_w at equal time intervals starting from $t^w = 0$ to maximize the difference between interest income rB_n and total withdrawal fees ϕn. As shown in Figure 1, more frequent withdrawals permit leaving higher amounts invested in interest-bearing bonds b_t, where in the limit as $n \to \infty$, money is withdrawn at each instant t. The solution for (3) is identical to the solution derived from the cost minimization problem (1) and is given in (2), where again, the number of withdrawals is approximated by a positive real number.

The demand for cash specified in (2) applies only to the transaction demand for cash and therefore neglects the precautionary and speculative demand for cash. It also relies on perfect certainty with respect to the amount of spending. The above model is based on the assumption that the consumer lives off her invested capital and does not earn any new income during the analyzed period.

2.1.2 Extensions of the Baumol-Tobin model

Miller and Orr (1966) observe that business firms hold about half of the total money stock and that cash management by business firms and professional households is much more complicated than the optimization problem solved in the basic model. The authors develop a model that replaces the deterministic net cash flows assumption with random cash flows. The model is solved for an optimal policy that allows cash balance to wander freely until it reaches either a lower bound or an upper bound. When an upper bound is reached there will be a lump sum transfer from cash. When a lower bound is triggered there will be a transfer to cash. Milbourne (1983) extends the analysis by assuming that costs of transferring money consist of a fixed component and a proportional component that depends on the amount of the transfer. The author finds that the rule used in Miller and Orr (1966) is a special case when the cost of transferring money is fixed. In the more general case, the optimal solution consists of setting two targets of holding money and

two thresholds that trigger the actions. Milbourne, Buckholtz, and Wasan (1983) recognize that adjustments of money holdings need not be instantaneous (may require time) and derive optimal short run adjustments of money holdings toward their desired level.

Romer (1986) constructs a general equilibrium version of the Baumol-Tobin model in which agents optimize the frequency of their trips to the bank. His model identifies three channels through which changes in the interest rate affect money holdings: the frequency of conversions, the pattern of spending between conversions, and wealth effects. Among other findings, the author concludes that money demand is well approximated by conventional partial equilibrium formulas as long as the rate of inflation is relatively how and individuals go the the bank relatively frequently. Whitesell (1989) extends the model in a different direction by introducing variable payment amounts and transaction cost that vary with payment amounts and by payment method. The author concludes that this extension can help explain variable empirical elasticity estimates. Karni (1973) extends the model by decomposing the cost of cash withdrawals ϕ into a fee and forgone income from time-consuming withdrawals. The time cost then affects income and hence spending S and the elasticity of cash holding with respect to spending.

Santomero (1974) points out two limitations of the basic Baumol-Tobin model. First, the assumption that consumers make infinitely many purchases over a given time period (continuous spending) is not appropriate given the fact that a non-zero cost is associated with each purchase. Second, money demand is not homogeneous because demand deposits and currency possess distinct characteristics. In his model, consumers make a finite number of purchases and allocate their funds among currency, demand deposits, saving deposits, and commodity inventories. Santomero (1979) integrates fixed and variable costs into a single analytical model. The author concludes that the more general specification requires both variables to be in the estimated equation of demand deposits. McCallum and Goodfriend (1987) extend the Baumol-Tobin model by introducing shopping time costs. Bar-Ilan (1990) extends the cash management model to allow for overdrafting at some penalty rate. The author concludes that a proper definition of the medium of exchange has to include some measure of approved credit lines that are available to the public.

2.2 Testing the theory of cash management

The empirical literature that tests Baumol-Tobin's inventory theory of transaction demand for cash includes Paroush and Ruthenberg (1986) who, using data from Israel during the 1980s, find that a more intensive use of ATMs increases real demand deposit balances and reduces the ratio of currency to demand deposits. Using U.S. data from 1984 and 1986, Daniels and Murphy (1994) test the effect of new technologies and find that a shift to ATM use results in lower currency inventory. Using survey data from the Netherlands over 1990–1994, Boeschoten (1998) finds that intensive use of cash dispensers or ATMs corresponds to 10 to 20 percent lower transaction balances.

Snellman, Vesala, and Humphrey (2001) estimate the substitution of noncash for cash payments in 10 European countries and how it is influenced by the diffusion of card payment infrastructures such as EFT-POS terminals. The authors find that the trend in cash substitution across countries is quite similar, but the countries themselves are at different stages in this process. Stix (2004) estimates the impact of ATM cards and EFT-POS payments on cash demand in Austria and shows that ATM usage is associated with 24 percent lower cash holdings. Using a representative sample of French individuals, Bounie and François (2008) estimate individuals' total cash holding and find that ATM surcharges increase cash holdings. Using 2005 survey data of French individuals, Bounie, François, and Waelbroeck (2016) estimate the effects of debit cards (which also function as ATM cards) on the demand for cash. They find that the negative effect on the use of cash dominates the positive ATM effect, thereby reducing the overall demand and usage of cash. Using panel data of Italian households over 1993–2004, Lippi and Secchi (2009) study the effect of changes in transaction technology on the demand for currency. They find that both the level and the interest rate elasticity of cash holding depend on the withdrawal technology available to households. Using consumer survey data over 2008–2010, Briglevics and Schuh (2014) estimate cash demand of U.S. consumers and find that credit card borrowing affects consumers' cash management practices and the interest elasticity of cash demand.

Recall that the goal of this article is to review the literature on cash and not other forms of money. However, it is not always clear how to separate paper notes and coins from the broader class of money, say M1, in which cash in the form of tangible currency notes and coins constitutes

only a fraction of consumer holding of money. More precisely, M1 includes funds that are readily available for spending. In the U.S., M1 consists of: (i) currency outside the U.S. Treasury, Federal Reserve Banks, and the vaults of depository institutions; (ii) demand deposits at commercial banks; and (iii) other liquid deposits, consisting of other checkable deposits OCDs and savings deposits (including money market deposit accounts).[1]

The goal of this review article is to focus on item (i) in the above list, which is only part of the money demand equation. However, most of the literature on welfare measurements is based on the area under the money demand curve or money in the utility function without separating cash from other components of M1. Therefore, this literature does not fully capture the effects of a reduction in cash use and cash holding if the reduction in cash is offset by an increase in other components of M1.

Models that incorporate M1 include Benati, Lucas, Nicolini, and Weber (2018), who empirically explore the long-run demand for M1 in the form of $M_t = P_t Y_t \phi(r_t)$, where $\phi'(r_t) < 0$. Under this formulation, consumers, producers, or government agencies' choice of how much money to hold are based on expected spending flow (value of production flow, $P_t Y_t$) and on the opportunity cost of holding cash (short-term interest rate, r_t). Among other findings, the authors conclude that using the correct money demand specification has important implications for the ability to correctly estimate the welfare costs of inflation. Freeman and Kydland (2000) construct a dynamic model with production and consumers who choose consumption and leisure and then calibrate the model to U.S. data. In their model, cash withdrawals are time consuming and consumers use deposits to pay for large purchases and currency for low-value purchases. They show how productivity shocks affect the equilibrium ratio of deposits to currency and hence the money multiplier and M1. Lucas and Nicolini (2015) modify the model and the calibration of Freeman and Kydland (2000) by adding money market deposit accounts (MMDA), which, due to regulatory changes in the early 1980s, became substitutes for demand deposits but not for cash. They find that these regulatory changes can explain the instability of money demand.

[1]The definition of M1 in the U.S. is taken from the Federal Reserve Bank of St. Louis, https://fred.stlouisfed.org/series/M1SL. The definition of M1 has changed in 2020 to include savings and money market deposit accounts following a change in Regulation D that no longer imposes limits on the number of transactions or withdrawals permitted on savings deposit accounts.

2.3 Money demand and the welfare cost of inflation

There is a large amount of theoretical and empirical literature that measures the cost of inflation using money demand models. Bailey (1956) associates welfare with the area under the inverse demand curve for real balances less seigniorage revenue. The inverse demand curve is plotted with the interest rate r on the vertical axis and real money balances (alternatively, money divided by income or nominal GDP) on the horizontal axis. Sidrauski (1967) incorporates the flow of services derived from holdings of real cash balances into consumers' utility function. The author constructs a growth model and shows that a rise in the rate of monetary expansion results in an equal increase in the rate of inflation which then reduces the stock of real cash but does not affect steady state consumption. Unlike Sidrauski's model, Brock (1974) analyzes what happens if the change in money supply is perfectly foreseen. In the finite horizon case, the author shows that an increase in the rate of growth of nominal transfer payments increases the equilibrium holdings of real balances. In the infinite horizon case, real balances fall until a new lower steady state is reached.

Drazen (1979) analyzes optimal inflation in a model in which holding more money allows the economic unit to economize on time spent on conducting transactions (allowing for more leisure time). In his model, perfectly anticipated inflation is viewed as a commodity tax on money. The author concludes it is not always optimal to have a positive tax on money and that the sign and magnitude of optimal inflation rate must be determined by econometric estimations of demand functions.

Note that above literature (and references therein) reflects two modeling approaches: one that incorporates real money balances into the utility function, and one that in which money reduces transaction costs that can be entered into the budget constraint. Feenstra (1986) analyzes the two approaches and shows analytically that there exists a functional equivalence between using real balances as an argument of the utility function and using money to reduce liquidity costs which are incorporated into the budget constraint.

Models of money demand are often used to evaluate the welfare costs of inflation, high interest rates, and the Friedman rule regarding the benefits from a deflationary monetary policy that leads

to low interest rates, see Friedman (1969). Based on U.S. time series for 1900–1994, Lucas (2000) estimates that the gain from reducing the annual inflation rate from 10 percent to zero is equivalent to an increase in real income of slightly less than one percent. Using more recent data, Ireland (2009) estimates the welfare cost of 2 percent inflation at less than 0.04 percent of income and the cost of 10 percent inflation at less than 0.25 percent of income, which are much lower than those computed in Lucas (2000).

Mulligan and Sala-i-Martin (2000) show that the relevant monetary decision is not the fraction of assets to be held in interest-bearing forms (intensive margin), but whether to hold such assets at all (extensive margin). The authors argue that ignoring extensive margins may lead to an overestimation of the cost of inflation at low interest rates. Attanasio, Guiso, and Jappelli (2002) estimate currency demand derived from a generalized Baumol-Tobin model. They find the welfare cost of inflation to be below 0.1 percent of consumption and that it varies considerably within the population. Alvarez and Lippi (2009) extend the Baumol-Tobin model to a dynamic environment with an opportunity to withdraw cash at random. Using panel data of Italian households, the authors predict the welfare cost of inflation to be 40 percent lower than in the Baumol-Tobin models.

Finally, Alvarez, Lippi, and Robatto (2019) link consumers' real resource transaction costs that are associated with the adjustments of their money balances to welfare measured by the area under the money demand curve, which is the welfare cost of inflationary tax if agents have a small intertemporal discount rate. To demonstrate this linkage, define welfare first as the transaction cost of withdrawing money, formally $\tilde{w} = \phi n_w$, where n_w is the number of cash withdrawals given in (2). Note that the authors do not subtract interest costs, arguing that for the society as a whole these are just transfers among agents. Then, using (2),

$$\tilde{w}(r) = \phi n_w(r) = \sqrt{\frac{\phi r S}{2}}. \tag{4}$$

Also using (2), the gross area under the average balance of cash holding less forgone interest on holding the average cash balance is

$$w(r) = \int \frac{c(r)}{2} dr - r\frac{c(r)}{2} = \int \frac{1}{2}\sqrt{\frac{2\phi S}{r}} dr - \frac{r}{2}\sqrt{\frac{2\phi S}{r}} = \tilde{w}(r). \tag{5}$$

Therefore, (4) and (5) yield the same solution ($w(r) = \tilde{w}(r)$) which demonstrates how resource costs of cash withdrawals are also captured by the welfare measured by the area under the money demand curve. The authors note that this result generalizes to a large class of theoretical inventory models.

3. Holding and hoarding cash: Data analyses

It is hard to distinguish the meaning of *hoarding* from *holding* cash. Therefore, for the purpose of this survey, I will use the term *holding* as the most general type of activity that encompasses both hoarding motives and other reasons for holding cash, such as transactional motives. Under this interpretation, hoarding may be viewed as long-term holding of cash. Figure 2 depicts the classifications of cash holding that are used in this survey.

Insert Figure 2 about here

Figure 2 highlights the complexity involved in any empirical research that tries to quantify the distribution of cash in circulation between hoarding (stock variable) and transactional purposes (flow variables). Even within these two groups, cash can be moved abroad or used domestically in the shadow economy which make it even more difficult to trace movements of cash.

Empirical investigations of cash holding involve four basic questions: (i) for what purpose cash is held by the public; (ii) how much cash is held by the public; (iii) who holds cash (demographics); and (iv) where cash is stored (domestic or abroad). The complexity of obtaining good estimates of these four indicators of currency demand are discussed in Sprenkle (1993).

Figure 1 in Lippi and Secchi (2009) depicts world averages of currency over GDP between 1954 and 2006. The averages are weighted by the share of countries' GDP. The figure displays an increasing trend in the ratio of cash to GDP in both high and low income countries. The column labeled CIC/GDP in Table 1 displays the ratio of the value of currency in circulation to nominal GDP for 22 countries in 2019.

Insert Table 1 about here

In Table 1, the countries are listed according to a decreasing CIC/GDP ratio. Japan (21.3 percent), Hong Kong SAR (18.5 percent), Switzerland (12.1 percent), and India (12 percent) have the highest CIC to GDP ratios. All four countries experienced positive growth in this variable during 2012–2019. For example, the compounded annual growth rate was 2.1 percent in Japan and 2.8 percent in Switzerland. Norway and Sweden have the lowest ratio of CIC to nominal GDP, 1.3 percent, and also experienced steep declines in their compound annual rate of change (negative 4.5 and 9.4 percent, respectively).

The column labeled CIC/M1 in Table 1 displays the ratio of the value of currency in circulation to the value of M1 (narrow money). It provide some indication of how liquid money, which is available for spending, is allocated between cash and other forms of M1. It also provides some measure of the transaction demand for cash, which will be characterized in section 4.

Judson and Porter (2004) study the determinants of regional currency demand in the U.S. from 1974 to 1998 and show how currency demand depends on a transaction measure and nominal interest rate. Jobst and Stix (2017) analyze time series from the late 19th century to 2015 for several economies and also for 72 countries from 2001 to 2014. They find the recent increases in the circulation of the euro, the U.S. dollar, and the Swiss franc to be strong even if viewed in perspective of 100 years. In addition, increases in cash circulation are observed in the majority of 72 countries from 2001 to 2014. Shirai and Sugandi (2019) investigate time series movements of cash in circulation for 22 economies during 2000–2018. Arango and Suárez-Ariza (2020) analyze longitudinal dataset for 54 developing and developed economies from 1991 to 2014 and find that the adoption of digital payments reduces the demand for cash. Using survey data from 10 European countries from 2010 and 2011, Stix (2013) finds that the preference for holding cash can be attributed more to a lack of trust in banks and weak tax enforcement and less to whether people are banked or unbanked. Ashworth and Goodhart (2020) analyze the reasons for the rise in currency holding since the late 1980s/early 1990s after the long decline since World War II. They attribute this rise to the sharp decline in nominal interest, grey economy proxies, self employment, VAT rates, and cigarette consumption that evades tax.

3.1 Separating the motives for holding cash

It is hard to empirically estimate the amount of cash hoarded by consumers because they are unlikely to report these amounts. In addition, hoarded cash is a stock variable whereas holding cash for the purpose of making payments is a flow variable. In that sense, hoarded cash serves as a store of value whereas transaction cash balances serve as means of payment. Sumner (1990) finds hoarding balances to be the largest and the most variable component of total currency demand.

Boeschoten and Fase (1992) find that during the 1980s, 60 to 70 percent of Netherlands' Fl. 1000 currency notes (worth more than 500 U.S. dollars that time) were used for hoarding purposes. Finlay, Staib, and Wakefield (2020) employ five different methods to estimate the stock of banknotes used to facilitate legitimate transactions in Australia. They estimate that 15 to 35 percent of Australian banknotes are used to facilitate legitimate transactions, roughly half to three-quarters are hoarded as store of wealth or for other purposes, of which 10 to 20 percentage are domestic hoarding and up to 15 percent are international hoarding, 4 to 8 percent are used in the shadow economy, and 5 to 10 percent are lost.

One way to disentangle the two types of cash demand is to assume that large-denomination notes are held mostly as a store of value (hoarding) and smaller denominations are held for the purpose of making payments (transaction demand). Fischer, Köhler, and Seitz (2004) find significant differences between the determinants of holdings of small and large banknote denominations. While demand for small-value banknotes is driven mainly by domestic transactions, the demand for large-value banknotes depends on the short-term interest rate, the exchange rate of the euro as a proxy for foreign demand, and inflation variability. Amromin and Chakravorti (2009) decompose cash into three denomination categories in order to separate store of wealth from payment functions. They analyze changes in cash demand in 13 advanced economies from 1988 to 2003. Denominations larger than those commonly dispensed by a country's automated teller machines (ATMs) are posited to be better suited for store of value purposes. They show that demand for small-denomination currency decreases with greater debit card usage and that the demand for high-denomination notes decreases when interest rates rise but is generally unaffected by changes in debit card usage.

Bech, Faruqui, Ougaard, and Picillo (2018) use a uniform threshold of $75 across countries adjusted for purchasing power to distinguish between the two components of cash demand. Otani and Suzuki (2008) attribute the circulation of ¥1000 notes to transactional demand and ¥10,000 notes to non-transactional demand. Engert, Fung, and Segendorf (2019) find that the difference in the trends of cash demand between Canada and Sweden is due to differences in the demand for larger-denomination notes that can be used as store of value and less in the demand for the smaller-denomination notes that are used for frequent payments. This finding provides some explanation for why aggregate cash demand in Sweden falls faster than in Canada.

Humphrey, Kaloudis, and Øwre (2004) estimate the total value of cash for consumer payments in Norway by subtracting estimated consumer check payments and the value of all card payments from the value of personal consumption expenditure where cash is commonly used. Formally, Cash = PerCons − estCheck − Card. Khiaonarong and Humphrey (2019) demonstrate several methods for estimating the transactional demand for cash and apply these methods to estimate cash use in 11 countries. Their preferred method is based on the observation that it is relatively easier to obtain reliable data on electronic payments and debit and credit cards than trying to deduce cash use directly from data on net cash in circulation. If we assume that most cash withdrawals via ATMs and over the counter at banks (OTC) represent the use of cash, the share of cash used for transactions in the market for cash is the ratio (ATM + OTC)/(ATM + OTC + Card + SV), which is the value of transactions financed by cash withdrawals from ATMs and over the counter divided by the value of withdrawals plus payments made with two of the currently strongest substitutes for cash: debit and credit cards and the value of stored value cards or mobile phones with value stored on a chip.

3.2 Hoarding cash and the shadow economy

Throughout history, people all around the globe viewed government-issued currencies of large stable democratic economies as relatively safe and reliable means to store value for future consumption and also for transferring wealth to subsequent generations. The U.S. dollar and the euro are now the dominant currencies in this dimension, but other currencies, such as the Deutsche mark before Germany switched to the euro, the British pound, the Swiss franc, and the Japanese

yen were also commonly used as store of value.

While the share of cash transactions has been declining over the years, the demand for currency kept growing both in the U.S. and the euro area. This observation is often referred to as the *paradox of banknotes*. Jiang and Shao (2020) analyze this paradox in a model with two sectors: a cash-credit sector and a cash-only sector, where the substitutability between cash and credit varies across different economic activities. The model is then calibrated to cash usage and demand in Australia, Canada, the U.K., and the U.S.

Because the demand for large denomination currency notes has been steadily rising over the years, some authors obtain rough estimates on the amount of hoarded cash by analyzing the changes in the circulation of large-denomination currency notes. Figure 3 shows that since the 2008 financial crisis there has been a sharp increase in the demand for $100 currency notes, which is currently the largest denomination in the U.S.

Insert Figure 3 about here

Figure 3 shows that the total value of $100 bills in circulations increased significantly relative to all other denominations. In relative terms, in 2000, the share of value of all $100 bills in total cash in circulation was 67 percent. That share increased to 80 percent in 2020. The sharp increase during 2020 (the Covid-19 pandemic) will be analyzed in section 5.2. As shown later in section 4 and Figure 6, cash payments are made mostly for low-value purchases (below $20). That implies that most large denomination currency notes, in particular the $100 bills, are hoarded as store of value.

Figure 4 shows that the circulation of the €500 currency notes (euro's largest denomination) grew faster than other denominations until about 2009. From 2005 until 2011, the total value of €500 notes was higher than any other denomination. Then, it reached a plateau until 2015. In 2014, the European Central Bank announced that central banks will cease distributions of €500 bills after 2018. Consequently, the circulation of €500 bills has been declining since 2016.

Insert Figure 4 about here

Disregarding the €500 note, Figure 4 shows that the circulation of €50 and €100 currency notes grew faster than other denominations. In addition, from 2018, the circulation of the €200 currency note (euro's second largest denomination) changed from a moderate rate of increase to a steep increase, which may reflect a shift from hoardings of €500 notes to €200 notes that are still issued by the European Central Bank.

3.3 Foreign hoarding of U.S. dollars and other currencies

Perhaps the greatest challenge of the research on cash hoarding is how to estimate the amount of cash that is hoarded outside the currency's territory. Another difficulty in measuring cash circulation outside the currency region stems from the fact that some of the cash is shipped backed to the issuing countries without declarations, part of it as money laundering. Therefore, policy makers in the U.S. would benefit from knowing the amount of U.S. dollars held abroad. The same applies for the amount of euro circulating outside the euro area. Note that central banks earn seignorage revenue from issuing currency regardless of whether the currency is circulated domestically or abroad. This may be one of the reasons why central banks have no incentives to reduce the amount of currency held abroad. Sprenkle (1993) provides a discussion on the economic implications of not knowing who holds U.S. currency and where it is held.

The absence of reliable domestic saving opportunities and lack of advanced payment systems in developing and transitioning economies induce their residents to acquire foreign cash and store it as part of their wealth. This incentive is magnified when the domestic currency exhibits high inflation rates. Porter and Judson (1996) point out that today foreigners hold U.S. currency for the same reasons that people once held gold coins. Foreign currencies from large democratic countries are viewed as stable store of value when the purchasing power of the domestic currency is uncertain or when other assets lack sufficient anonymity, portability, divisibility, liquidity, or security. As a safe asset in an unpredictable world, U.S. dollars and euro banknotes often flow into a country during periods of economic and political upheaval and sometimes remain there long after the crisis has subsided.

Porter and Judson (1996) and Judson (2012) explore three methods of estimating foreign holdings of U.S. currency. A *direct* method and two indirect methods: the *seasonal* method and the

biometric method. These methods indicate that a large share of U.S. currency, which could be between 66 and 75 percent, is held abroad mostly in $100 bills. The *direct* method measures inflows and outflows of U.S. currency. The *seasonal* method compares seasonal amplitudes of a country that faces foreign demand (the U.S. for example) with those of a country that can be thought of having very similar seasonal amplitudes but no foreign demand for their currencies (Canada for example). The observed difference between Canada and the U.S. can then be used to estimate the domestic share in the U.S. The *biometric* method relies on record keeping of new series of currency notes. The new series are easily recognizable because they embed improved security against counterfeiting (such as additional colors, threads, and holograms). By comparing the fraction of new $100 notes between samples drawn from foreign countries and domestic samples, and knowing the amount of new $100 notes shipped abroad, it is possible to compute an estimate of the total amount of $100 notes (new and old) that are held abroad.

Doyle (2000) estimates foreign-held currency notes of U.S., German, and Swiss currencies. He finds that the share of U.S. currency fell slowly during the 1960s, reached a low of 5 percent during the early 1970s, and then rose to 30 percent in 1996. The author concludes that currency substitution among foreign holding of U.S., German, and Swiss currencies has roughly tripled from 1986 to 1996. Using data on international currency flows between the U.S. and other countries, Banegas, Judson, Sims, and Stebunovs (2015) find these flows to be a significant component of capital flows in emerging economies where U.S currency functions as a safe asset. Demand for U.S. currency was extremely strong through the 1990s, eased in the early 2000s, and then rose sharply after the 2008 financial crisis.

Seitz (1995) analyzes hoarding of the Deutsche mark (DM) before the euro currency was introduced. Rogoff (1998) estimates that the OECD underground economy holds at least 50 percent of OECD's currency notes and perhaps 70 to 80 percent are held by both the OECD underground economy and in developing countries. Bartzsch, Rösl, and Seitz (2013) estimate that about 20 percent of euro notes issued by Germany's central bank are used for transactions in Germany. The rest are hoarded (10 percent), circulate in other euro area countries (25 percent), or held outside the euro area (45 percent). Feige (2012) finds that only 30 to 37 percent is held abroad. Lalou-

ette et al. (2021) survey the literature on the drivers of foreign demand for euro banknotes. They also analyze euro holding and shipments of euro banknotes to central, eastern, and south-eastern European countries and find the share of euro banknotes in circulation outside the euro area to be between 30 to 50 percent of the total value of euro banknote circulation. Rua (2020) estimates a model of euro demand using full denominational breakdown to unveil the heterogeneous role placed by several drivers. He finds that external demand is relevant for large denominations and that the announcement of the removal of the €500 banknote has led to a reduction in the overall demand for euro banknotes.

3.4 Hoarding cash policy

Under pressure to reduce money laundering and other unrecorded large transactions, in 2018 the European Central Bank stopped issuing new €500 banknotes in order to make it more costly to move large sums of cash in and out of the euro area. There have been similar suggestions in the U.S. to remove large denomination notes from circulation ($100, or even $50) and to replace smaller denomination currency notes with (heavy) coins in order to reduce crime, tax evasion, or to allow for negative interest rates, see Rogoff (2016) and counter arguments in McAndrews (2017) and Hendrickson and Park (2021). In 2016, in an attempt to combat the shadow economy, the Indian government announced the removal of all INR 500 and INR 1000 banknotes and the issuance of new INR 500 and INR 2000 banknotes. Bech, Faruqui, Ougaard, and Picillo (2018) note that although cash in circulation in India has initially dropped by more than 40 percent, cash in circulation in 2018 was almost back to its 2016 level.

Camera (2001) develops a general equilibrium model that characterizes the links between availability of currency and illegal economic activities. His model shows that a policy directed at limiting the amount of currency in circulation can reduce illicit activities. However, using currency as an exogenous discipline on illicit undertakings may have unintended consequences. Immordino and Russo (2018) investigate the relationship between cash payments and VAT evasion in 25 European countries from 2000 to 2012. They find that credit and debit card payments are negatively correlated with VAT evasion and that more intensive use of ATMs fosters VAT evasion. Rainone and Valentini (2020) analyze the relationship between cash and tax evasion in Italy

by studying the effects of two measures to fight evasion: accessing taxpayers' financial data and imposing upper limits on the value of cash payments. In 2017, 16 out of 20 European member countries imposed such limits. They find that tracing deposits generates a conversion to the highest denomination banknotes generally used as store of value and that placing upper limits on cash payments decreases cash inventory.

Wallace (2018) analyzes the possibility of having negative interest rates in the absence of physical cash and argues that the desirability of eliminating the zero lower bound on nominal interest rate is questionable without an appropriate specification of the fiscal policies to accompany alternative interest-rate settings chosen by central banks. Drehmann, Goodhart, and Krueger (2002) analyze the arguments for and against abolishing cash and argue that any attempt to force a complete shift to electronic payments or to ban domestic use of cash would be appallingly illiberal.

4. Cash payments

Compared to data on electronic payments, data on cash payments are much harder to obtain. Data on who pays cash, to whom, and for what purposes are collected mostly from consumer surveys. In particular, diary surveys record, either in real time or by the end of each day, all consumers' payment-related activities including dollar amount, spending type, merchant type, and payment method, as well as money transfers in general and ATM cash withdrawals in particular. Diary surveys are costly and are therefore limited to samples of few thousands respondents, although some diaries collect information from more than twenty thousand respondents, see Jonker, Hernández, Vree, and Zwaan (2018). For some specific research purposes, such studying ATM cash withdrawals and debit cards payments, administrative data that are based on bank account information can generate very large samples, for example see Magnac (2017) and Brown, Hentschel, Mettler, and Stix (2020).

The heavy reliance on consumer diary surveys bears some methodological issues, such as the time length that respondents are asked to record all their payments. Jonker and Kosse (2013) design and compare different surveys in the Netherlands and find that measurement errors are minimized when consumers use a self-reported transaction diary for one day only. The authors

also find that around 40 percent of the transactions registered in a one-day survey are missed out in a one-week survey. Using data on payment behavior of German consumers, Schmidt (2014) finds that the number of small cash payments recorded does not decrease during a one-week diary period although respondents tend to report a higher number of transactions on the first day of the diary period than on subsequent days. The author concludes that short diaries may be sufficient to reflect adequately the payment behaviour of consumers.

The physical nature of cash makes it unusable for online payments. Therefore, with the exception of rare cases when cash is sent over the mail or with a messenger, all other cash payments are made in person. The restriction of cash to in-person payments applies to all sorts of payments including payments for goods and services, bill payments, receiving cash, and person-to-person money transfers.

4.1 Who pays cash, to whom, and for what purposes?

4.1.1 Six reasons for why people pay cash

Why do people pay with cash? There are several reasons for that:

(i) Cash payments are anonymous and do not leave any record.

(ii) Cash payments provide instantaneous final settlement and do not require clearing via third party servers.

(iii) Cash payments can be made offline without the use of electricity, internet connection, or cellular antennas.

(iv) Consumers view cash is a low-cost payment method.

(v) Cash spending and budgeting are easy to control.

(vi) Social norm and habit formation.

Reasons (i), (ii), and (iii) reflect the technology embedded in cash payments in which currency notes and coins pass from one hand to another. Reason (iii) is supported by the observations that electricity and all electronic communication channels stop functioning during natural disasters such as floods, hurricanes, earthquakes, and extreme temperatures. For example, after hurricane Maria ripped through Puerto Rico in 2017, the Federal Reserve has flown in shipments of cash to the island to meet the extraordinarily high demand for greenbacks. Rösl and Seitz (2021) provide

evidence from several countries that cash demand always increases during crises. Reason (iv) is confirmed by consumer surveys which show that a large number of respondents rate cash as the least-costly payment instrument, see section 7.2.

Reason (v) reflects consumers' need to have precise information on their remaining budget when facing randomly-occurring unplanned consumption opportunities. Using a survey of German consumers in 2008, Kalckreuth, Schmidt, and Stix (2014) find that consumers who need to keep control over their remaining liquidity and who have elevated costs of information processing conduct a larger percentage of their payments using cash and also hold larger cash balances than other consumers. Using Canadian diary data from 2009, Arango, Hogg, and Lee (2015) estimate the marginal effect of consumers' perspective on the importance of controlling overspending and find that the probability of paying cash increases due to this effect. Using data on Dutch consumers from 2012, Hernández, Jonker, and Kosse (2017) find the use of cash and debit cards helpful for monitoring household finances. In particular, low-earners and liquidity-constrained individuals prefer paying with cash as a budgeting tool. Agarwal, Ghosh, Li, and Ruan (2020) find that consumers spent more after they were forced to switch to noncash payment instruments during the demonetization in India.

Reason (vi) is supported by Kahn, Liñares-Zegarra, and Stavins (2017) who, using a 2008–2014 annual survey of U.S. consumers, find evidence that consumers' perception of security of a payment method is influenced by their peers' average security assessment. Note that assessments and perceptions of payment methods are discussed in section 7.3. With respect to habit formation, Shy (2021b) tests habit formation (habit inertia) by regressing consumers' choice of paying cash on their choice of payment method for their previous purchase. The regression shows that the probability of paying cash increases by 0.32 if the consumer chose to pay cash for the previous purchase.

Outside the U.S., Van der Cruijsen and Knoben (2020) use payment diary data of Dutch consumers to show that payment behavior can be influenced by peer effects, especially when the environment is characterized by strong social cohesion. Van der Cruijsen, Hernández, and Jonker (2017) find that persistent habits provide an important explanation for why the substitution of

cash by debit cards took place at a slower pace than was expected. Jonker, Hernández, Vree, and Zwaan (2018) report that 68 percents of consumers who prefer cash stated habit as a reason and 82 percent stated keeping track of spending (budgeting) as a reason.

Before proceeding to the empirical literature on cash payments, it is worthwhile to review some of the theoretical research that analyzes environments in which agents benefit from transacting with cash. In a theoretical model with two means of payment: checks drawn on interesting-bearing accounts and currency, Prescott (1987) shows that low-value payments are paid with cash whereas checks are used for high-values. Lucas and Stokey (1987) analyze a general equilibrium model in which the use of money is motivated by a cash-in-advance constraint applied to purchases of a subset of goods. Stokey (2019) analyzes consumers' decision to pay cash in a model with three payment instruments. In her model, cash payments have no time costs but cash bears the risk of getting lost or stolen. In contrast, cards and electronic payments do have time cost. Under these assumptions, efficiency implies that small payments are made with cash, middle-size with cards, and large payments electronically.

The search literature such as Kiyotaki and Wright (1989) and Wang, Wright, and Liu (2017), as well as random matching models such as Wallace and Zhu (2004) also provide intuition why trading partners agree to use cash to complete a transaction. Greene, Prescott, and Shy (2022) develop a random matching model of person-to-person payments and calibrate the distribution of individuals' preference rankings for person-to-person payments using three payment methods: cash, paper checks, and electronic. They find that about two-thirds of U.S. consumers have a first p2p payment preference for cash, one-third rank checks first, and approximately 94 percent of consumers rank electronic technologies second.

4.1.2 Empirical models of cash use

In order to analyze the features that characterize cash payments, consider the following regression model:

$$\text{Payment Method} = f(\overbrace{\text{Amount},\ \text{In-person},\ \text{Merchant}}^{\text{transaction characteristics}},\ \underbrace{\text{Age},\ \text{Gender},\ \text{Marital},\ \text{Education},\ \text{Work},\ \text{HH income},\ \text{HH size}}_{\text{payer characteristics}}). \quad (6)$$

The purpose of the regression model (6) is to explain and predict which payment method (cash, check, credit card, debit card, or prepaid card) will be used for each transaction type. The predicting variables are divided into two groups: transaction-specific variables and payer-specific variables.

Amount is the payment value (measured in dollars, euro, yen, etc.). For retail payments, amount refers to the prices of goods and services plus all applicable taxes. In-person is a binary variable indicating whether the transaction was paid in person or remotely (online or via the mail). Merchant refers to merchant type (grocery store, gas station, another person, etc.). The demographic variables Age, Marital status, and Education need no explanation. Work indicates employed or not employed, HH income and HH size are the payer's household income and number of people living in the household, respectively.

Because cash cannot be used for online payments, the variable "in-person" becomes a key predictor for cash payments. For this reason, depending on the type of analysis, it can be excluded from regression models such as (6) as long as the data are also restricted to payments made in person only. The empirical literature surveyed in this section shows that, in addition to "in-person," the payment "amount" is also a key predictor of whether individuals pay cash.

Figure 5 displays a machine learning classification tree which splits and classifies the observed use of the main payment methods for in-person purchases according to the regression model (6) applied to U.S. diary data over 2017–2019. The tree algorithm is structured to minimize a function of the number of classification errors among the predicted payment methods relative to the

actually-observed methods.[2] The tree displayed in Figure 5 omits the variable "Merchant" in the regression model (6) in order to reduce cluttering associated with listing 21 merchant types. However, the reader should bear in mind that this variable is important and often appears as a second split in decision trees.

Insert Figure 5 about here

The top of this up-side-down tree shows that the tree algorithm selects the $10 payment amount threshold as the strongest predictor for cash payments. For payments equal to or below $10, consumers are predicted to pay cash for in-person purchases. For payments over $10, consumers with no college degree (second left branch) pay cash for exact $20 payments and with debit cards for payments exceeding $20. For payments less than $20, individuals over 56 are predicted to pay cash whereas younger consumers are predicted to pay with debit cards. For consumers with higher education (second right branch), the splits are determined by payment amount $25, and then age, and household income. The branches on the out-most right hand side of the tree correspond to payments over $25 made by consumers with higher education who are predicted to be noncash users regardless of age. Note that the threshold cutoff amounts $10 and $20 are correlated with the U.S. currency denominations, which are analyzed in section 6.2.

4.2 Characteristics of cash payments

Most of the literature that characterizes cash payments relies on descriptive sample statistics and logistic regressions of empirical models such as equation (6). The literature that I review below attempts to distinguish key predictors for cash payments from less important predictors. That means that papers would have to be reviewed multiple times because they may fit into multiple subsections of this analysis. However, in order to avoid repetitions, the review below attempts to (sometimes artificially) fit each paper into one subsection. Despite this limitation, the categorizations according to the subsections below provide a short overview to the nonexpert reader who

[2]The classification tree algorithm was constructed and tuned with cross validations using the `rpart` R-package. The left-most branch in Figure 5 should be interpreted as a prediction that consumers pay cash for exact $20 payment amounts although it indicates "≥ 20" instead of "$= 20$". Because currency denominations are discrete numbers (with 1¢ increments in the U.S.), the tree algorithm cannot split at the exact $20 amount and therefore cannot classify $20 separately.

wishes to learn about the main characteristics of cash payments.

4.2.1 Key predictors for cash payments: *In-person* and payment *amount*

Using U.S. diary data from 2019, Kim, Kumar, and O'Brien (2020) find that 87 percent of all non-bill payments in the U.S. were made in person and that cash was used in 35 percent of non-bill payments. Because the use of cash is limited to in-person transactions, some of the empirical research on cash payments restricts the sample observations to payments that are made in person only.

If we had to choose one and only one variable that predicts the use of cash for in-person payments, it would be the *amount* of the payment (payment value). The vertical axis in Figure 6 displays the shares of in-person payments made in the U.S. with cash, checks, credit, debit, and prepaid cards. The horizontal axis measures actual payment dollar amounts in $1 intervals up to $50. Figure 6 reveals that the share of cash payments declines very rapidly with the payment dollar amount.

Insert Figure 6 about here

Figure 6 shows that 80 percent of the payments below $1 are made with cash. These transactions must involve some coins, either paid or received as change. Over 60 percent of the payments below $5 are made with cash. This ratio drops to 40 percent around $10 and then below 30 percent above $20 payment values. The spikes at payment amounts that are multiples of $5 are correlated with the U.S. currency denominations and are analyzed in section 6.2.

Whereas surveys are generally restricted to samples of few thousand respondents, data from grocery and retails stores contain hundreds of thousands, millions, or even billions of payment observations. The drawback of scanner data is that they are restricted to a single merchant type. Klee (2008) analyzes U.S. grocery store scanner data from 2001 with 10 million transactions and finds that cash captures the greatest share of transactions, at 54 percent. These transactions are concentrated at low values (median is $14.20) and low number of items bought (median is 6). Consumers are less likely to use cash on Mondays, Tuesdays, and Wednesdays, and Thursdays. Wang and Wolman (2016) analyze three years of transaction data from a discount retailer with

thousands of stores and also find a negative relationship between the share of cash payments and transaction size at any given location.

Using U.S. diary data from 2019, Kim, Kumar, and O'Brien (2020) find that 47 percent of payments under $10 are made with cash. Briglevics and Schuh (2020) show that transaction size does not matter after controlling for the amount of cash consumers have in their wallets. They find that consumers with $25 in their wallet make only about one-third of their small-value transactions with cash. In contrast, for large cash holdings (e.g., $250), the probability of cash use is near 80 percent.

Outside the U.S., using Bank of Canada's 2009 Methods-of-Payment survey, Arango, Hogg, and Lee (2015) also find that the share of cash payments decreases with the payment amount and income, and increases with age. The share of cash payments does not vary between males and females. Simon, Smith, and West (2010) find similar relationships using transaction-level data commissioned by the Reserve Bank of Australia in 2007. Using 1987 data from the Netherlands, Mot and Cramer (1992) also find that the share of cash payments declines with the payment amount and education. A 10 percent increase in the payment amount reduces currency use by 1.3 to 2.3 percent. Using consumer survey data over 2010–2016 from the Netherlands, Jonker, Hernández, Vree, and Zwaan (2018) find that cash usage declines with transaction amount, increases with age and decreases with income. Using 2005 survey data of households in Austria, Mooslechner, Stix, and Wagner (2006) also find that the share of cash payments declines by transaction value. Note that Austria is a cash-intensive country, where the authors find the share of cash to be 86 percent by volume and 70 percent by value, with both declining over time.

To conclude the discussion about payment amount, almost all the research that is based on transaction-level data, including the literature cited in other sections of this review, find that the share of cash payments declines with payment value. International comparisons, reviewed in section 4.4, also confirm this relationship.

4.2.2 Other characteristics of cash users and cash payments

Most of literature on payment choice analyzes the demographics of cash users using consumer surveys in different countries. To avoid repetitions of similar results, I had to select only a sample

of this literature. In particular, I tried to avoid reciting the literature that is also cited in other subsections even if these articles also describe the demographics of cash users and transaction characteristics of cash payments.

Stavins (2001) analyzes the effects of consumer characteristics using the 1998 U.S. Survey of Consumer Finances. Using annual U.S. consumer survey data over 2003–2013, Stavins (2016) finds that the effects of age, education, and race are significant for explaining payment behavior. Using survey data from 2001, Hayashi and Klee (2003) find that consumers who use new technologies or computers are more likely to use electronic payments methods (as opposed to paper-based methods). Using 1992 survey data of gasoline users, Carow and Staten (1999) find that consumers are more likely to use cash when they have less education, lower income, are middle-aged, and own fewer credit cards.

Cash is heavily used by unbanked consumers and less heavily by consumers who are banked and can therefore use debit cards or credit cards to pay for their purchases. Using payment diary surveys of U.S. consumers in 2017 and 2018, Shy (2021a) reports that consumers who possess both debit and credit cards used cash for 31.9 percent of their payments (by number). Consumers with no credit cards (but may have debit cards) used cash for 49.9 percent of their payments. In contrast unbanked consumers with no debit or credit cards used cash for 85.7 percent of their payments and prepaid cards for 14.3 percent of their payments.

Outside the U.S., using 2009 Bank of Canada diary data, Fung, Huynh, and Sabetti (2012) show how payment innovations in the form of contactless credit cards and stored-value cards have led to a reduction in cash usage. Using a 2019 consumer payments survey in Australia, Delaney, McClure, and Finlay (2020) find that cash is still used extensively although it keeps declining over the years. High cash users tend to be older, live in regional areas, have lower household income, or have poor internet access. Kosse and Jansen 2013 provide evidence that foreign background has an effect on payment choice where first-generation migrants are more likely to use cash in the Netherlands compared with individuals with a Dutch background.

Using French data from 2005 and 2011, Bouhdaoui and Bounie (2012) find that cash holding is a better predictor for cash payments than payment amount. Using Bank of Canada survey data

from 2009, Arango, Huynh, and Sabetti (2011) find that higher initial cash holdings leads to higher probability of paying with cash, in particular for transactions below 25 dollars. The probability of paying with cash for an individual carrying 150 dollars could be twice as large compared with someone with only 5 dollars. These results are also supported analytically in Alvarez and Lippi (2017), who show that the decision whether to pay cash at each point in time depends on the payer's stock of cash. This observation is often referred to as a *cash burn* or *cash first* decision to pay cash. Arango, Bouhdaoui, Bounie, Eschelbach, and Hernández (2018) confirm this consumer behavior using payment diaries from Austria, Canada, France, Germany, Netherlands, and the U.S.

4.2.3 Merchant type and card acceptance

In addition to payment amount, merchant type (to whom the payment is made) is also a key variable for predicting cash payments. Using U.S. diary data from 2019, Shy (2020b) analyzes the share of payment volumes made with cash in 21 merchant categories and finds that person-to-person payments are the most cash intensive, with 71.8 percent payments made with cash. Fast food and coffee shops rank second, with 43 percent cash payments. Payments for arts/entertainment are 39.2 percent cash, and public transport/tolls payments are 39.1 percent cash. Charitable/religious donations are 38.8 percent cash, and payments for general services are 38 percent cash.

Outside the U.S., Bounie and François (2006) analyze transaction characteristics of cash payments using French diary data from 2005 and find that cash is used for small transactions, at small stores, and mainly to pay for newspapers, tobacco, lotteries, food, beverages, restaurant, hotel, and culture and leisure. Simon, Smith, and West (2010) compute the share of cash payments made at 17 merchant categories in Australia and find high use of cash in take-away food stores and pubs. Using 2016 survey data from the Netherlands, Jonker, Hernández, Vree, and Zwaan (2018) find that 86 percent of the payments made to street vendors are made with cash, compared with 60 to 64 percent of payments made in food/tobacco shops, leisure and entertainment, and to service providers.

Consumer choice of whether to pay cash is also influenced by merchant behavior. Using Bank of Canada diary data, Arango, Huynh, and Sabetti (2015) find that the high share of cash pay-

ments for low-value transactions can also be explained by the observations that some merchants do not accept credit cards for low-value purchases. This is because card processing fees consume a larger portion of the revenue generated from low-value sales. Using diary data from Austria and Canada, Huynh, Schmidt-Dengler, and Stix (2014) estimate the impact of increased card acceptance on the demand for cash. Their results confirm that card acceptance exerts a substantial impact on the demand for cash. Using Bank of Canada survey data from 2009, Wakamori and Welte (2017) investigate whether the high use of cash is a consequence of lack of merchants' card acceptance or because consumers truly prefer to pay cash. The authors conclude that even if all merchants decide to accept cards, the overall cash usage will decrease by only 8 percentage points. This shows that cash use for low-value payments is driven mainly by consumer preference for cash.

4.3 Price incentives

Consumers and merchants often have different preferences for payment methods. These differences lead some merchants to differentiate their prices according to payment method. In addition, issuers of payment cards often reward consumers for the payments they make with cards.

4.3.1 Steering consumer payment choice

Issuers of payment cards (debit, credit, and prepaid) collect fees from merchants for each card payment. Therefore, some merchants pass some of their fees on to the consumer by surcharging consumers who pay with cards. Small stores often refuse to accept credit card payments below a certain amount. Although both, card surcharges and cash discounts, steer consumers towards using more cash, Carlton and Frankel (1995) and Frankel (1998) show that these two merchant strategies are very different. This is because different card brands and card types (reward cards versus non-reward cards) impose different merchant discount rates. Therefore, merchants may be better off by surcharging card payments according to the card-specific fee that they bear instead of providing a uniform price discount to all consumers who pay cash.

Ingene and Levy (1982) characterize the conditions under which cash discounts are advantageous to retailers and their consumers and show that cash discounts are feasible under some

circumstances. Barron, Staten, and Umbeck (1992) describe the evolution of cash discounts in gas stations and show how the decision to start offering cash discounts was driven by a rise in the cost of financing accounts receivable per gallon sold from 1978 to 1982. Using U.S. consumer diary data from 2012, Briglevics and Shy (2014) find that steering consumers to pay cash or with debit cards via price discounts yields very small benefits to merchants because most of the discounts are absorbed by existing cash and debit card users. Using U.S. consumer diary data from 2012, Stavins and Shy (2015) find almost no evidence that merchants either surcharge card payments or provide discounts for cash payments, with the exception of cash discounts given by gas stations and small service providers. Using U.S. diary data from 2015, Stavins (2018) finds the occurrence of price incentives to be low, but the probability that a cash transaction is conducted by a consumer who prefers other payment methods increases by 19.2 percent if cash discounts are offered.

Outside the U.S., based on 2006 survey data from the Netherlands, Bolt, Jonker, and Renselaar (2010) show that surcharges imposed on debit card payments steer consumers away from debit cards towards cash. Note that the regulations of card surcharges in the E.U. have changed over the years. Bolt, Humphrey, and Uittenbogaard (2008) find that direct point-of-sale pricing by payment method in Norway accelerated the shift to electronic payments by about 20 percent. Using Bank of Canada survey data from 2009, Welte (2016) also finds that cash discounts intended to steer consumers to pay cash are not profitable for merchants.

The research described above focused on price incentives (card surcharge and cash discount) that some merchants provide to their customers in order to steer consumers to pay with the payment method that is less costly for them. However, card issuers (commercial banks in the U.S.) often provide the opposite incentives to consumers in order to steer consumers to pay with cards instead of cash. This is accomplished by offering consumers rewards on card payments such as cash back and points. Based on U.S. survey data from 2005–2006, Ching and Hayashi (2010) conduct a policy experiment showing that removing card reward programs would increase the share of paper-based in-store payments (cash and checks) by no more than 4 percentage points for consumers who hold both credit and debit cards. Using U.S. data from 2004, Borzekowski, Kiser, and Shaista (2008) estimate that a 1.8 percent fee on PIN debit card payments is associated with a 12

percent decline in debit card use, which the authors view as the primary substitute for cash and checks.

Outside the U.S., using transaction-level data from a 2007 Reserve Bank of Australia survey, Simon, Smith, and West (2010) show how credit card loyalty programs steer consumers away from cash. They find that the share of cash payments among consumers who hold credit cards with loyalty programs is 61 percent compared with 66 percent for consumers who have credit card with no rewards.

4.3.2 Price incentives and cross subsidies

If merchants charge the same price to consumers regardless of whether they pay cash or pay with credit cards, then the cash price may incorporate some of the cost merchants bear for receiving credit card payments. This conjecture has motivated some authors to investigate whether cash payers subsidize consumers who pay with credit cards when merchants do not provide cash discounts or do not impose surcharges on card payments. Quoting from FRS (1983): "...the fundamental thesis underlying the Cash Discount Act is that credit card transactions are more costly to retailers than cash or check transactions, and that the higher costs of credit cards are incorporated in the prices of goods and services paid by all customers, resulting in a subsidy of credit buyers by cash purchasers."

Barron, Staten, and Umbeck (1992) investigate this hypothesis by comparing price of gas at gas stations that do not provide cash discount to cash and credit prices at gas stations that provide cash discount. They find that the cash price was significantly lower at stations offering a cash discount relative to similar stations that did not offer a discount for cash. Berkovich (2009) finds that rewards paid to consumers for credit card payments in grocery stores and gas stations amount to transfers from low income to high income consumers because higher income consumers receive higher rewards on their credit cards. Mariotto and Verdier (2017) construct a model where, in the absencee of card surcharge, merchants may pass through the costs of card payments to cash users.

Using a 2008 representative U.S. sample of all purchases, Schuh, Shy, and Stavins (2010) find that, on average, each cash-using household pays $149 to card-using households and each card-using household receives $1,133 from cash users every year. Because credit card spending and

rewards are positively correlated with household income, credit card payments induce a regressive transfer from low-income to high-income households. More recently, using data from Canada and the U.S., Felt, Hayashi, Stavins, and Welte (2021) also find that credit card transactions are cross-subsidized by cheaper debit and cash payments. Card rewards and consumer fees paid to financial institutions are additional sources of cross-subsidies. Consequently, consumers in the lowest-income cohort pay the highest net pecuniary cost as a percentage of transaction value.

4.4 International comparisons of cash payments

Earlier country comparisons include Humphrey, Pulley, and Vesala (1996), who analyze the payment systems of 14 developed countries using payments data compiled by the Bank of International Settlements over 1987–1993. Lacking data on actual cash payments, the authors use two indicators of cash use: cash holding by the public divided by population and the ratio of currency to GDP.

Bagnall et al. (2016) measure consumers' use of cash by harmonizing payment diary surveys from 7 industrial countries: Canada, Australia, Austria, France, Germany, the Netherlands, and the U.S. In all countries, the use of cash is strongly correlated with the payment amount, demographics, and merchant characteristics. The authors find that, by number, 46 to 83 percent of all payments are made with cash. By value, the share of cash payments in Austria and Germany (cash-intensive countries) is over 50 percent whereas in Canada, France, and the U.S. this share drops to about 25 percent. With respect to payers' demographics, cash usage decreases with education and income but varies with age across countries.

Esselink and Hernández (2017) present a comprehensive study of the number and value of cash transactions in 19 euro area countries based on survey results from 2016. They find that 79 percent by volume and 54 percent by value of all payment at points of sale are made with cash. By volume, more than 80 percent of point-of-sale transactions are conducted with cash in southern euro countries as well as in Germany, Austria, and Slovenia. In contrast, the shares of cash payments in the Netherlands, Estonia, and Finland range from 45 to 54 percent by number. By value, the shares of cash payments observed in Greece, Cyprus, and Malta are over 70 percent, whereas the shares in Belgium, Luxembourg, Netherlands, France, and Finland are below 33 percent. Us-

ing survey data of 17 euro area countries in 2019, ECB (2020) finds that 73 percent of the volume (41 percent by value) of point-of-sale and person-to-person transactions are paid with cash.

Khiaonarong and Humphrey (2019) estimate the trend in the use of cash in 11 countries over 2006–2016. The authors show that during this period cash use fell faster in China, Denmark, Netherlands, and Singapore than in Australia, which reflected the median change. Cash use in Germany, Norway, U.K., and U.S. fell at slower rates than in Australia while for India it did not fall at all. The average reduction in the share of cash use was 2.2 percentage points. Older adults tend to use more cash (but leave the population each year) while new adults tend to use less cash (and enter the population).

4.5 Estimating the benefit and cost of paying cash

The literature that investigates the benefits derived from paying cash often estimates the loss to consumers caused by a hypothetical ban on the use of cash. Using transaction data from a representative sample of U.S. consumers, Briglevics and Schuh (2020) find that eliminating either cash or payment cards reduces consumer welfare significantly. Shy (2021a) simulates the welfare loss caused by a hypothetical complete transition to cashless stores. He finds the loss to consumers who do not have debit or credit cards to be multiple times higher than the loss to consumers who have both cards. Using data from counties in Missouri and the bordering counties between 1990 and 2011, Wright, Tekin, Topalli, McClellan, Dickinson, and Rosenfeld (2017) show that the implementation of the electronic benefit transfer program, which provides debit cards to recipients of government benefits, reduced the overall crime rate and rates of burglary, assault, and larceny.

Koulayev, Rysman, Schuh, and Stavins (2016) conduct welfare analyses by separating consumers' decision to adopt (own, possess) payment instruments from the decision to use them (conditional on adoption). Using 2008 payment survey data of U.S. individuals, they find cash to be the most significant substitute for debit cards in essential retail settings, where both are the most preferred payment methods.

Outside the U.S., using data on Uber riders in Mexico, where riders have the option of paying with cash and cards, Alvarez and Argente (2019) estimate the loss to riders if a ban on paying cash is implemented. The authors estimate the loss to be approximately 50 percent of riders' ex-

penditure on trips paid in cash before the ban is implemented. Alvarez and Argente (2020b) find cash and card payments to be imperfect substitutes at both the intensive and extensive margins (only about a third of pure-cash users registered a card with Uber after the ban). Alvarez, Argente, Jimenez, and Lippi (2021) estimate social benefits of restricting cash usage (reduction in some criminal activities) and private costs (distortions that the anti-cash regulation imposes on the individual choices). They find that the private costs of heavily taxing the use cash outweigh the social benefits.

Using data from Greece, Hondroyiannis and Papaoikonomou (2017) find that a percentage point increase in the share of card payments in private consumption results in approximately one percent higher VAT revenue through increased compliance. Lahiri (2020) describes the demonetization of the 500 and 1,000 rupee notes in India during 2016, which amounted to 86 percent of the Indian currency in circulation. The author concludes that the demonetization has failed to eradicate undeclared wealth and corruption because it attacked the stock of cash but that did very little to impede the fresh creation of undeclared income, which is a flow variable. Chodorow-Reich, Gopinath, Mishra, and Narayanan (2020) also analyze the Indian demonetization and find that cash still plays a special role in facilitating transactions in modern India. They also find that the demonetization had an adverse effect on real economic activity.

5. Other issues related to consumer use of cash

5.1 How people get cash

Currency notes and metal coins are objects that cannot be transferred electronically. Therefore, cash must be obtained in person. So, how do people get cash?

Using 2017 survey data of U.S. consumers, Greene and Shy (2019) find that most consumers get cash from family or friends (35.1 percent by volume and 27.4 percent by dollar value). ATM withdrawals comes second (20.9 percent by volume and 24.1 percent by value). Employer comes third (12.9 percent by volume and 24.7 percent by value). Cash back at a retail stores accounted for 12.7 percent by volume and 3.6 percent by value. The latter is similar to earlier findings in Klee (2008) that 15 percent of debit card transactions are associated with cash back. Bank tellers account

for 9.3 percent by volume and 12.5 percent by value. Payday lenders account for 0.55 percent by volume and 0.1 percent by value. Check cashing stores' volume and value were found to be very small in percentage terms.

In the above survey, the weighted mean and median dollar values of cash receipts were $119 and $40 respectively. By source: (i) $92 and $25 were the weighted mean and median amounts received from family or friend, (ii) $137 and $100 from an ATM, (iii) $227 and $62.9 from an employer, (iv) $34 and $20 from cashback at retail stores, and (v) $159 and $80.8 from bank tellers. Note that the median amounts received were mostly multiples of $20 which is related to the discussion in section 6.2 on how currency denominations affect cash transactions.

Outside the U.S., using survey data from 2016 in 19 euro area countries, Esselink and Hernández (2017) find that respondents obtained 39 percent of their cash from an ATM (61 percent by value), 18 percent from family or friends (8 percent by value), 14 percent from cash reserves at home (8 percent by value), 7 percent from stores' cash back (2 percent by value), and 6 percent at the bank (8 percent by value). The authors also document variations across the 19 countries with respect to volume, value, frequency of withdrawals, and the average amount of cash withdrawals. Using data from Canada, Austria, and the U.S., Fung, Huynh, and Stuber (2015) compare three sources of cash withdrawals: ATM, bank teller, and cashback and find that ATMs are the major source of cash.

The number of ATMs per capita often serves as one indicator of financial inclusion. The horizontal axis in Figure 7 displays the number of ATMs per 100,000 adults in the 48 most populous countries. Russia, United States, and Canada have the highest number of ATMs per capita (over 160 ATMs per 100,000 adults). Ten countries have less than 10 ATMs per 100,000 adults. West European countries, Thailand, Japan, and Peru have over 100 ATMs per 100,000 adults.

Insert Figure 7 about here

The dollar values displayed in Figure 7 are the countries' per-capita GDP adjusted for purchasing power parity in current U.S. dollars. These numbers show a positive correlation between countries' per-capita GDP and the number of per-capita ATMs. The correlation coefficient between these two variables is 0.79. However, it is important to note that this correlation may not

hold for small countries. For example, Finland, Israel, and Sweden have population less than 10 million and per-capita GDPs $51,426, $42,146, and $55,819, respectively. The number of ATMs per 100,000 adults in these countries are 34.71, 133.17, and 31.86, respectively.

5.2 Covid-19 and cash

In 2020, a highly contagious virus called Covid-19 quickly spread throughout the world. Countries and states reacted strongly by imposing periods of lockdowns as well as business and school shutdowns that kept people at home. Despite the initial sharp decline in spending and the reduced ability to shop in person and hence to pay cash, several countries experienced sharp increases in the demand for cash (see Figures 3 and 4). In the U.S., Foster and Greene (2021) find that there has been a surge in currency in circulation during March 2020 despite the fact that, during the pandemic, consumers had fewer opportunities to shop and pay in person. The median value of consumer cash holding increased to $70 in spring 2020 compared to $40 in October 2019 before the pandemic.

Outside the U.S., ECB (2020) analyzes a 2020 survey in euro area countries on the impact of the pandemic on the use of cash. Almost half of the respondents reported that they used cash and cards in a similar way as they did before the pandemic. However, 40 percent stated that they used cash much less often. Using consumer survey data from 22 European countries, Wisniewski, Polasik, Kotkowski, and Moro (2021) find that consumers who believe that cash poses a relatively high risk of viral transmission opt for cashless alternatives.

Jonker, Van der Cruijsen, Bijlsma, and Bolt (2020) study the shift in payment behavior and payment preferences in the Netherlands during the first phase of the pandemic. They find that since the start of the lockdown, the likelihood that consumers pay cash declined 13 percentage points relative to the use of debit cards and that 60 percent of this shift persisted much longer. Using data from Italy, Ardizzi, Nobili, and Rocco (2020) find that the pandemic has led to a greater use of cashless payment instruments, notably via e-commerce purchases and contactless cards. The authors also document an increase in the demand for cash for precautionary motives. Kraenzlin, Meyer, and Nellen (2020) report on aggregate decline in cash usage in Switzerland by examining the share of domestic cash withdrawals to payments at points of sale. In Austria (a cash-intensive

country), Fenz and Stix (2021) estimate the weekly value of cash and card transactions during the pandemic. They find that cash use initially declined but then somewhat recovered during the summer.

Caswell, Smith, Learmonth, and Pearce (2020) observe similar behavior in the U.K. where both the total value of banknotes in circulation and cash held by people have increased although people spent less during the pandemic. Chen, Engert, Huynh, Nicholls, Nicholson, and Zhu (2020, 2021) explain the sharp increase in currency in circulation in Canada during the first few months of this pandemic by: (i) precautionary steps taken by financial institutions to increase their cash inventories to mitigate possible disruptions in cash transportation, and (ii) increase in consumer demand for holding cash. Eventually, by August 2020 the median value of consumer cash holdings returned to the August 2019 prepandemic level.

Finally, the literature described above shows that during the pandemic the demand for cash has increased in most countries despite the early warnings that the virus may be transmitted by contact. Observing the decline in cash payments during the Covid-19 pandemic, using data on ATM cash disbursement in Argentina and the U.S., Alvarez and Argente (2020a) estimate that doubling the intensity of the virus would increase the transaction cost of cash by 2 percent. Auer, Cornelli, and Frost (2020) present scientific evidence showing that the probability of viral transmission via banknotes is low compared with other frequently-touched objects such as credit card terminals and PIN pads.

6. Currency denominations

Currency denominations play an important role in consumers' decision whether and how to use cash. There are two main reasons for that: First, currency denominations affect the benefit and cost of paying cash. In particular, denominations determine the cost of receiving change for cash payments, which includes counting time and the burden of carrying heavy change in the wallet. Second, currency denominations affect the cost of hoarding cash because large denominations are easier to carry and store than small denomination banknotes. Table 2 displays denominations of coins and notes in circulation in seven large economies: Argentina, Canada, Euro area, India,

Japan, Mexico, and the United States.

Insert Table 2 about here

If we view, for the sake of this discussion, the Canadian dollar, the euro, and the U.S. dollar as having similar purchasing power, Table 2 reveals two major differences in denominations among these regions: (i) Canada uses only coins for the $1 and $2 denominations whereas the $1 and $2 currency notes are still circulating in the U.S. Similar to Canada, the euro area uses only coins for the €1 and €2 denominations. (ii) The one penny coin is still circulating in the U.S. and in the euro area but not in Canada. Canada removed the one penny coin in 2013 and provided guidelines how to round prices to their nearest multiples of the 5¢ coin. Chande and Fisher (2003) (Canada) and Whaples (2007) (U.S.) show that proper rounding of prices should not have inflationary consequences. Note that the guidelines for rounding apply to cash payments and not to payments made electronically.

The research on currency denominations is divided into two main topics: First, theoretical research that focuses on finding optimal denominations of notes and coins that minimize the transaction burden on sellers and buyers. Most of the burden is associated with having to sort, receive, and carry change. The burden of hoarding cash increases with the size, weight, and number of currency notes that are used as store of value and transported from one place to another. The second type of research focuses on the identification and characterization of the correlations between currency denominations and consumers' decision whether to pay cash for a particular transaction value (dollar amount).

6.1 The debate on optimal currency denominations

One approach to computing the optimal currency denominations is often referred to as the *principle of least effort*. According to this principle, denominations of notes and coins should be designed to minimize the number of tokens (notes and coins) exchanged in cash transactions between the trading parties. Cramer (1983) formulates the following problem. Suppose that D tokens with face value v_d ($d = 1, \ldots, D$) circulate in the economy. Consider an individual who pays for a transaction value (price) p, where p is denominated in the same unit of account as the circulating tokens

(for example, dollars or cents). Let, $n_d^+(p)$ be the number of denomination d tokens paid and $n_d^-(p)$ the number of denomination d tokens received as change in the completion of a transaction valued at p. Note that there are only three possible cases for each denomination d: $n_d^+(p) > 0$ and $n_d^-(p) = 0$, $n_d^+(p) = 0$ and $n_d^-(p) > 0$, or $n_d^+(p) = n_d^-(p) = 0$. That is, each denomination d is either paid, received as change, or not used at all in a payment of p.

To minimize the number of tokens exchanged between the buyer and seller (including change), the transacting parties solve

$$N(p) = \min_{\substack{n_1^+,\ldots,n_D^+ \\ n_1^-,\ldots,n_D^-}} \sum_{d=1}^{D} \left(n_d^+ + n_d^-\right) \quad \text{s.t.} \quad \sum_{d=1}^{D} (n_d^+ - n_d^-) v_d = p. \tag{7}$$

That is, for each transaction value p, the transacting parties agree on which denominations d to use as a payment ($n_d^+(p) > 0$), and which denominations to use as change ($n_d^-(p) > 0$). The goal is to minimize the sum of tokens exchanged in both directions. This decision is constrained so that the total value of exchanged tokens (paid tokens less tokens received as change) equals the value of the payment p. Table 3 provides simple examples how $N(p)$ is determined.

Insert Table 3 about here

Each row in Table 3 corresponds to a transaction in which p dollars must be paid. Each column corresponds to a pair of currency denominations in circulation in this economy. Consider a transaction value $p = \$3$ and suppose that currency notes are available only in \$1 and \$5 denominations. There are two possible ways to complete this transaction using a minimum number of notes exchanged between the parties: (i) a payment of three \$1 bills; (ii) an overpayment of one \$5 bill where the payee returns two \$1 bills as change. As shown in Table 3, in either case three tokens (notes in this example) must be exchanged.

The bottom row in Table 3 demonstrates how optimal currency denominations can be determined assuming hypothetically a uniform distribution of prices and that consumers must pay for all ten transactions in the range of \$1 to \$10. First note that \$1 bills must be in circulation as otherwise low transaction values will have to be either excluded or rounded up to the lowest available denomination. Second, in this example, both pairs of denominations (\$1, \$4) or (\$1, \$5) are optimal

because they reduce the total number of exchanged tokens in all ten transactions to 23.

Following Cramer (1983), using 1984–1986 survey data of Dutch households, Boeschoten and Fase (1989) apply the observed distribution of cash payments and find that, on average, efficient payment involved the use of 3.3 notes and coins per payment. Using U.S. consumer transaction diary data from 2015 to 2019, Prescott and Shy (2021) find that each cash transaction corresponds to an average exchange of 3.14 tokens (notes and coins) if consumers and merchants can use all denominations. However, this number increases to 4.96 tokens if consumers have only $20 bills at the start of a cash payment. Note that many ATMs dispense only $20 bills. The authors also show that the two numbers drop to 2.73 and 4.55 tokens in a counterfactual economy where the penny coin is eliminated and prices are rounded to their nearest 5 penny value (nickel).

Sumner (1993) and Telser (1995) formulate the problem differently, suggesting that the problem of choosing the optimal spacing of currency and coin denominations is related to the problem of spacing units of standard weight measurements (the problem of Bâchet) to be used on a scale (or two-pan balance) in order to measure the weight of items. For a uniform distribution of transaction values, this approach yields denominations that are powers of 3, such as 1, 3, 9, 27, and so on when overpayments and the return of change are allowed. Shallit (2003) solves a different problem by focusing on denominations of coins that minimize the average number of coins needed to hand out change.

Using the *principle of least effort*, Van Hove and Heyndels (1996) show that, for a uniform distribution of transaction values, the average number of notes and coins exchanged in a transaction is minimized by spacing denominations apart by a factor of two (rather than three), even when allowing for overpayments and the return of change. Van Hove (2001) argues that Bâchet's problem of weights cannot be transposed blindly to the problem of finding optimal currency denominations. The reasons are: (i) Bâchet's problem minimizes the number of standard weights rather than the number of weights used in a typical weighing; and (ii) it is based on the assumption that the set of weights contains only one weight of each size. The author concludes that the problem of finding optimal denominations involves a multicriteria optimization problem in which the principle of least effort should be given the greatest weight. For example, to facilitate computations,

denominations should be compatible with the decimal system. In addition, issuing a large number of denominations is costly and harder to distribute.

Several papers examine the two theories of optimal denominations by comparing the results to denominations in circulation in various countries. Wynne (1997) finds that only five countries have denominations that are either powers or integer multiples of three. Tschoegl (1997) finds that the average ratio of adjacent denominations is 2.6 for coins and 2.62 for notes. Lee (2010) compares a binary-decimal denomination structure (1, 2, 5, 10, 20, 50...) used in Europe and the U.S. to a decimal-pair structure (1, 5, 10, 50...) used in Japan and South Korea. Denominations of medieval coinage systems are described in Sargent and Velde (1999, 2003).

6.2 Currency denominations and the decision to pay cash

Perhaps the most striking observations shown in Figure 6 are the sharp drops in the share of cash used for payment amounts slightly above $5, $10, $15, $20, $25, $30, $35, $40, $45, and $50. These sharp drops are preceded by sharp increases in the share of cash payments in the amounts slightly below these thresholds. The exact percentage increases and drops are displayed in Table 4.

Insert Table 4 about here

The last three columns in Table 4 display the percentage of in-person cash payments (in total of cash, checks, credit cards, debit cards, and prepaid cards payments) in three payment amount intervals around multiples of $5. For example, the row labeled $20 shows that 23.5 percent of all payments in the amounts between $18.01 and $19 are made with cash. This percentage increases to 58.3 percent for payment amounts between $19.01 and $20, and then drops to 22.7 percent for payment amounts between $20.01 and $21.

Using payment diary data from Canada and the U.S., Chen, Huynh, and Shy (2019) and Shy (2020a), respectively, attribute the discontinuities in the share of cash payments to three related features of cash: (i) the burden of having to count, receive, and carry change, in particular change in the form of metal coins; (ii) currency denominations; (iii) ATM currency denominations. For example, a large number of ATMs in the U.S. dispense only multiples of $20 notes. A consumer who pays for a transaction just below $20, say $19.95, will receive one 5¢ coin as change. In

contrast, a consumer who pays for a transaction just above $20, say $20.05, will receive 95¢ change in the form of multiple coins. Thus, the burden of paying cash slightly above $20 is much higher than the burden of paying cash slightly below $20. Paying exactly $20 is the least-costly transaction because it involves no change if the consumer pays with a $20 note.

Theoretical models include Lee, Wallace, and Zhu (2005) who construct a model of random pairwise meetings in which trading parties choose the portfolio of denominations they carry. In their model, there is a tradeoff between the benefits of small denominations and the cost of carrying a large quantity of small denominations. The prices are endogenously determined by offers made by the buyer which may involve a demand for change from the seller. Van Hove (2020) constructs a simple cost-benefit model of consumer payment choice that highlights the differences in net benefit of paying cash for amounts just below multiples of currency denominations and for transaction amounts just above multiples of currency denominations.

6.3 Currency denominations and convenient prices

The literature reviewed so far analyzed how consumers' choice of whether to pay cash is influenced by currency denominations. There is evidence that sellers are also influenced by currency and coin denominations. That is, merchants in some lines of business take into consideration the burden on buyers and sellers caused by having to count and carry change for products and services that they sell for cash. Therefore, some merchants adjust prices to reduce or even eliminate the need for change. For example, during the 1980s local newspapers were sold for 25¢ during weekdays. The use of a single coin (one quarter) has greatly reduced distribution costs by utilizing technologically-unsophisticated newspaper vending machines. Parking meters still use quarters. Parking prices are raised by adjusting the number of quarters consumers need to insert for each hour of parking. The prices of concession items at some sports events and state fairs require little or no change.

Knotek (2008) uses the term *convenient prices* for prices that are set in order to reduce transaction time at the point of sale. He develops a theoretical model where convenience is quantified by the number of currency units in a transaction in order to illustrate behaviors that can arise. Using a quarterly dataset extending from 1904 to 2004, the author finds that weekday newspaper prices

were more convenient than adjacent prices in 61 percent of the quarters. Knotek (2011) identifies four conditions that give merchants stronger incentives to set convenient prices: (i) items are sold for cash; (ii) transaction time matters; (iii) items are either tax exempt, or are quoted inclusive of tax; and (iv) items are sold alone. The last condition is important because sellers cannot set convenient prices if the consumer pays for multiple items, such as in grocery shopping.

Levy and Young (2004) provide evidence for convenient prices by showing that the price of a 6.5-oz Coca-Cola was 5¢ (a nickel) for 73 years (1886 to 1959). This price lasted despite major changes in the soft drink industry as well as two World Wars. The authors note that a single-coin vending machine technology has limited the company's price adjustment options and was also a contributing factor to the prolonged nickel price. Bouhdaoui, Bounie, and François (2014) construct a model to examine the link between convenient prices and the use of cash for payments. The authors test the model with a dataset of payments reported in shopping diaries in 2011 by a representative sample of French consumers. They show that the share of cash payments increases with convenient prices.

7. Cost of using cash and other payment methods

Perhaps the most difficult task facing researchers who analyze payment methods is to quantify the cost of paying with different payment instruments. There are two reasons for that. First, there are several parties involved in each transaction where a payment instrument is used: the payer (say, consumer), the payee (say, merchant), and the issuing and distributing authorities (the federal government and commercial banks). Hence, statements such as "payment instrument X is more costly than payment instrument Y" are not very informative because one may want to ask: "costly for whom?"

Second and more importantly, Hayashi and Keeton (2012) and Shampine (2012) highlight the problem that the profession lacks accounting standards for cost estimations of using different payment methods. Developing such standards would facilitate cost comparisons across time and across countries. In particular, it is very hard to distinguish between fixed and variable costs. For example, should the monthly fees paid by bank account holders be considered as part of con-

sumers' cost of paying with debit cards and cash? The lack of accounting standards for computing costs of using payment instruments explains why cost studies often yield very different cost estimates.

7.1 An overview of cost definitions

Different cost studies often rely on different definitions. Therefore, the following cost definitions should be viewed as an example for the wide variety of costs that may be borne by the parties involved in payment activities. To simplify, consider three payment methods: cash, debit cards, and credit cards, and four agents: (i) consumers, (ii) merchants, (iii) financial institutions and card networks and, (iv) central banks and finance ministries. The following list decomposes the costs according the participating party, fixed costs, transaction-linked variable costs, and value-linked variable costs.

(i) Consumers:

- Cash: Fixed costs include ATM withdrawal fees and travel time. Variable costs (by number or value) include storing and carrying notes and coins (fat wallets), counting change, loss, and theft.
- Debit card: Fixed costs may include part of the fees on maintaining a bank account.
- Credit card: Fixed costs may include annual fees. Value-linked variable costs include interest on unpaid balances and rewards (negative cost).

(ii) Merchants:

- Cash: Fixed costs include travel time to the bank to deposit cash, preparing small change, and security. Transaction-linked variable costs include time spent on receiving and counting cash payments and handing back the exact change.
- Debit card: Fixed costs include acquisition and service of card terminals. Transaction-linked and value-linked variable costs include per-payment card processing fees.
- Credit card: Same as debit cards, but variable costs are significantly higher.

(iii) Financial institutions and card networks:

- Cash: Fixed and variable costs include transport and storage costs, security, ATM maintenance, and teller time.

- Debit card: Fixed costs include issuing cards to bank customers, network administration and fees, and fraud prevention. Value-linked variable costs include loss from fraudulent activities.
- Credit card: Fixed costs are similar to debit cards but apply to different card networks. Value-linked variable costs include rewards to card holders and fraudulent activities.

(iv) Central banks/finance ministries:

- Cash: Fixed costs include production, distribution, and storage of notes and coins, regulation, and anti money laundering supervision.
- Debit card: Fixed costs include regulation, consumer protection, and network supervision.
- Credit card: Same as debit card but apply to different card networks.

In addition to the private costs listed above, some cost studies also estimate overall social or resource cost by payment method. Social cost of each payment method can be defined as the sum of costs borne by all parties. However, as noted in Kosse, Chen, Felt, Jiongo, Nield, and Welte (2017), adding up the private costs borne by all four parties may result in measurement errors because fees paid by one party may be counted as revenue by another party. For example, interchange fees that merchants pay for each card payment they receive are transfers to the card issuing banks and therefore should not be counted as resource cost. In contrast, value of time and cost of maintaining infrastructures are part of the total resource cost.

7.2 Cost studies

I am not aware of recent comprehensive cost studies for the U.S. Older studies include Garcia-Swartz, Hahn, and Layne-Farrar (2006a,b) who conduct cost-benefit analyses of several industries in the U.S. taking into consideration the cost and benefits to merchants, consumers, central banks, and commercial banks. They find grocery stores' marginal cost of receiving a payment in 1998 to be \$0.30–\$0.43 for cash, \$0.44–\$0.47 for verified check, \$0.61–\$1.22 for credit card, \$0.68–\$0.82 for signature debit, and \$0.57 for PIN debit. These marginal costs are computed by adding the cost of theft/counterfeiting, float, tender time, deposit preparation, bank charges, and other costs. The authors calculate consumer marginal costs in 1998 to be \$0.65–\$1.27 for cash, \$0.65 for verified

check, $0.46 for credit card, $0.46 for signature debit, and $0.55 for PIN debit.

Outside the U.S., Humphrey, Willesson, Lindblom, and Bergendahl (2003) analyze the cost of paying with cash and other payment methods in several countries according to bank payment costs, retailer payment costs, and social costs. They find retailer payment cost of a cash payment to be €0.09–€0.15 in Germany (1999), €0.15 in the Netherlands (2002), and $0.12 in the U.S. (2000). At that time, these costs were lower than the cost of debit card payments: €0.87 in Germany, €0.27 in the Netherlands, and $0.34 in the U.S. Van Hove (2004a) provides some cost estimates from the Netherlands that show a reduction in retailers' average per-payment cost of electronic purse (a stored-value payment card) relative to cash.

Note that the payment method that is least costly for society is not necessarily the least costly for retailers, and vice versa. Using 2002 data from the Netherlands, Brits and Winder (2005) find that the overall social cost of the point-of-sale payment system amounted to 0.65 percent of GDP or €0.35 per transaction. The average cost of a cash transaction was €0.30 and that of a debit card transaction was €0.49. They also found that debit card payments were less costly to society than cash payments for amounts of €11.63 or higher. Bergman, Guibourg, and Segendorf (2007) find the social cost of cash payments in Sweden to be lower than the cost of debit card and credit card payments for amounts below €8 and €18, respectively. Segendorf and Jansson (2012) updated the above two thresholds to €1.88 and €42.37, respectively. In the Netherlands, Jonker (2013) finds the average social cost of a cash payment in 2012 to be €0.44 and €0.30 for a debit card payment. In addition, the threshold payment amount under which a cash payment is less costly than a debit card payment has declined from €11.63 in 2002 to €3.06 in 2009. Humphrey (2010) ranks the cost of payments (from low to high) as cash $<$ check $<$ debit card $<$ credit cards for merchants, and credit card $<$ debit card $<$ check $<$ cash for consumers.

Using a Bank of Canada survey of 500 merchants from 2005, Arango and Taylor (2008) estimate the variable cost of a $36.50 payment (the median value of cash transactions in their survey) to be $0.25 for cash compared to $0.19 for a debit card payment and $0.82 for a credit card payment. The authors arrive at the $0.25 figure by adding up $0.051 for tender time, $0.033 for deposit reconciliation time, $0.033 for deposit preparation time, $0.025 for deposit time at the bank, $0.078

cash deposit fee, $0.006 coin ordering, $0.025 for theft and counterfeit risk, and $0.006 for float. However, they find cash to be less costly for merchants than debit cards for payments below $12.60 assuming that merchants pay a 7 cents debit card fee, below $23.40 assuming a 12 cents debit card fee, and below $51.30 assuming a 25 cents debit card fee. In addition, the authors find that most merchants perceive cash as the least costly payment method.

Moving on to more recent cost studies, Krüger and Seitz (2014) compare and analyze cost studies in several countries. Schmiedel, Kostova, and Ruttenberg (2012) analyze cost data from 13 national central banks in Europe (Denmark, Estonia, Ireland, Greece, Spain, Italy, Latvia, Hungary, Netherlands, Portugal, Romania, Finland, and Sweden). They find that, on average, per-transaction social costs are €0.42 (lowest) for cash payments and €0.70 for debit card payments. However, in 5 out of the 13 countries, debit card payments have lower social costs than cash. Using data from Australia, Stewart, Chan, Ossolinski, Halperin, and Ryan (2014) find the resource cost of cash and contactless debit card payments to be similar for transactions below $20.

Álvez, Lluberas, and Ponce (2020) estimate the cost of cash in Uruguay based on the cost of producing notes and coins, cost of transportation and security incurred by the banks and retailers, and the costs incurred by consumers in terms of fees paid and other implicit costs such as liquidity cost, time cost, and costs associated with the risk of holding cash. They find the cost of cash in Uruguay to be 0.61 percent of GDP; of this 77.1 percent is borne by banks and retailers and 21 percent by households.

Using Bank of Canada data from 2014, Kosse, Chen, Felt, Jiongo, Nield, and Welte (2017) find cash to be the most costly in terms of total resources. However, cash is the least costly payment method with respect to variable resource costs for payments up to $6. With respect to retailers' cost, the authors compute $20.13 as the threshold payment value below which cash is the least costly and above it debit cards are the least costly. From consumer perspective, the authors compute a threshold of $77.87 payment amount below which cash is the least costly and above it debit cards are the least costly.

In terms of time to complete a transaction, Klee (2008) uses U.S. grocery store scanner data from 2001 and finds that cash is used for low-value of sales and that cash is the fastest (time-wise)

payment instrument (15 seconds faster than credit card and 10 seconds faster than debit cards). The reason for these differences can be attributed to slow authorization and verification costs of checks, credit cards, and debit cards during 2001. Paying cash with exact change adds on average 8.5 seconds, indicating some asymmetry between tendering coins and receiving coins as change. Schmiedel, Kostova, and Ruttenberg (2012) compute 22 seconds to complete a cash payment, 89 seconds for checks, 29 seconds for debit cards, and 31 seconds for credit cards in 13 European countries. Kosse, Chen, Felt, Jiongo, Nield, and Welte (2017) find the average transaction time to be 11.61 seconds for cash, which is faster than contactless debit and credit card payments (15.70 and 14.43 seconds) and chip and PIN (25.71 and 25.61 seconds). Stewart, Chan, Ossolinski, Halperin, and Ryan (2014) find tender time in Australia for a cash payment to be about 25 seconds, which is faster than card and check payments but slower than contactless card payments.

7.3 Consumer assessments and perceptions of cost and other attributes

Consumer costs of using payment methods tend to vary widely among individuals. For example, the cost of cash is affected by travel distances to ATMs and the value of time of each individual. The cost of paying with credit cards depends on whether the consumer is a borrower or a non-revolver and whether the consumer earns rewards on purchases made with credit cards.

To overcome the lack of good estimates of consumer cost of using cash (and other payment methods), some researchers use consumers' self-reported assessments and perceptions of a variety of attributes of each payment method. For example, Table 5 displays consumer ratings of six payment attributes taken from the 2015–2019 Survey of Consumer Payments Choice which are based on representative samples of the U.S. adult populations, see Foster, Greene, and Stavins (2020).

Insert Table 5 about here

Table 5 shows that consumers rate cash as the best with respect to cost (least costly) and the worst with respect to keeping records and security. Note that consumers' ratings of payment attributes do not change much over the years. Consumer rate cash as less convenient than credit and debit cards but more convenient than checks and prepaid cards. Greene and Stavins (2017) find that

consumers' rating of debit and credit cards relative to cash with respect to security of personal information has decreased after the 2013 data breach at Target stores in the U.S. However, the authors do not find evidence that the Target breach caused any long-term effect on payment behavior.

Outside the U.S., the Methods-of-Payment survey by the Bank of Canada also collects data on consumer assessments (perceptions) of payment methods' attributes, see Henry, Huynh, and Welte (2018). Banegas, Judson, Sims, and Stebunovs (2015) compare consumer perceptions of three cash attributes: acceptance, cost, and ease of use among five countries: Austria, Canada, France, Germany, Netherlands, and the U.S. Using survey data from the Netherlands, Kosse (2013) finds that consumers' payment preferences are strongly influenced by their views on the safety of payment instruments. Consumers who perceive a particular payment instrument to be unsafe use it less often. Using data from the Netherlands, Van der Cruijsen and Plooij (2018) analyze how payment behavior at the point-of-sale is driven by sociodemographic factors and perceived attributes of payment instruments. Van der Cruijsen and Horst (2019) show that socio-psychological factors are important for payment behavior.

8. Can cash be replaced?

Cash in the form of fiat money constitutes an integral part of the payment system and also serves as store of value, see Kahn and Roberds (2009). Noncash users may wonder why cash is still alive (and actually doing well). Moreover, all the predictions made in the past about the "end of cash" turned out to be wrong. Why is that? There are several reasons, mainly on the demand side, such as the direct benefits consumers derive from perfect anonymity, immediate settlement, offline functionality, and easy budgeting. Kahn, McAndrews, and Roberds (2005) show that cash derives value from its use in anonymous exchanges that facilitate certain otherwise infeasible transactions. Privacy means that no information about the buyer is revealed to the seller in the course of a transaction.

The success of introducing a new payment instrument is never guaranteed. Achieving ubiquity is influenced by network effects which make it harder to achieve a critical mass of users.

For example, Amromin, Jankowski, and Porter (2006) describe car drivers' slow adoption of electronic transponders on the Illinois Tollway which aimed at reducing the use of cash toll booths. The slow adoption has led the transportation authority to double the price of cash tolls relative to the I-Pass tolls in order to motivate drivers to subscribe to the new electronic payment method. Crouzet, Gupta, and Mezzanotti (2020) find that the 2016 cash demonetization in India has led to a large persistent increase in the overall use of electronic payment technologies and show how this observation is consistent with a dynamic model with adoption externalities.

There is another issue related to electronic cash which is whether electronic cash could serve as a legal tender in the same way as physical cash. The term "legal tender" may have several legal interpretations as to whether merchants in all lines of business must accept cash. But, for the purpose of this discussion, it is clear that legislative authorities and central banks will be challenged with the need for new legislation that addresses the question whether to require retailers to accept physical cash and whether to grant newly emerging electronic payment methods and digital currencies the same legal tender status as cash, see an earlier discussion in Van Hove (2005).

There are also supply-side constraints that affect consumers who cannot get or do not want to use credit cards and also unbanked and underbanked consumers who do not use debit cards. These consumers continue to rely on cash as their main payment instrument because they do not have ways to transfer money to emerging noncash payment methods.

8.1 The problem of funding

Heavy users of mobile phones may be wondering whether mobile devices could substitute for physical cash. As it turns out, most mobile apps that are available today cannot replace cash because they are merely extensions of existing noncash payment instruments, such as credit cards, debit cards, and bank accounts. Finding an electronic solution that can substitute physical cash is difficult because of one key barrier called *funding* which is also referred to as the problem of *the last mile*, see Shy (2021c). That is, unlike cash, electronic solutions (mobile included) and all debit and credit card transactions must be funded by cash or by moving money in-and-out of bank accounts.

The problem of funding is the main obstacle in trying to induce consumers to switch from paying cash to paying with electronic methods. However, there is one good example of a mobile

phone payment method that managed to overcome the problem of funding faced by unbanked individuals. M-Pesa, launched in 2007 by Safaricom (the largest mobile network operator in Kenya), was extremely successful in providing access to electronic money transfers without relying on the banking sector. The main innovation was not so much on the technology side (which relied on simple text messages) but precisely because it tackled the problem of funding right from the beginning. This was accomplished by contracting with local kiosks all over Kenya that convert cash to mobile money and vice versa without the use of bank accounts.

The problem of funding is not much of a concern in countries where most residents have active bank accounts. Countries where mobile payments replaced a substantial segment of in-person cash payments (China, Norway, and Sweden) have managed to achieve ubiquity by focusing on a small number of mobile applications: Vipps in Norway (http://www.vipps.no), Swish in Sweden (https://www.swish.nu), and WeChat (https://www.wechat.com/en) and Alipay (https://intl.alipay.com) in China. Users of these apps fund their purchases from a linked bank account.

Unlike Norway and Sweden, FDIC (2020) reports that 7.1 million U.S. households (5.4 percent) were unbanked in 2019. Cole and Greene (2017) analyze the demographics of unbanked and underbanked consumers and their ownership (adoption) of the different payment instruments. Similar analyses are conducted in Shy (2020c, 2021a). Table 6 displays the share of U.S. consumers by household income who have both debit and credit cards, no credit cards (but may have debit cards), no debit cards (but may have credit cards), and none (no debit and no credit cards).

Insert Table 6 about here

Table 6 shows that the fraction of consumers who have both debit and credit cards increases with household income (from 35.9 percent in the lowest income group to 82.1 percent in the highest income group). In contrast, the share of unbanked consumers (with no debit or credit cards) declines with household income (from 17.8 percent in the lowest income group to below 1 percent for household incomes above $80,000). This group of U.S. consumers faces the (last mile) funding barrier because most existing electronic payment options must be linked to a bank account or to a debit or credit card.

Baradaran (2015) advocates reenlisting the U.S. Post Office in its historic function of providing

basic bank services. Post offices could mimic the solution used by M-Pesa by providing consumers with access to places that can convert cash to mobile money and mobile money to cash without charging fees.

8.2 Past and present attempts to replace cash

During the late 1990s several cities across the world and some European countries were experimenting with electronic cash cards (also called smart cards or e-purses) that were capable of storing electronic cash on a memory chip embedded into a card. That form of e-cash was designed to facilitate payments and transfers of e-cash from merchants to consumers, consumers to merchants (main use), and even from card to card (using the Mondex card). The cards were designed to preserve the anonymity feature of physical cash (except for loading and unloading the card using ATMs) because payments were transferred directly without having to clear via servers.

The crucial difference between debit cards and e-purses is that the latter work offline because they interact directly with the terminal of the merchant. This feature made it possible to use cheaper terminals and without having to bear telecommunication costs. Unlike credit and debit cards, payments made with electronic cash cards do not involve significant bookkeeping or verification costs in central registries.

Van Hove (2004b) documents the penetration rates and usage of 16 European electronic purses during 1995–2002. Van Hove (2000) analyzes a 15-month experiment of Mondex and Visa Cash cards in Manhattan's Upper West Side that ended in 1998. The author explains the termination of this pilot by lack of growth in consumer and merchant adoption rates. He also compares the New York City experiment to similar experiments conducted by Mondex in Swindon U.K., and by Proton in Louvain and Wavre in Belgium. Santomero and Seater (1996) develop an analytical framework to model diverse consumer payment choice and apply it to the (then) emerging smart-card technology. The authors note that smart (chip-in) cards offer some of the features of demand deposits, such as ease of transfer and acceptability, while avoiding the fixed costs of a checking account. Just like cash, smart cards do not bear interest. Shy and Tarkka (2002) develop a theoretical framework to model the pricing of electronic cash cards and the market domain in which these cards will be used in an environment where debit cards and cash are the competing

payment media. The authors attribute the slow adoption of electronic cash cards to consumers' lack of confidence in the cards' money storage technology.

The U.S. military maintains its own version of electronic cash card called *EagleCash* see, https://fiscal.treasury.gov/eaglecash. The card works both offline and online. The offline feature makes it a good substitute for cash. The online feature of the card works just like a debit card. In 2012, Canada's Royal Mint developed an electronic cash card called *MintChip* which was designed to work both offline and online, see https://en.wikipedia.org/wiki/MintChip. The project was terminated before it reached the market. The *Octopus* card is commonly used in Hong Kong as a cash replacement. The card can be funded by physical cash or a bank account and operates both offline and online, see https://www.octopus.com.hk/en. The success of this card can be attributed to its extensive use in public transport.

Recently, central banks in Canada, China, and Sweden started developing central bank digital currencies (CBDC) that could either substitute or complement the existing government-issued currencies. The literature on CBDC includes Huynh, Molnar, Shcherbakov, and Yu (2020), BIS (2020), BOS (2021), and references therein. Khiaonarong and Humphrey (2019) analyze cash use across countries and conclude that demand for digital currency will be weak in countries where the adoption of cards and mobile phone payments has suppressed the demand for cash. By contrast, demand for digital currency should be stronger in counties where cash use is high due to lack of substitutes.

At the time of writing this review, it is not known whether unbanked consumers will be able to access CBDC in these countries. However, there is one example of CBDC that managed to provide access to unbanked consumers. The Bahamas, with a large number of unbanked inhabitants and tourists, introduced its central bank digital currency to provide unbanked individuals with easy access, see https://www.sanddollar.bs/. Also known as Sand Dollar and B$, it provides nondiscriminatory access to a digital payment system without regard for age, immigration, or residency status. Banked or unbanked individuals can fund their mobile app (e-wallet) or a payment card at authorized financial institutions up to $500 with no identification and $8,000 with proper identification.

A number of research papers investigate the effects of payment innovations, such as newly-introduced mobile and contactless methods, on the use of cash. Both innovations have been viewed (or marketed as) game changers but in reality they had little or no impact on the use of cash mainly because they attracted mostly existing card users rather than cash users. Brown, Hentschel, Mettler, and Stix (2020) find that contactless payments do not exert a causal effect on cash demand and cash use in Switzerland in aggregate, although some effects can be identified for young urban consumers. Chen, Felt, and Huynh (2017) find no significant effect of contactless credit cards on cash use in Canada and only a two percent reduction in cash usage stemming from single-purpose stored value cards. Using panel data over 2010–2017 in Canada, Felt (2020) finds that the use contactless credit cards negatively influences the intensive margin of cash usage but not its extensive margin. Using consumer survey data of U.S. consumers in 2012, Trütsch (2016) finds that mobile payments do not statistically significantly influence consumer use of payment methods at the point-of-sale.

9. Concluding remarks

The purpose of this review article is to introduce the reader to the research economists do on cash and a wide variety of related issues. The data presented in this article show a decline in the use of cash as a payment instrument and increase in the demand for cash holding and hoarding. Despite the decline in the transaction demand for cash, cash is still heavily used as a payment instrument in general, particularly for low-value payments.

Section 8 describes the difficulties in finding an electronic payment method that could replicate all the attributes of cash. Section 8.1 highlights the problem of funding (the problem of the last mile) in which unbanked and underbanked individuals face difficulties in transferring cash in and out of electronic payment instruments. Spaanderman (2020) provides a comprehensive discussion of the future role of cash in the presence of a gradual decline in the use of cash. The author points out that the recent decline in cash use was mainly a result of citizens' own choice; but this raises the question as to whether this decline jeopardises the independence of people who depend on cash and whether the resilience of the payment system would be consequently compromised.

Section 8.2 described several technological innovations that have the potential of replacing cash (at least partially). With a heavy use of mobile payment technologies, China and Sweden are rapidly becoming cashless. Incidentally, both countries are also ahead in experimenting with central bank digital currency (CBDC). Is this a coincidence? Can we infer from these two countries that getting ahead in mobile payments leads to a faster adoption of CBDC and related technologies? Probably not, but this question should be investigated in the future after more countries shift to low use of cash for payment purposes. For now, it is important to observe that some countries with a heavy use of cash have managed to leapfrog other countries with respect to payment technologies. For example, Kenya's population was over 80 percent unbanked when M-Pesa was introduced. Similarly, the Bahamas is probably the first country to provide access to CBDC to people with no bank accounts.

As noted in the introduction, during the late 1990s new forms of e-cash cards were tested and the feeling among researchers at that time was that the need for cash may disappear. This prediction was wrong. The feeling now among researchers is that cash is not going away. Even Sweden, where the use of cash has diminished significantly, does not have plans to remove physical cash from circulation. In fact, quoting from a recent Bank of Sweden report on its e-krona pilot: "An e-krona that is represented by tokens differs to some extend from cash...This means that the e-krona possibly should not be regarded as belonging to the same asset type as cash, but should rather be seen as a new type of means of payment."

Other reasons for why cash will likely remain a payment method include climate change, natural disasters, economic and political instability, and wars in some parts of the world. In all these cases the supply of electricity and transmission of mobile phone signals are not guaranteed. These deficiencies in users' ability to transmit electronic payments may be partly corrected if the industry and governments react and shift some of the transmissions from cables and cell towers to low-orbit satellites that connect directly with mobile phones. But that will take many years of heavy investments.

The continuing decline in the use of cash for payment purposes will likely have an effect on the directions of future research. Questions that are likely to be tackled in future research include:

(i) Can a change in technology have an impact on prices if currency denominations disappear? (ii) Should governments and antitrust authorities regulate fees on electronic payments if they become costly for consumers and merchants? (iii) What should government policy be if cash is hardly used as a payment method but is heavily used as store of value for hoarding purposes? (iv) Will the current literature on the transaction demand for money "survive" the recent introduction of new electronic payment technologies?

References

Agarwal, Sumit, Pulak Ghosh, Jing Li, and Tianyue Ruan (2020). "Digital Payments and Consumption: Evidence from the 2016 Demonetization in India". Available at SSRN No. 3641508.

Allais, Maurice (1947). *Economie et intérêt*. Paris: Imprimerie Nationale.

Alvarez, Fernando and David Argente (2019). "Consumer Surplus of Alternative Payment Methods: Paying Uber with Cash". University of Chicago, Becker Friedman Institute for Economics Working Paper No. 2019-96.

— (2020a). "Cash-Management in Times of Covid-19". University of Chicago Working Paper.

— (2020b). "On the Effects of the Availability of Means of Payments: The Case of Uber". NBER Working Paper no. w28145.

Alvarez, Fernando, David Argente, Rafael Jimenez, and Francesco Lippi (2021). "Cash: A Blessing or a Curse?" University of Chicago working paper.

Alvarez, Fernando and Francesco Lippi (2009). "Financial Innovation and the Transactions Demand for Cash". *Econometrica* 77 (2), pp. 363–402.

— (2017). "Cash Burns: An Inventory Model with a Cash-Credit choice". *Journal of Monetary Economics* 90, pp. 99–112.

Alvarez, Fernando, Francesco Lippi, and Roberto Robatto (2019). "Cost of Inflation in Inventory Theoretical Models". *Review of Economic Dynamics* 32, pp. 206–226.

Álvez, Marcelo, Rodrigo Lluberas, and Jorge Ponce (2020). "The cost of Using Cash and Checks in Uruguay". *Journal of Central Banking Theory and Practice* 9 (2), pp. 109–129.

Amromin, Gene and Sujit Chakravorti (2009). "Whither Loose Change? The Diminishing Demand for Small-Denomination Currency". *Journal of Money, Credit and Banking* 41 (2-3), pp. 315–335.

Amromin, Gene, Carrie Jankowski, and Richard Porter (2006). "Inducing More Efficient Payment on the Illinois Tollway". *Chicago Fed Letter* (225), p. 1.

Arango, Carlos, Dylan Hogg, and Alyssa Lee (2015). "Why is Cash (Still) So Entrenched? Insights from Canadian Shopping Diaries". *Contemporary Economic Policy* 33 (1), pp. 141–158.

Arango, Carlos, Kim Huynh, and Leonard Sabetti (2011). "How Do You Pay? The Role of Incentives at the Point-of-Sale". Bank of Canada, Working Paper No. 2011-23.

— (2015). "Consumer Payment Choice: Merchant Card Acceptance Versus Pricing Incentives". *Journal of Banking and Finance* 55, pp. 130–141.

Arango, Carlos and Nicolás Suárez-Ariza (2020). "Digital Payments Adoption and the Demand for Cash: New International Evidence". *Journal of Payments Strategy and Systems* 14 (4), pp. 392–410.

Arango, Carlos and Varya Taylor (2008). "Merchants' Costs of Accepting Means of Payment: Is Cash the Least Costly?" Bank of Canada Review, Winter.

Arango, Carlos A, Yassine Bouhdaoui, David Bounie, Martina Eschelbach, and Lola Hernández (2018). "Cash Remains Top-of-Wallet! International Evidence from Payment Diaries". *Economic Modelling* 69, pp. 38–48.

Ardizzi, Guerino, Andrea Nobili, and Giorgia Rocco (2020). "A Game Changer in Payment Habits: Evidence from Daily Data During a Pandemic". Bank of Italy, Economic Research and International Relations Area.

Ashworth, Jonathan and Charles Goodhart (2020). "The Surprising Recovery of Currency Usage". *International Journal of Central Banking* 16 (3), pp. 239–277.

Attanasio, Orazio, Luigi Guiso, and Tullio Jappelli (2002). "The Demand for Money, Financial Innovation, and the Welfare Cost of Inflation: An Analysis with Household Data". *Journal of Political Economy* 110 (2), pp. 317–351.

Auer, Raphael, Giulio Cornelli, and Jon Frost (2020). "Covid-19, Cash, and the Future of Payments". Bank of International Settlements Bulletin No. 3.

Bagnall, John, David Bounie, Kim Huynh, Anneke Kosse, Tobias Schmidt, Scott Schuh, and Helmut Stix (2016). "Consumer Cash Usage: A Cross-Country Comparison with Payment Diary Survey Data". *International Journal of Central Banking* 12 (4), pp. 1–61.

Bailey, Martin (1956). "The Welfare Cost of Inflationary Finance". *Journal of Political Economy* 64 (2), pp. 93–110.

Banegas, Ayelen, Ruth Judson, Charles Sims, and Viktors Stebunovs (2015). "International Dollar Flows". Board of Governors of the Federal Reserve System, International Finance Discussion Paper No. 1144.

Bar-Ilan, Avner (1990). "Overdrafts and the Demand for Money". *American Economic Review* 80 (5), pp. 1201–1216.

Baradaran, Mehrsa (2015). *How the Other Half Banks: Exclusion, Exploitation, and the Threat to Democracy*. Harvard University Press.

Barron, John, Michael Staten, and John Umbeck (1992). "Discounts for Cash in Retail Gasoline Marketing". *Contemporary Economic Policy* 10 (4), pp. 89–102.

Bartzsch, Nikolaus, Gerhard Rösl, and Franz Seitz (2013). "Currency Movements Within and Outside a Currency Union: The case of Germany and the Euro Area". *Quarterly Review of Economics and Finance* 53 (4), pp. 393–401.

Baumol, William (1952). "The Transactions Demand for Cash: An Inventory Theoretic Approach". *Quarterly Journal of Economics* 66 (4), pp. 545–556.

Baumol, William and James Tobin (1989). "The Optimal Cash Balance Proposition: Maurice Allais' Priority". *Journal of Economic Literature* 27 (3), pp. 1160–1162.

Bech, Morten, Umar Faruqui, Frederik Ougaard, and Cristina Picillo (2018). "Payments Are A-Changin' But Cash Still Rules". Bank of International Settlements, Quarterly Review, March.

Benati, Luca, Robert Lucas, Juan-Pablo Nicolini, and Warren Weber (2018). "Long-run Money Demand Redux". University of Bern, Department of Economics Discussion Paper no. 18-04.

Bergman, Mats, Gabriela Guibourg, and Bjorn Segendorf (2007). "The Costs of Paying — Private and Social Costs of Cash and Card Payments". Riksbank Research Paper Series No. 212.

Berkovich, Efraim (2009). "Trickle-Up Wealth Transfer: Cross-Subsidization in the Payment Card Market". Working paper, The Hispanic Institute, November.

BIS (2020). "Central Bank Digital Currencies: Foundational Principles and Core Features". Bank of International Settlements.

Boeschoten, Willem (1998). "Cash Management, Payment Patterns and the Demand for Money". *De economist* 146 (1), pp. 117–142.

Boeschoten, Willem and Martin Fase (1992). "The Demand for Large Bank Notes". *Journal of Money, Credit and Banking*, pp. 319–337.

Boeschoten, Willem Cornelis and Martinus Maria Gerardus Fase (1989). "The Way We Pay with Money". *Journal of Business and Economic Statistics* 7 (3), pp. 319–326.

Bolt, Wilko, David Humphrey, and Roland Uittenbogaard (2008). "Transaction Pricing and the Adoption of Electronic Payments: A Cross-Country Comparison". *International Journal of Central Banking* 4 (1), pp. 89–123.

Bolt, Wilko, Nicole Jonker, and Corry van Renselaar (2010). "Incentives at the Counter: An Empirical Analysis of Surcharging Card Payments and Payment Behaviour in the Netherlands". *Journal of Banking and Finance* 34 (8), pp. 1738–1744.

Borzekowski, Ron, Elizabeth Kiser, and Ahmed Shaista (2008). "Consumers' Use of Debit Cards: Patterns, Preferences, and Price Response". *Journal of Money, Credit and Banking* 40 (1), pp. 149–172.

BOS (2021). "E-krona Pilot Phase 1". Bank of Sweden.

Bouhdaoui, Yassine and David Bounie (2012). "Modeling the Share of Cash Payments in the Economy: An Application to France". *International Journal of Central Banking* 8 (4), pp. 175–195.

Bouhdaoui, Yassine, David Bounie, and Abel François (2014). "Convenient Prices, Cash Payments and Price Rigidity". *Economic Modelling* 41, pp. 329–337.

Bouhdaoui, Yassine, David Bounie, and Leo Van Hove (2013). "When Do Plastic Bills Lower the Bill for the Central Bank? A Model and Estimates for the US". *Journal of Policy Modeling* 35 (1), pp. 45–60.

Bounie, David and Abel François (2006). "Cash, Check or Bank Card? The Effects of Transaction Characteristics on the Use of Payment Instruments". Telecom Paris Economics and Social Sciences Working Paper No. ESS-06-05.

— (2008). "Is Baumol's 'Square Root Law' Still Relevant? Evidence from Micro-Level Data". *Applied Financial Economics* 18 (13), pp. 1091–1098.

Bounie, David, Abel François, and Patrick Waelbroeck (2016). "Debit Card and Demand for Cash". *Journal of Banking and Finance* 73, pp. 55–66.

Briglevics, Tamás and Scott Schuh (2014). "U.S. Consumer Demand for Cash in the Era of Low Interest Rates and Electronic Payments". European Central Bank Working Paper Series No. 1660.

— (2020). "This Is"What's in Your Wallet"... and Here's How You Use It". West Virginia University, Working Paper.

Briglevics, Tamás and Oz Shy (2014). "Why Don't Most Merchants Use Price Discounts to Steer Consumer Payment Choice?" *Review of Industrial Organization* 44 (4), pp. 367–392.

Brits, Hans and Winder (2005). "Payments Are No Free Lunch". Netherlands Central Bank, Research Department.

Brock, William (1974). "Money and Growth: The Case of Long Run Perfect Foresight". *International Economic Review*, pp. 750–777.

Brown, Martin, Nicole Hentschel, Hannes Mettler, and Helmut Stix (2020). "Financial Innovation, Payment Choice and Cash Demand–Causal Evidence from the Staggered Introduction of Contactless Debit Cards". University of St. Gallen, Working Papers in Finance No. 2020/2.

Camera, Gabriele (2001). "Dirty Money". *Journal of Monetary Economics* 47 (2), pp. 377–415.

Carlton, Dennis and Alan Frankel (1995). "The Antitrust Economics of Credit Card Networks". *Antitrust Law Journal* 63, pp. 643–668.

Carow, Kenneth A and Michael E Staten (1999). "Debit, Credit, or Cash: Survey Evidence on Gasoline Purchases". *Journal of Economics and Business* 51 (5), pp. 409–421.

Caswell, Ellen, Miranda Hewkin Smith Smith, David Learmonth, and Gareth Pearce (2020). "Consumer Behavior in a Health Crisis: What Happened with Cash?" Bank of England, Quarterly Bulletin 2020 Q4.

Chande, Dinu and Timothy Fisher (2003). "Have a Penny? Need a Penny? Eliminating the One-Cent Coin from Circulation". *Canadian Public Policy* 29 (4), pp. 511–517.

Chen, Heng, Walter Engert, Kim Huynh, Gradon Nicholls, Mitchell Nicholson, and Julia Zhu (2020). "Cash and COVID-19: The Impact of the Pandemic on the Demand for and Use of Cash". Bank of Canada Staff Discussion Paper No. 2020-6.

— (2021). "Cash and COVID-19: The Effects of Lifting Containment Measures on Cash Demand and Use". Bank of Canada Staff Discussion Paper No. 2021-3.

Chen, Heng, Marie-Hélène Felt, and Kim Huynh (2017). "Retail Payment Innovations and Cash Usage: Accounting for Attrition by Using Refreshment Samples". *Journal of the Royal Statistical Society* 180 (2), pp. 503–530.

Chen, Heng, Kim Huynh, and Oz Shy (2019). "Cash Versus Card: Payment Discontinuities and the Burden of Holding Coins". *Journal of Banking and Finance* 99, pp. 192–201.

Ching, Andrew and Fumiko Hayashi (2010). "Payment Card Rewards Programs and Consumer Payment Choice". *Journal of Banking and Finance* 34 (8), pp. 1773–1787.

Chodorow-Reich, Gabriel, Gita Gopinath, Prachi Mishra, and Abhinav Narayanan (2020). "Cash and the Economy: Evidence from India's Demonetization". *The Quarterly Journal of Economics* 135 (1), pp. 57–103.

Cole, Allison and Claire Greene (2017). "Financial Inclusion and Consumer Payment Choice". *Journal of Financial Transformation* 46, pp. 219–235.

Cramer, Jan Salomon (1983). "Currency by Denomination". *Economics Letters* 12 (3-4), pp. 299–303.

Crouzet, Nicolas, Apoorv Gupta, and Filippo Mezzanotti (2020). "Shocks and Technology Adoption: Evidence from Electronic Payment Systems". Northwestern University Working Paper.

Dalton, George (1982). "Barter". *Journal of Economic Issues* 16 (1), pp. 181–190.

Daniels, Kenneth and Neil Murphy (1994). "The Impact of Technological Change on the Currency Behavior of Households: An Empirical Cross-Section Study". *Journal of Money, Credit and Banking* 26 (4), pp. 867–874.

Delaney, Luc, Nina McClure, and Richard Finlay (2020). "Cash Use in Australia: Results from the 2019 Consumer Payments Survey". Reserve Bank of Australia Bulletin, June.

Doyle, Brian (2000). "'Here, Dollars, Dollars...'-Estimating Currency Demand and Worldwide Currency Substitution". Federal Reserve Bank of New York, International Finance Discussion Paper No. 657.

Drazen, Allan (1979). "The Optimal Rate of Inflation Revisited". *Journal of Monetary Economics* 5 (2), pp. 231–248.

Drehmann, Mathias, Charles Goodhart, and Malte Krueger (2002). "The Challenges Facing Currency Usage: Will the Traditional Transaction Medium Be Able to Resist Competition From the New Technologies?" *Economic Policy* 17 (34), pp. 193–228.

ECB (2020). "Study on the Payment Attitudes of Consumers in the Euro Area (SPACE)". European Central Bank, December.

Engert, Walter, Ben Fung, and Björn Segendorf (2019). *A Tale of Two Countries: Cash Demand in Canada and Sweden*. Bank of Canada, Staff Discussion Paper No. 2019-7.

Esselink, Henk and Lola Hernández (2017). "The Use of Cash by Households in the Euro Area". European Central Bank, Occasional Paper No. 201.

FDIC (2020). "How America Banks: Household Use of Banking and Financial Services". Federal Deposit Insurance Corporation.

Feenstra, Robert (1986). "Functional Equivalence Between Liquidity Costs and the Utility of Money". *Journal of Monetary Economics* 17 (2), pp. 271–291.

Feige, Edgar (2012). "New Estimates of US Currency Abroad, the Domestic Money Supply and the Unreported Economy". *Crime, Law and Social Change* 57 (3), pp. 239–263.

Felt, Marie-Hélène (2020). "Losing Contact: The Impact of Contactless Payments on Cash Usage". Bank of Canada Staff Discussion Paper 2020–56.

Felt, Marie-Hélène, Fumiko Hayashi, Joanna Stavins, and Angelika Welte (2021). "Distributional Effects of Payment Card Pricing and Merchant Cost Pass-through in Canada and the United States". Bank of Canada, Staff Working Paper No. 2021-8.

Fenz, Gerhard and Helmut Stix (2021). *Monitoring the Economy in Real time with the Weekly OeNB GDP Indicator: Background, Experience and Outlook*. Austria National Bank, Monetary Policy and The Economy Q4/20–Q1/21.

Finlay, Richard and Anny Francis (2019). "A Brief History of Currency Counterfeiting". Reserve Bank of Australia Bulletin, September.

Finlay, Richard, Andrew Staib, and Max Wakefield (2020). "Where's the Money? An Investigation into the Whereabouts and Uses of Australian Banknotes". *Australian Economic Review* 53 (1), pp. 22–34.

Fischer, Björn, Petra Köhler, and Franz Seitz (2004). "The Demand for Euro Area Currencies: Past, Present and Future". European Central Bank, Working Paper No. 330.

Foster, Kevin and Claire Greene (2021). "Consumer Behavior in a Health Crisis: What Happened with Cash?" Federal Reserve Bank of Atlanta, Policy Hub No. 2021-1.

Foster, Kevin, Claire Greene, and Joanna Stavins (2020). "2019 Survey of Consumer Payment Choice". Federal Reserve Bank of Atlanta, Research Data Report No. 2020-2.

Frankel, Alan (1998). "Monopoly and Competition in the Supply and Exchange of Money". *Antitrust Law Journal* 66 (2), pp. 313–361.

Freeman, Scott and Finn Kydland (2000). "Monetary Aggregates and Output". *American Economic Review* 90 (5), pp. 1125–1135.

Friedman, Milton (1969). *The Optimum Quantity of Money: And Other Essays*. Aldine Transaction.

FRS (1983). "Credit Cards in the U.S. Economy". A study by the Board of Governors of the Federal Reserve System.

Fung, Ben, Kim Huynh, and Leonard Sabetti (2012). "The Impact of Retail Payment Innovations on Cash Usage". Bank of Canada, Working Paper No. 2012-14.

Fung, Ben, Kim Huynh, and Gerald Stuber (2015). "The Use of Cash in Canada". *Bank of Canada Review* 2015 (Spring), pp. 45–56.

Garcia-Swartz, Daniel, Robert Hahn, and Anne Layne-Farrar (2006a). "The Move Toward a Cashless Society: A Closer Look at Payment Instrument Economics". *Review of Network Economics* 5 (2), pp. 175–198.

— (2006b). "The Move Toward a Cashless Society: Calculating the Costs and Benefits". *Review of Network Economics* 5 (2), pp. 199–228.

Goetzmann, William and K Geert Rouwenhorst (2005). *The Origins of Value: The Financial Innovations That Created Modern Capital Markets*. Oxford University Press.

Graeber, David (2012). *Debt: The First 5000 Years*. Penguin.

Greene, Claire, Brian Prescott, and Oz Shy (2022). "How People Pay Each Other: Data, Theory, and Calibrations". *Journal of Behavioral and Experimental Economics* 96.

Greene, Claire and Oz Shy (2019). "How Consumers Get Cash: Evidence from a Diary Survey". Federal Reserve Bank of Atlanta, Research Data Report No. 19-01.

Greene, Claire and Joanna Stavins (2017). "Did the Target Data Breach Change Consumer Assessments of Payment Card Security?" *Journal of Payments Strategy and Systems* 11 (2), pp. 121–133.

Hayashi, Fumiko and William Keeton (2012). "Measuring the Costs of Retail Payment Methods". Federal Reserve Bank of Kansas City, Economic Review, Second Quarter.

Hayashi, Fumiko and Elizabeth Klee (2003). "Technology Adoption and Consumer Payments: Evidence from Survey Data". *Review of Network Economics* 2 (2).

Hendrickson, Joshua and Jaevin Park (2021). "The Case Against Eliminating Large Denomination Bills". *Journal of Macroeconomics* 68.

Henry, Christopher, Kim Huynh, and Angelika Welte (2018). "2017 Methods-of-Payment Survey Report". Bank of Canada Staff Discussion Paper No. 2018-17.

Hernández, Lola, Nicole Jonker, and Anneke Kosse (2017). "Cash versus Debit Card: The Role of Budget Control". *Journal of Consumer Affairs* 51 (1), pp. 91–112.

Hondroyiannis, George and Dimitrios Papaoikonomou (2017). "The Effect of Card Payments on VAT Revenue: New Evidence from Greece". *Economics Letters* 157, pp. 17–20.

Howgego, Christopher (1995). *Ancient History from Coins*. Routledge.

Humphrey, David (2010). "Retail Payments: New Contributions, Empirical Results, and Unanswered Questions". *Journal of Banking and Finance* (8), pp. 1729–1737.

Humphrey, David, Aris Kaloudis, and Grete Øwre (2004). "The Future of Cash: Falling Legal Use and Implications for Government Policy". *Journal of International Financial Markets, Institutions and Money* 14 (3), pp. 221–233.

Humphrey, David, Lawrence Pulley, and Jukka Vesala (1996). "Cash, Paper, and Electronic Payments: A Cross-Country Analysis". *Journal of Money, Credit and Banking* 28 (4), pp. 914–939.

Humphrey, David, Magnus Willesson, Ted Lindblom, and Göran Bergendahl (2003). "What Does it Cost to Make a Payment?" *Review of Network Economics* 2 (2).

Huynh, Kim, Jozef Molnar, Oleksandr Shcherbakov, and Qinghui Yu (2020). "Demand for Payment Services and Consumer Welfare: The Introduction of a Central Bank Digital Currency". Bank of Canada Staff Working Paper 2020-7.

Huynh, Kim, Philipp Schmidt-Dengler, and Helmut Stix (2014). "The Role of Card Acceptance in the Transaction Demand for Money". Bank of Canada, Working Paper No. 2014-44.

Immordino, Giovanni and Francesco Flaviano Russo (2018). "Cashless Payments and Tax Evasion". *European Journal of Political Economy* 55, pp. 36–43.

Ingene, Charles and Michael Levy (1982). "Cash Discounts to Retail Customers: An Alternative to Credit Card Sales". *Journal of Marketing* 46 (2), pp. 92–103.

Ireland, Peter (2009). "On the Welfare Cost of Inflation and the Recent Behavior of Money Demand". *American Economic Review* 99 (3), pp. 1040–52.

Jiang, Janet Hua and Enchuan Shao (2020). "The Cash Paradox". *Review of Economic Dynamics* 36, pp. 177–197.

Jobst, Clemens and Helmut Stix (2017). "Doomed to Disappear? The Surprising Return of Cash Across Time and Across Countries". Center for Economic and Policy Research, Discussion Paper No. DP12327.

Jonker, Nicole (2013). "Social Costs of POS Payments in the Netherlands 2002-2012: Efficiency gains from Increased Debit Card Usage". Netherlands Central Bank, Occasional Studies No. II/2.

Jonker, Nicole, Lola Hernández, Renate de Vree, and Patricia Zwaan (2018). "From Cash to Cards: How Debit Card Payments Overtook Cash in the Netherlands". Netherlands Central Bank, Occasional Studies No. 1.

Jonker, Nicole and Anneke Kosse (2013). "Estimating Cash Usage: The Impact of Survey Design on Research Outcomes". *De Economist* 161 (1), pp. 19–44.

Jonker, Nicole, Carin Van der Cruijsen, Michiel Bijlsma, and Wilko Bolt (2020). "Pandemic Payment Patterns". Netherlands Central Bank, Working Paper No. 701.

Judson, Ruth (2012). "Crisis and Calm: Demand for US Currency at Home and Abroad from the Fall of the Berlin Wall to 2011". FRB International Finance Discussion Paper No. 1058.

Judson, Ruth and Richard Porter (2004). "Currency Demand by Federal Reserve Cash Office: What Do We Know?" *Journal of Economics and Business* 56 (4), pp. 273–285.

Kahn, Charles, José Liñares-Zegarra, and Joanna Stavins (2017). "Are There Social Spillovers in Consumers' Security Assessments of Payment Instruments?" *Journal of Financial Services Research* 52 (1), pp. 5–34.

Kahn, Charles, James McAndrews, and William Roberds (2005). "Money is Privacy". *International Economic Review* 46 (2), pp. 377–399.

Kahn, Charles and William Roberds (2009). "Why Pay? An Introduction to Payments Economics". *Journal of Financial Intermediation* 18 (1), pp. 1–23.

Kalckreuth, Ulf von, Tobias Schmidt, and Helmut Stix (2014). "Using Cash to Monitor Liquidity: Implications for Payments, Currency Demand, and Withdrawal Behavior". *Journal of Money, Credit and Banking* 46 (8), pp. 1753–1786.

Karni, Edi (1973). "The Transactions Demand for Cash: Incorporation of the Value of Time Into the Inventory Approach". *Journal of Political Economy* 81 (5), pp. 1216–1225.

Khiaonarong, Tanai and David Humphrey (2019). "Cash Use Across Countries and the Demand for Central Bank Digital Currency". *Journal of Payments Strategy and Systems* 13 (1), pp. 32–46.

Kim, Laura, Raynil Kumar, and Shaun O'Brien (2020). "2020 Findings from the Diary of Consumer Payment Choice". Federal Reserve Bank of San Francisco, Cash Product Office.

Kiyotaki, Nobuhiro and Randall Wright (1989). "On Money as a Medium of Exchange". *Journal of Political Economy* 97 (4), pp. 927–954.

Klee, Elizabeth (2008). "How People Pay: Evidence from Grocery Store Data". *Journal of Monetary Economics* 55 (3), pp. 526–541.

Knotek, Edward (2008). "Convenient Prices, Currency, and Nominal Rigidity: Theory with Evidence From Newspaper Prices". *Journal of Monetary Economics* 55 (7), pp. 1303–1316.

— (2011). "Convenient Prices and Price Rigidity: Cross-Sectional Evidence". *Review of Economics and Statistics* 93 (3), pp. 1076–1086.

Kosse, Anneke (2013). "The Safety of Cash and Debit Cards: A Study on the Perception and Behavior of Dutch Consumers". *International Journal of Central Banking* 9 (4), pp. 77–98.

Kosse, Anneke, Heng Chen, Marie-Hélène Felt, Valéry Dongmo Jiongo, Kerry Nield, and Angelika Welte (2017). "The Costs of Point-of-Sale Payments in Canada". Bank of Canada Staff Discussion Paper No. 2017–4.

Kosse, Anneke and David-Jan Jansen (2013). "Choosing How to Pay: The Influence of Foreign Backgrounds". *Journal of Banking and Finance* 37 (3), pp. 989–998.

Koulayev, Sergei, Marc Rysman, Scott Schuh, and Joanna Stavins (2016). "Explaining Adoption and Use of Payment Instruments by US Consumers". *The RAND Journal of Economics* 47 (2), pp. 293–325.

Kraenzlin, Sébastien, Christoph Meyer, and Thomas Nellen (2020). "COVID-19 and Regional Shifts in Swiss Retail Payments". *Swiss Journal of Economics and Statistics* 156 (1), pp. 1–20.

Krüger, Malte and Franz Seitz (2014). "Costs and Benefits of Cash and Cashless Payment Instruments: Overview and Initial Estimates". Study commissioned by the Deutsche Bundesbank.

Lahiri, Amartya (2020). "The Great Indian Demonetization". *Journal of Economic Perspectives* 34 (1), pp. 55–74.

Lalouette, Laure, Alejandro Zamora-Pérez, Codruta Rusu, Nikolaus Bartzsch, Emmanuelle Politronacci, Martial Delmas, António Rua, Marco Brandi, and Martti Naksi (2021). "Foreign Demand for Euro Banknotes". European Central Bank, Occasional Paper Series No. 253.

Lambert, Michael and Kristin Stanton (2001). "Opportunities and Challenges of the US Dollar as an Increasingly Global Currency: A Federal Reserve Perspective". Federal Reserve Bulletin, September, 567-575.

Lee, Manjong (2010). "Carrying Cost of Money and Real Effects of Denomination Structure". *Journal of Macroeconomics* 32, pp. 326–337.

Lee, Manjong, Neil Wallace, and Tao Zhu (2005). "Modeling Denomination Structures". *Econometrica* 73 (3), pp. 949–960.

Levy, Daniel and Andrew Young (2004). ""The Real Thing": Nominal Price Rigidity of the Nickel Coke, 1886–1959". *Journal of Money, Credit and Banking*, pp. 765–799.

Lippi, Francesco and Alessandro Secchi (2009). "Technological Change and the Households' Demand for Currency". *Journal of Monetary Economics* 56 (2), pp. 222–230.

Lucas, Robert (2000). "Inflation and Welfare". *Econometrica* 68 (2), p. 247.

Lucas, Robert and Juan-Pablo Nicolini (2015). "On the Stability of Money Demand". *Journal of Monetary Economics* 73, pp. 48–65.

Lucas, Robert and Nancy Stokey (1987). "Money and Interest in a Cash-In-Advance Economy". *Econometrica* 55 (3), p. 491.

Magnac, Thierry (2017). "ATM Foreign Fees and Cash Withdrawals". *Journal of Banking and Finance* 78, pp. 117–129.

Mariotto, Carlotta and Marianne Verdier (2017). "Who Pays for Card Payments? A General Model on the Role of Interchange Fees". *Review of Network Economics* 16 (3), pp. 307–349.

McAndrews, James (2017). "The Case for Cash". ADBI Working Paper No. 679.

McCallum, Bennett and Marvin Goodfriend (1987). "Money: Theoretical Analysis of the Demand for Money". NBER Working Paper No. w2157.

Milbourne, Ross (1983). "Optimal Money Holding under Uncertainty". *International Economic Review*, pp. 685–698.

Milbourne, Ross, P Buckholtz, and MT Wasan (1983). "A Theoretical Derivation of the Functional Form of Short Run Money Holdings". *The Review of Economic Studies* 50 (3), pp. 531–541.

Miller, Merton and Daniel Orr (1966). "A Model of the Demand for Money by Firms". *Quarterly journal of economics* 80 (3), pp. 413–435.

Mooslechner, Peter, Helmut Stix, and Karin Wagner (2006). "How Are Payments Made in Austria? Results of a Survey on the Structure of Austrian Households' Use of Payment Means in the Context of Monetary Policy Analysis". *Monetary Policy & the Economy Q* 2, pp. 111–134.

Mot, Esther and J.S. Cramer (1992). "Mode of Payment in Household Expenditures". *De Economist* 140 (4), pp. 488–500.

Mulligan, Casey and Xavier Sala-i-Martin (2000). "Extensive Margins and the Demand for Money at Low Interest Rates". *Journal of Political Economy* 108 (5), pp. 961–991.

Norges Bank (2020). "Retail Payment Services 2019". Norges Bank Papers No. 1/2020.

Otani, Akira and Takashi Suzuki (2008). "Background to the High Level of Banknotes in Circulation and Demand Deposits". Bank of Japan Review No. 2008-E-5.

Paroush, Jacob and David Ruthenberg (1986). "Automated Teller Machines and the Share of Demand Deposits in the Money Supply: the Israeli Experience". *European Economic Review* 30 (6), pp. 1207–1215.

Porter, Richard and Ruth Judson (1996). "The Location of US Currency: How Much is Abroad". *Federal Reserve Bulletin.* 82, p. 883.

Prescott, Brian and Oz Shy (2021). "The Burden of Change and the Penny Policy Debate". Available at SSRN 3822693.

Prescott, Edward (1987). "A Multiple Means-of-Payment Model". *New Approaches to Monetary Economics: Proceedings of the Second International Symposium in Economic Theory and Econometrics*. Ed. by William Barnett and Kenneth Singleton. Cambridge University Press, pp. 42–51.

Rainone, Edoardo and Massimo Valentini (2020). "Tax Evasion Policies and the Demand for Cash". ResearchGate Publication No. 337085187.

Rhodes, Karl (2012). "The Counterfeiting Weapon". Federal Reserve Bank of Richmond, Region Focus, First Quarter.

Rogoff, Kenneth (1998). "Blessing Or Curse? Foreign and Underground Demand for Euro Notes". *Economic Policy* 13 (26), pp. 262–303.

— (2016). *The Curse of Cash*. Princeton University Press.

Romer, David (1986). "A Simple General Equilibrium Version of the Baumol-Tobin Model". *Quarterly Journal of Economics* 101 (4), pp. 663–685.

Rösl, Gerhard and Franz Seitz (2021). "Cash and Crises: No Surprises by the Virus". Goethe University Frankfurt, Institute for Monetary and Financial Stability, Working Paper No. 150.

Rua, António (2020). "Modelling Currency Demand: The Case of the Euro". *Empirical Economics*, pp. 1–17.

Santomero, Anthony (1974). "A Model of the Demand for Money by Households". *Journal of Finance* 29 (1), pp. 89–102.

Santomero, Anthony (1979). "The Role of Transaction Costs and Rates of Return on the Demand Deposit Decision". *Journal of Monetary Economics* 5 (3), pp. 343–364.

Santomero, Anthony and John Seater (1996). "Alternative Monies and the Demand for Media of Exchange". *Journal of Money, Credit and Banking* 28 (4), pp. 942–960.

Sargent, Thomas and François Velde (1999). "The Big Problem of Small Change". *Journal of Money, Credit, and Banking*, pp. 137–161.

— (2003). *The Big Problem of Small Change*. Princeton University Press.

Schmidt, Tobias (2014). "Consumers' Recording Behaviour in Payment Diaries–Empirical Evidence from Germany". *Survey Methods: Insights from the Field*.

Schmiedel, Heiko, Gergana Kostova, and Wiebe Ruttenberg (2012). "The Social and Private Costs of Retail Payment Instruments: A European Perspective". ECB Occasional Paper No. 137.

Schuh, Scott, Oz Shy, and Joanna Stavins (2010). "Who Gains and Who Loses from Credit Card Payments? Theory and Calibrations". Federal Reserve Bank of Boston, Public Policy Discussion Paper No. 10-03.

Segendorf, Björn and Thomas Jansson (2012). "The Cost of Consumer Payments in Sweden". Bank of Sweden Working Paper No. 262.

Seitz, Franz (1995). "The Circulation of Deutsche Mark Abroad". Discussion Paper, Economic Research Group of the Deutsche Bundesbank, Discussion Paper No. 1/95.

Shallit, Jeffrey (2003). "What This Country Needs is an 18¢ Piece". *The Mathematical Intelligencer* 25 (2), pp. 20–23.

Shampine, Allan (2012). "An Evaluation of the Social Costs of Payment Methods Literature". Available at SSRN 1984248.

Shirai, Sayuri and Eric Alexander Sugandi (2019). "What Explains the Growing Global Demand for Cash?" Asian Development Bank Institute, Working Paper Series No. 1006.

Shy, Oz (2020a). "How Currency Denomination and the ATM Affect the Way We Pay". *Journal of Economics and Business* 111.

— (2020b). "How Merchants Get Paid". Available at SSRN No. 3618759.

— (2020c). "Low-Income Consumers and Payment Choice". *Research in Economics* 74 (4), pp. 292–300.

— (2021a). "Cashless Stores and Cash Users". *Journal of Policy Modeling* 43 (3), pp. 622–638.

Shy, Oz (2021b). "Consumer Use of Multiple Payment Methods". *Review of Industrial Organization* 58 (3), pp. 339–355.

— (2021c). "Digital Currency, Digital Payments, and the 'Last Mile' to the Unbanked". Federal Reserve Bank of Atlanta, Policy Hub Paper No. 9-2021.

Shy, Oz and Juha Tarkka (2002). "The Market for Electronic Cash Cards". *Journal of Money, Credit and Banking*, pp. 299–314.

Sidrauski, Miguel (1967). "Rational Choice and Patterns of Growth in a Monetary Economy". *American Economic Review* 57 (2), pp. 534–544.

Simon, John, Kylie Smith, and Tim West (2010). "Price Incentives and Consumer Payment Behaviour". *Journal of Banking and Finance* 34 (8), pp. 1759–1772.

Snellman, Jussi, Jukka Vesala, and David Humphrey (2001). "Substitution of Noncash Payment Instruments for Cash in Europe". *Journal of Financial Services Research* 19 (2), pp. 131–145.

Spaanderman, Jurgen (2020). "The Role and Future of Cash". Netherlands Central Bank, Occasional Studies No. 18–2.

Sprenkle, Case (1993). "The Case of the Missing Currency". *Journal of Economic Perspectives* 7 (4), pp. 175–184.

Stavins, Joanna (2001). "Effect of Consumer Characteristics on the Use of Payment Instruments". *New England Economic Review* 3.

— (2016). "The Effect of Demographics on Payment Behavior: Panel Data with Sample Selection". Federal Reserve Bank of Boston, Working Paper No. 16-5.

— (2018). "Consumer Preferences for Payment Methods: Role of Discounts and Surcharges". *Journal of Banking and Finance* 94, pp. 35–53.

Stavins, Joanna and Oz Shy (2015). "Merchant Steering of Consumer Payment Choice: Evidence from a 2012 Diary Survey". *Journal of Behavioral and Experimental Economics* 55, pp. 1–9.

Stewart, Chris, Iris Chan, Crystal Ossolinski, David Halperin, and Paul Ryan (2014). "The Evolution of Payment Costs in Australia". Reserve Bank of Australia, Research Discussion Paper No. 2014-14.

Stix, Helmut (2004). "How Do Debit Cards Affect Cash Demand? Survey Data Evidence". *Empirica* 31 (2-3), pp. 93–115.

— (2013). "Why Do People Save in Cash? Distrust, Memories of Banking Crises, Weak Institutions and Dollarization". *Journal of Banking and Finance* 37 (11), pp. 4087–4106.

Stokey, Nancy (2019). "Means of Payment". University of Chicago Working Paper.

Sumner, Scott (1990). "The Transactions and Hoarding Demand for Currency". *Quarterly Review of Economics and Business* 30 (1), pp. 75–90.

— (1993). "Privatizing the Mint". *Journal of Money, Credit and Banking* 25 (1), pp. 13–29.

Telser, Lester (1995). "Optimal Denominations for Coins and Currency". *Economics Letters* 49 (4), pp. 425–427.

Tobin, James (1956). "The Interest-Elasticity of Transactions Demand for Cash". *Review of Economics and Statistics* 38 (3), pp. 241–247.

Trütsch, Tobias (2016). "The Impact of Mobile Payment on Payment Choice". *Financial Markets and Portfolio Management* 30 (3), pp. 299–336.

Tschoegl, Adrian (1997). "The Optimal Denomination of Currency". *Journal of Money, Credit and Banking* 29 (4), pp. 546–554.

Van der Cruijsen, Carin, Lola Hernández, and Nicole Jonker (2017). "In Love With the Debit Card But Still Married to Cash". *Applied Economics* 49 (30), pp. 2989–3004.

Van der Cruijsen, Carin and Frank van der Horst (2019). "Cash or Card? Unravelling the Role of Socio-Psychological factors". *De Economist* 167 (2), pp. 145–175.

Van der Cruijsen, Carin and Joris Knoben (2020). "Ctrl+ C Ctrl+ Pay: Do People Mirror Electronic Payment Behavior of their Peers?" *Journal of Financial Services Research*, pp. 1–28.

Van der Cruijsen, Carin and Mirjam Plooij (2018). "Drivers of Payment Patterns at the Point of Sale: Stable or Not?" *Contemporary Economic Policy* 36 (2), pp. 363–380.

Van Hove, Leo (2000). "The New York City Smart Card Trial in Perspective: A Research Note". *International Journal of Electronic Commerce* 5 (2), pp. 119–131.

— (2001). "Optimal Denominations for Coins and Bank Notes: In Defense of the Principle of Least Effort". *Journal of Money, Credit and Banking* 33 (4), pp. 1015–1021.

— (2004a). "Cost-Based Pricing of Payment Instruments: The State of the Debate". *De Economist* 152 (1), pp. 79–100.

— (2004b). "Electronic purses in Euroland: Why Do Penetration and Usage Rates Differ?" *SUERF studies* (2004/4).

— (2005). *Making Electronic Money Legal Tender: Pros & Cons*. Free University of Brussels, Unpublished.

— (2020). "How Currency Denomination and the ATM Affect the Way We Pay: A Comment on Shy". *Journal of Economics and Business* 111.

Van Hove, Leo and Bruno Heyndels (1996). "On the Optimal Spacing of Currency Denominations". *European Journal of Operational Research* 90 (3), pp. 547–552.

Velde, Francois (1998). "Lessons From the History of Money". Federal Reserve Bank of Chicago, Economic Perspectives, March.

Wakamori, Naoki and Angelika Welte (2017). "Why Do Shoppers Use Cash? Evidence from Shopping Diary Data". *Journal of Money, Credit and Banking* 49 (1), pp. 115–169. ISSN: 1538-4616.

Wallace, Neil (2018). "The Case for Imposing Cashlessness: A Review Article". *Journal of Economic Literature* 56 (4), pp. 1587–91.

Wallace, Neil and Tao Zhu (2004). "A Commodity-Money Refinement in Matching Models". *Journal of Economic Theory* 117 (2), pp. 246–258.

Wang, Liang, Randall Wright, and Lucy-Qian Liu (2017). "Money and Credit: Theory and Applications". IMF Working Paper no. 17/14.

Wang, Zhu and Alexander Wolman (2016). "Payment Choice and Currency Use: Insights from Two Billion Retail Transactions". *Journal of Monetary Economics* 84, pp. 94–115.

Welte, Angelika (2016). "Wait a Minute: The Efficacy of Discounting versus Non-Pecuniary Payment Steering". Bank of Canada, Staff Working Paper No. 2016-8.

Whaples, Robert (2007). "Time to Eliminate the Penny from the US Coinage System: New Evidence". *Eastern Economic Journal* 33 (1), pp. 139–146.

Whitesell, William (1989). "The Demand for Currency Versus Debitable Accounts: Note". *Journal of Money, Credit and Banking* 21 (2), pp. 246–251.

Wisniewski, Tomasz, Michal Polasik, Radoslaw Kotkowski, and Andrea Moro (2021). "Switching from Cash to Cashless Payments during the COVID-19 Pandemic and Beyond". Available at SSRN 3794790.

Wright, Richard, Erdal Tekin, Volkan Topalli, Chandler McClellan, Timothy Dickinson, and Richard Rosenfeld (2017). "Less Cash, Less Crime: Evidence from the Electronic Benefit Transfer Program". *Journal of Law and Economics* 60 (2), pp. 361–383.

Wynne, Mark (1997). "More on Optimal Denominations for Coins and Currency". *Economics Letters* 55 (2), pp. 221–225.

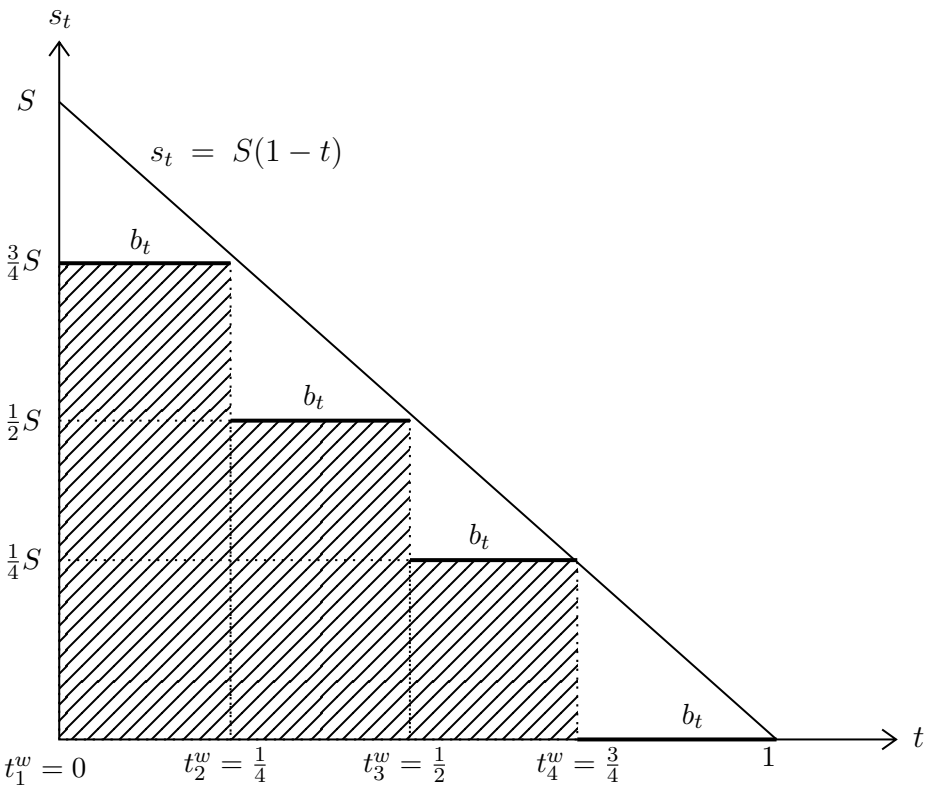

Figure 1: Allocation of money between interest-bearing assets and cash holding.

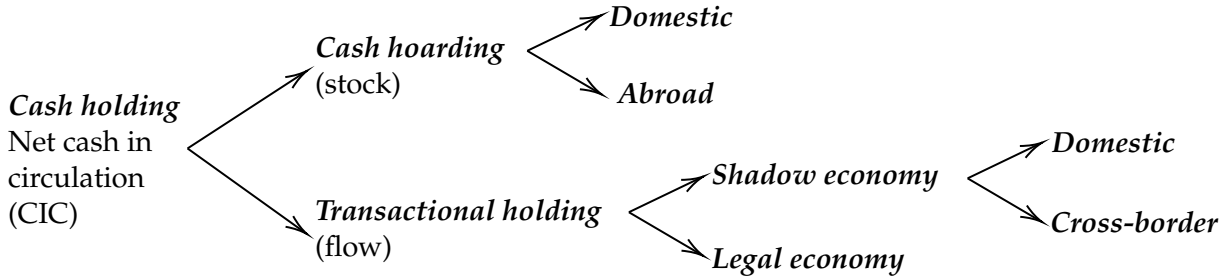

Figure 2: Classifications of cash holding.

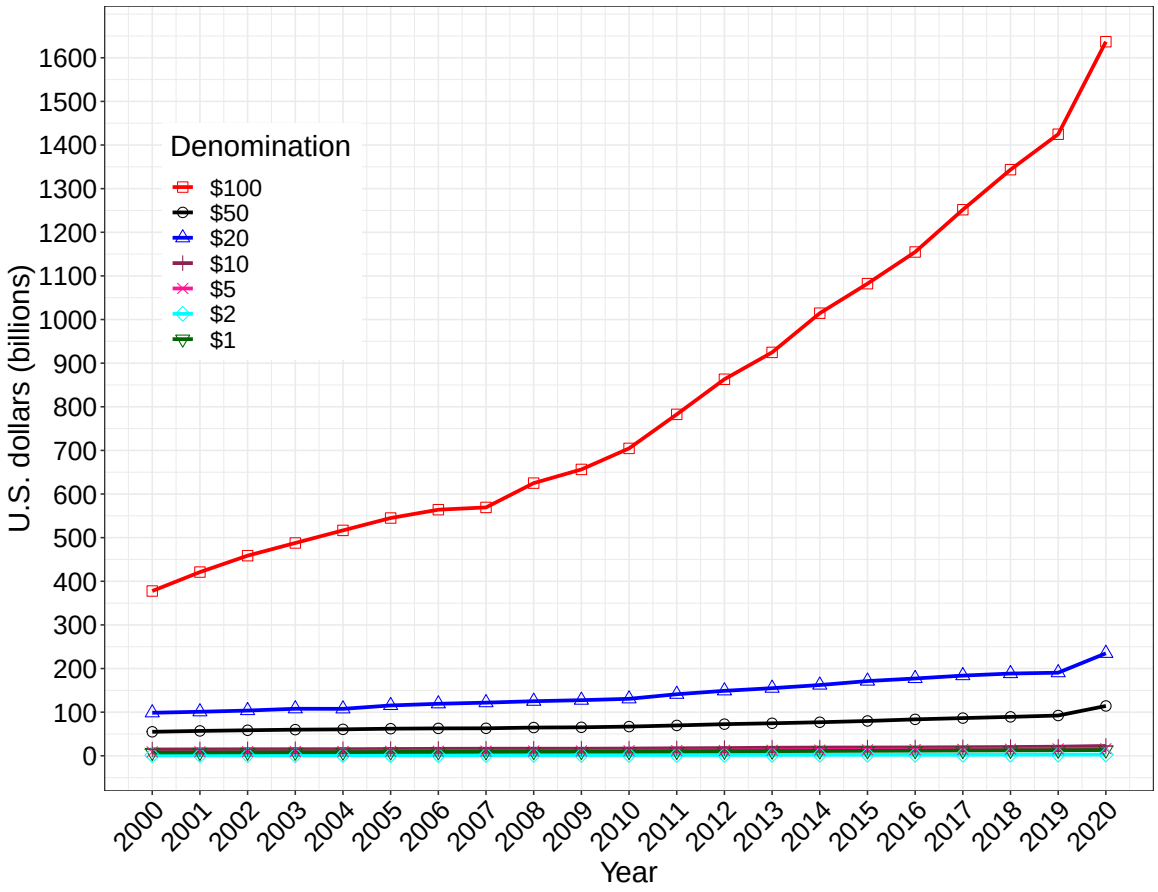

Figure 3: Value of U.S. currency in circulation by denomination (billions of dollars).

Source: Federal Reserve, https://www.federalreserve.gov/paymentsystems/coin_data.htm#value.

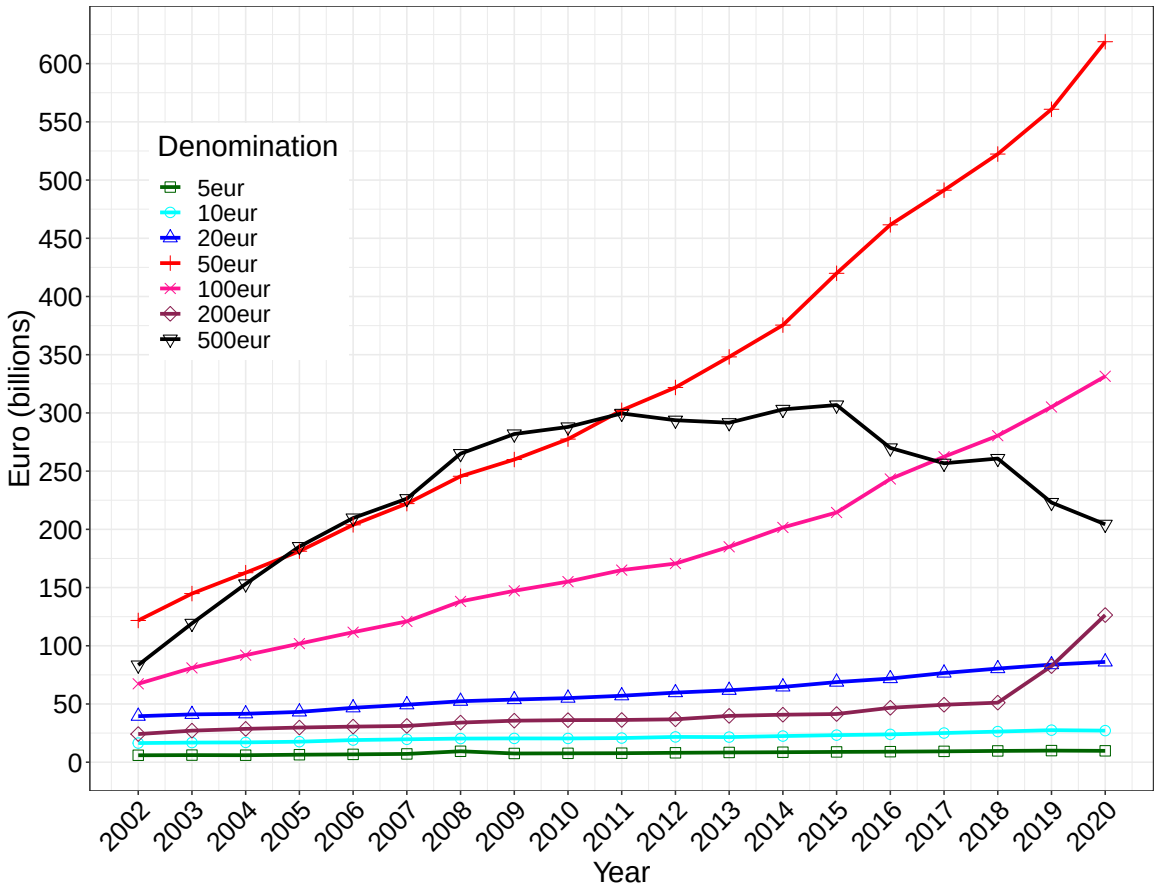

Figure 4: Value of euro currency in circulation by denomination (billions of euro).

Source: European Central Bank, https://sdw.ecb.europa.eu/reports.do?node=1000004105.

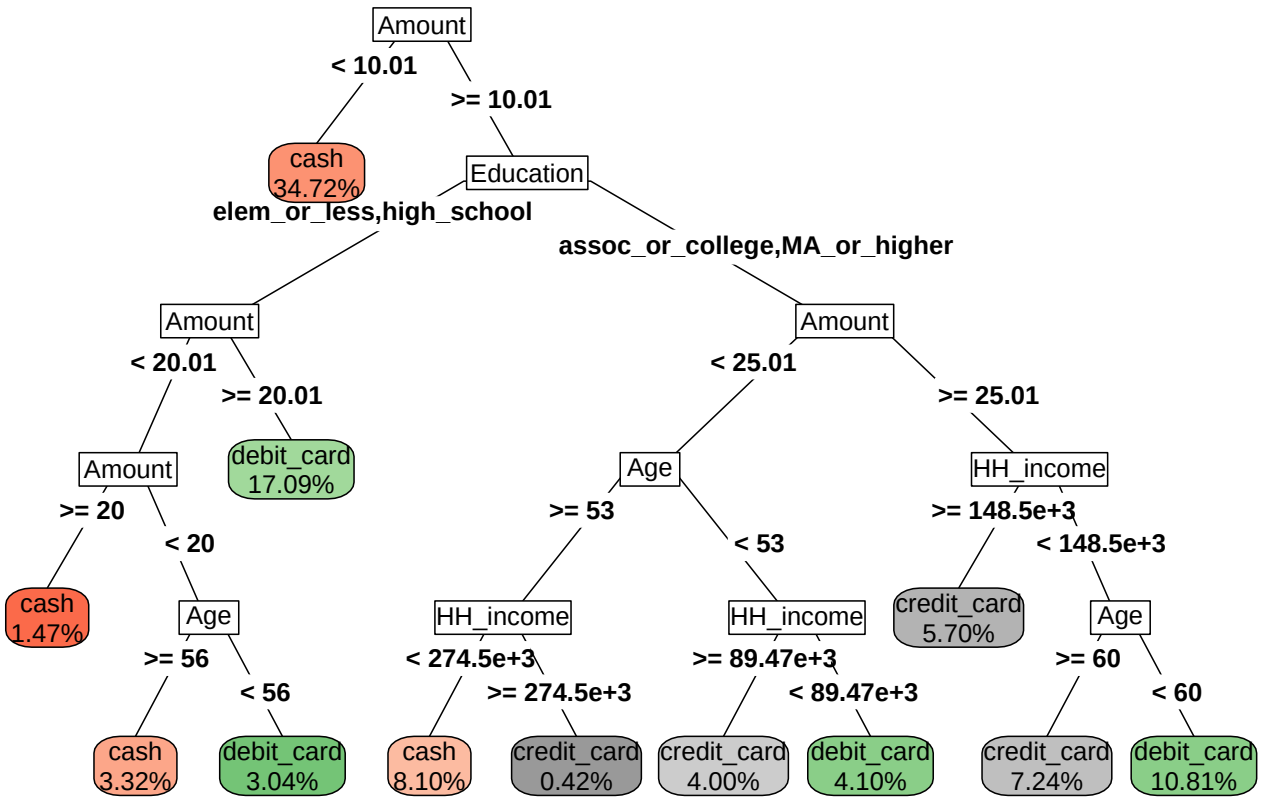

Figure 5: Machine learning payment method classification tree: Predicting the use of in-person payment methods based on payment dollar amount and consumer demographic variables.

Notes: The tree is based on 25,756 payment observations made by 3307 respondents in the U.S. Because of their low use, check and prepaid card payments are not predicted by this tree. See Footnote 2 for a technical explanation for why the left-most branch displays $\geq \$20$ instead of $= \$20$.

Source: Author's computations from the 2017, 2018, and 2019 Diary of Consumer Payment Choice, publicly available at https://www.frbatlanta.org/banking-and-payments/consumer-payments.aspx.

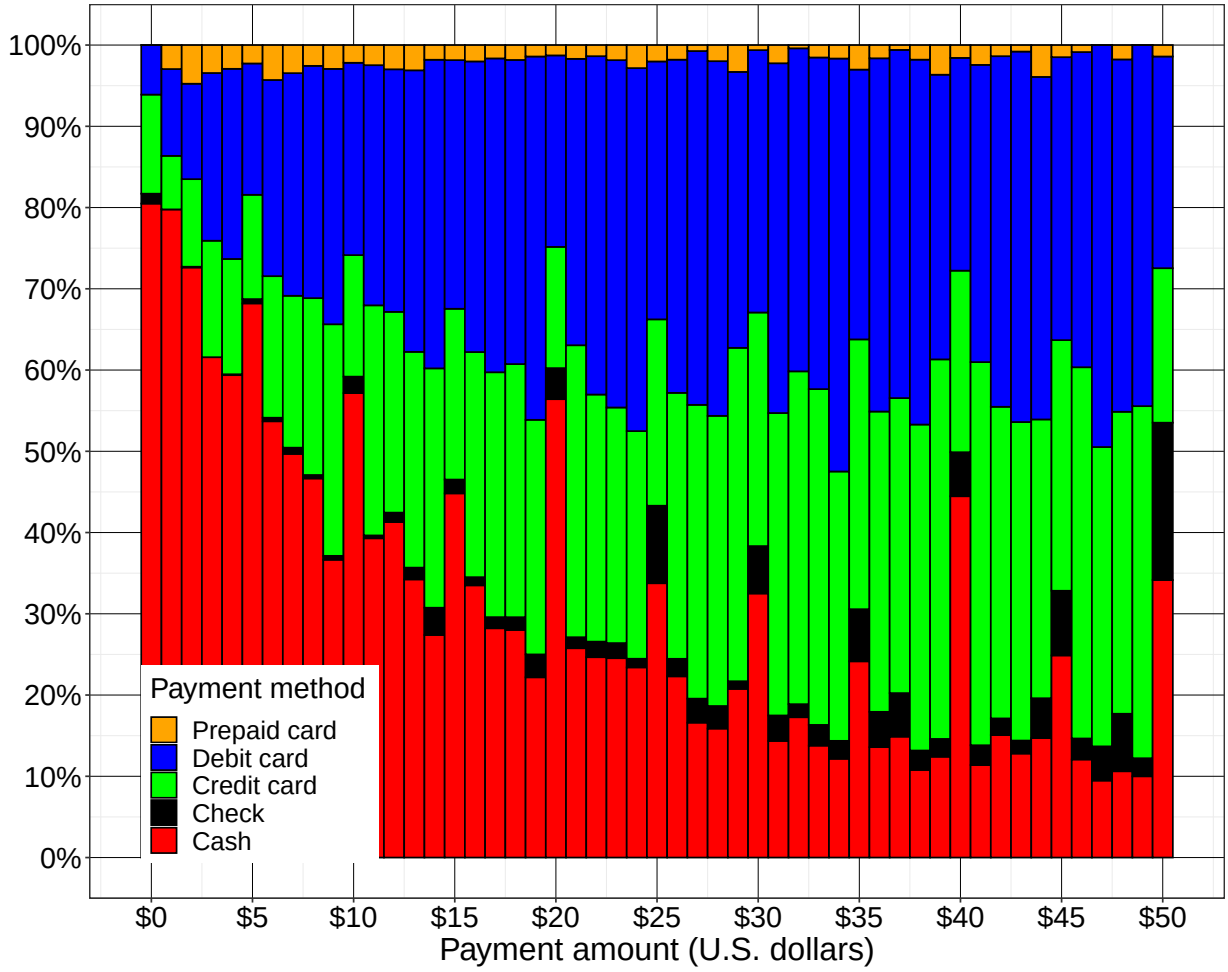

Figure 6: U.S. shares of cash, check, credit, debit, and prepaid card payments made in-person.

Note: The chart displays 21,444 in-person payments ($0 to $50) made with cash, checks, credit cards, debit cards, and prepaid cards by 3237 U.S. adult survey respondents.

Source: Author's computations from the 2017, 2018, and 2019 Diary of Consumer Payment Choice, publicly available at https://www.frbatlanta.org/banking-and-payments/consumer-payments.aspx.

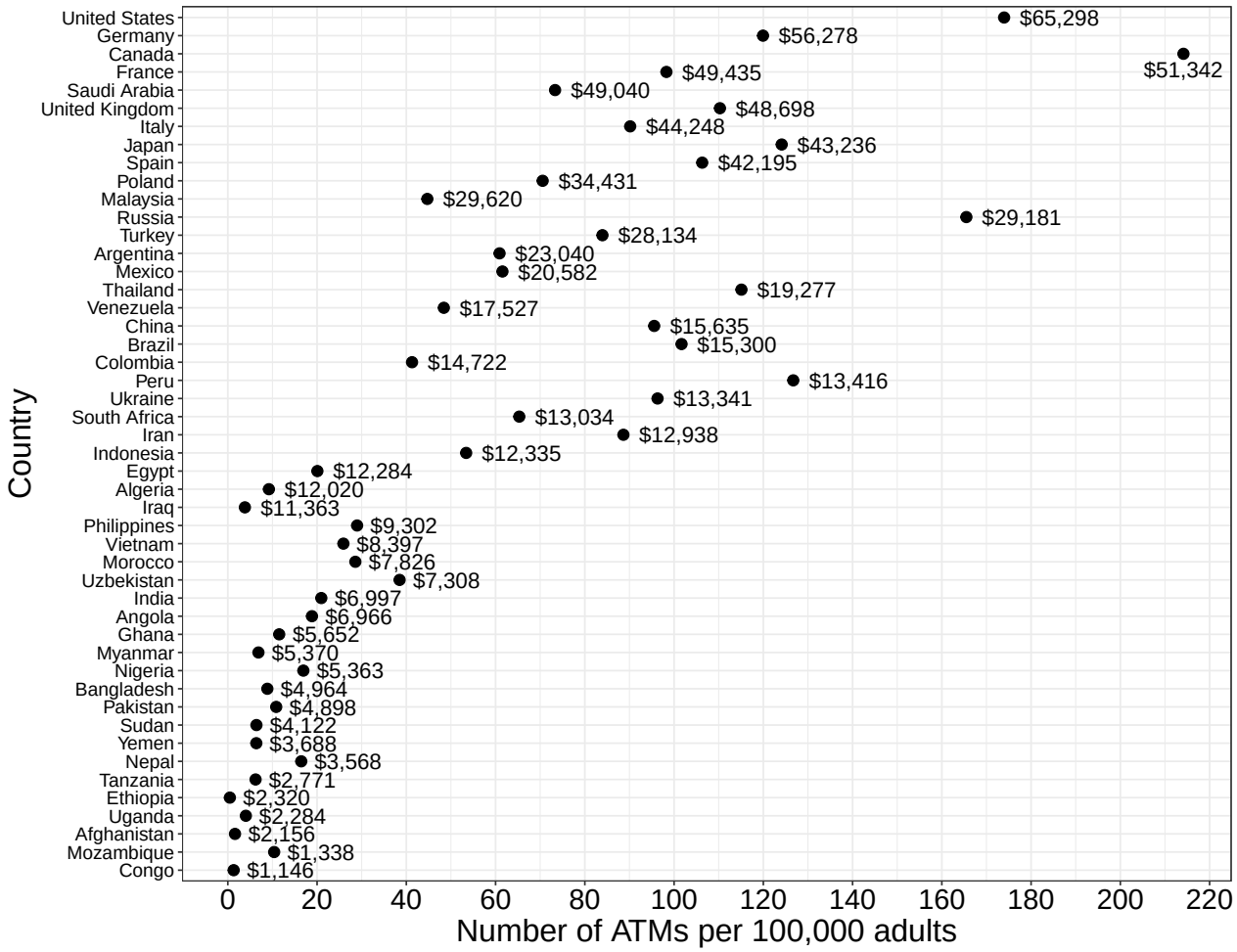

Figure 7: Number of ATMs per 100,000 adults in the 48 most populous countries.

Source: The World Bank: https://data.worldbank.org/indicator/FB.ATM.TOTL.P5 and https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD.

Notes: Data apply mostly to 2018 or 2019, or to the last reported year for some countries. The dollar values displayed in Figure 7 are the countries' per-capita GDP adjusted for purchasing power parity in current U.S. dollars.

Country	CIC/GDP	CAGR CIC/GDP	CIC/M1	CAGR CIC/M1
Japan	21.3	2.1	14.2	-2.0
Hong Kong SAR	18.5	3.2	34.6	0.8
Switzerland	12.1	2.8	13.0	1.0
India	12.0	0.1	66.4	0.3
Euro area	11.1	2.2	14.8	-2.9
Singapore	10.3	3.9	26.7	3.7
Russia	9.6	-2.3	44.5	-3.2
China	8.3	-4.2	14.4	-4.3
United States	8.3	2.3	44.7	-0.6
Saudi Arabia	7.3	4.1	17.0	-0.2
Mexico	7.1	4.5	37.0	-0.0
Korea	6.6	8.2	13.2	1.9
Indonesia	5.0	-0.3	50.7	-0.4
Argentina	4.6	-8.1	59.1	-0.1
Australia	4.4	1.0	8.2	-5.7
Canada	4.3	1.8	9.0	-2.2
Brazil	3.9	0.0	62.7	1.6
Turkey	3.6	-1.1	21.8	-6.3
United Kingdom	3.4	-0.4	4.1	-1.3
South Africa	3.3	-0.4	9.0	-2.6
Sweden	1.3	-9.4	2.0	-13.9
Norway	1.3	-4.5	1.8	-15.8

Table 1: Value of currency in circulation (CIC) divided by GDP and by M1 in 22 countries in 2019.

Notes: All values are in percent (%). The CAGR columns are compound annual growth rates computed from 2012 to 2019.

Source: Bank of International Settlements: https://stats.bis.org/statx/toc/CPMI.html and Norges Bank (2020).

Country	Denominations								
Argentina (ARS, notes)	2	5	10	20	50	100	200	500	1000
Argentina (ARS, coins)	0.01	0.05	0.10	0.25	0.50	1	2	5	10
Canada (CAD, notes)	5	10	20	50	100				
Canada (CAD, coins)	0.05	0.10	0.25	1	2				
Euro area (EUR, notes)	5	10	20	50	100	200			
Euro area (EUR, coins)	0.01	0.02	0.05	0.10	0.20	0.50	1	2	
India (INR, notes)	5	10	20	50	100	200	500	2000	
India (INR, coins)	0.10	0.20	0.25	0.50	1	2	5		
Japan (JPY, notes)	1000	2000	5000	10000					
Japan (JPY, coins)	1	5	10	50	100	500			
Mexico (MXN, notes)	20	50	100	200	500	1000			
Mexico (MXN, coins)	0.05	0.10	0.20	0.50	1	2	5	10	20
U.S. (USD, notes)	1	2	5	10	20	50	100		
U.S. (USD, coins)	0.01	0.05	0.10	0.25	0.50	1			

Table 2: Currency denominations of coins and notes in circulation in selected countries.

Notes: The table displays notes and coins in circulation. Some of these notes and coins are rarely used (for example, the $2 note and $1 coin in the U.S. and low-denomination notes and coins in Argentina).

Source: Central Banks of Argentina, Canada, European Central Bank, India, Japan, Mexico, and usa.gov.

CIC	($1, $2)	($1, $3)	($1, $4)	($1, $5)	($1, $6)	($1, $7)	($1, $8)	($1, $9)	($1, $10)
Price (p)	$N(p)$	$N(p)$	$N(p)$	$N(p)$	$N(p)$	$N(p)$	$N(p)$	$N(p)$	$N(p)$
$1	1	1	1	1	1	1	1	1	1
$2	1	2	2	2	2	2	2	2	2
$3	2	1	2	3	3	3	3	3	3
$4	2	2	1	2	3	4	4	4	4
$5	3	3	2	1	2	3	4	5	5
$6	3	2	3	2	1	2	3	4	5
$7	4	3	3	3	2	1	2	3	4
$8	4	4	2	4	3	2	1	2	3
$9	5	3	3	3	4	3	2	1	2
$10	5	4	4	2	4	4	3	2	1
Total # tokens	30	25	23	23	25	25	25	27	30

Table 3: Optimal currency denominations.

Notes: CIC refers to currency in circulation (two available denominations). $N(p)$ is the minimum number of currency notes needed to be exchanged in order to complete a transaction of p dollars, see equation (7). Total # tokens is computed under a hypothetical assumption that the consumer must pay for all ten transactions $p = \$1, \ldots, \$10$.

	Payment amount intervals		
Amount (A)	$(A - \$2, A - \$1]$	$(A - \$1, A]$	$(A, A + \$1]$
\$5	59.5	69.1	56.3
\$10	40.7	57.1	38.7
\$15	26.3	45.8	31.9
\$20	23.5	58.3	22.7
\$25	23.5	33.5	21.4
\$30	18.3	34.0	13.6
\$35	13.0	23.3	15.9
\$40	10.7	46.8	8.7
\$45	11.8	27.7	10.1
\$50	11.1	31.8	8.6

Table 4: Percentage (%) share of in-person U.S. cash payments by dollar amount intervals.

Notes: Columns apply to dollar amount intervals near multiples of \$5. For example, for a \$20 amount, columns display percentage of cash payments for the payment amount intervals: [\$18.01 to \$19], [\$19.01 to \$20], and [\$20.01 to \$21].

Source: Author's computations from the 2017, 2018, and 2019 Diary of Consumer Payment Choice, publicly available at https://www.frbatlanta.org/banking-and-payments/consumer-payments.aspx.

	Cash	Check	Debit card	Credit card	Prepaid card
			Acceptance		
2015	2	5	3	1	4
2016	2	5	3	1	4
2017	3	5	2	1	4
2018	2	5	3	1	4
2019	3	5	2	1	4
			Acquisition and setup		
2015	1	4	2	3	5
2016	1	3	2	4	5
2017	1	4	2	3	5
2018	1	4	2	3	5
2019	1	4	2	3	5
			Convenience		
2015	3	5	2	1	4
2016	3	5	1	2	4
2017	3	5	2	1	4
2018	3	5	2	1	4
2019	3	5	2	1	4
			Cost		
2015	1	3	2	5	4
2016	1	3	2	5	4
2017	1	3	2	5	4
2018	1	3	2	5	4
2019	1	3	2	5	4
			Payment records		
2015	5	3	2	1	4
2016	5	3	2	1	4
2017	5	3	2	1	4
2018	5	3	2	1	4
2019	5	3	2	1	4
			Security		
2015	5	3	2	1	4
2016	5	3	2	1	4
2017	4	3	2	1	5
2018	5	3	2	1	4
2019	5	3	2	1	4

Table 5: U.S. consumer rankings of six payment attributes over 2015–2019

Notes: "1" means that consumers rate the best and "5" rate the worst. This table has been modified from the original survey which ranks 8 payment methods.

Source: Author's computations from the 2019 Survey of Consumer Payment Choice, publicly available at https://www.atlantafed.org/banking-and-payments/consumer-payments/survey-of-consumer-payment-choice.aspx.

Card adoption	0–10k	10k–20k	20k–30k	30k–40k	40k–60k	60k–80k	80k–120k	120k–180k	180k+	All
Both cards (%)	35.9	45.6	56.2	59.6	66.9	76.0	77.6	80.7	82.1	67.2
No credit (%)	32.6	31.6	25.0	20.9	14.6	8.4	6.8	3.5	1.5	14.2
No debit (%)	8.9	6.6	11.0	11.8	13.4	12.7	12.8	13.8	15.3	12.2
None banked (%)	2.3	4.4	0.4	0.9	0.0	0.0	0.1	0.0	0.0	0.6
None unbanked (%)	17.8	9.2	5.9	4.1	2.5	1.5	0.4	0.8	0.0	3.8
Num respondents	304	228	272	339	529	526	688	399	196	3481
Percentage (%)	8.7	6.5	7.8	9.7	15.2	15.1	19.8	11.5	5.6	100.0
Percentage (%)(w)	9.3	5.7	7.1	9.6	14.8	15.2	21.2	11.5	5.5	100.0

Table 6: Possession of credit and debit cards by household income.

Source: Author's computations from the 2017, 2018, and 2019 Survey and Diary of Consumer Payment Choice.
Notes: The top five rows display percentage of respondents within each income group who have both credit and debit cards, no credit cards, no debit cards, and no credit or debit cards (banked and unbanked). (w) indicated weighted data to fit the U.S. 18 and older population.