How Currency Denomination and the ATM Affect the Way We Pay

Oz Shy

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Abstract: This article identifies transaction values beyond which consumers switch from paying cash to paying with cards. In particular, the sharpest changes in the share of cash payments occur at $20 and $40, which coincide with the observation that most ATMs in the United States dispense multiples of $20 bills. The analytical part proposes algebraic formulations of consumer preferences that support this type of behavior. Whereas causality cannot be established, this research shows that currency and ATM bill denominations influence consumers’ choice of which payment instrument to use for in-person purchases.

JEL classification: D9, E42

Key words: currency denomination, automated teller machines, ATM, consumer payment choice, payment methods, in-person purchases

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1. Introduction

Data collected on how consumers pay in the United States reveal two important characteristics of cash payments for in-person purchases: First, the use of cash declines with the payment value. Second, a large number of consumers switch from paying with cash to paying with cards for payment amounts exceeding the $20 and $40 thresholds. The second observation provides the motivation for this paper given the observation that automated teller machines (ATMs) in the United States dispense mostly multiples of $20 bills. Therefore, paying with cash subjects buyers to what is known as the “burden of receiving and carrying change.” The burden of change is larger for transaction values farther away from multiples of $20 where buyers exchange their $20 bills for smaller denomination coins and currency notes.

This paper utilizes various statistical techniques to conduct empirical analyses of consumers who choose to pay cash for in-person purchases just below certain threshold payment amounts, and pay with cards for transactions exceeding these thresholds. The analysis in this paper focuses on buyers’ choice between paying with cash and paying with checks, credit, debit, and prepaid cards. The benefit from paying cash stems from the ability to control spending. Unlike credit cards, cash payments involve no credit. The cost of paying cash includes having to travel to an ATM and receiving, counting, and carrying change after each cash transaction. The latter cost is proportional to the difference between the money in hand and the payment amount.

The complexity of analyzing the burden of receiving and handling change stems from the fact that change is composed of currency notes and metal coins. Knotek (2008, 2011) call it the “relative inconvenience of price” where inconvenience is measured by the minimum number of coins and bills needed to make a transaction. The burden of dealing with coins on buyers was analyzed in Chen, Huynh, and Shy (2019) using Canadian consumer diary data collected by the Bank of Canada. In contrast, this paper uses U.S. diary data to investigate whether the $20 and $40 payment amount thresholds (between paying cash and paying with cards) are more common than other payment amount thresholds. Using data from a discount chain, Wang and Wolman (2016) provide some empirical support that individual consumers choose between cash and non-cash payments based on a threshold transaction size.

This article is organized as follows. Section 2 describes the data and defines the variables of interest. Section 3 analyzes ATM cash withdrawals. Section 4 presents the main empirical results identifying payment amount thresholds that determine consumer payment choice. Section 5 proposes algebraic formulations of consumer preferences for paying cash that capture the empirical findings on payment amount thresholds. Section 6 concludes.

2. Data, variable selection, and coding

The study of consumer payment choice at the point-of-sale (POS) involves a classification of payment methods such as cash, paper checks, credit cards, debit cards, and prepaid cards. Data on “how consumers pay” are collected by consumer surveys in which consumers list all the payment instruments they have (adopt) and whether and how they use them at the POS. 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.

The data and the R-code used in this analysis are available for downloading from the author’s Webpage: www.ozshy.com (click on “Recent articles”). The data are taken from the 2017 and 2018 Diary of Consumer Payment Choice (DCPC). The DCPC is a representative sample of U.S. consumers that records transactions during three consecutive days during the month of October. Transactions include purchases, bill payments, ATM withdrawals and deposits. Respondents’

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1 The diary is conducted in collaboration of the Federal Reserve Banks of Atlanta, Boston, Richmond, and San Francisco (Cash Product Office). The data and assisting documents (codebooks) are publicly available for downloading from the Federal Reserve Bank of Atlanta Website: https://www.frbatlanta.org/banking-and-payments/consumer-payments.aspx, and are summarized in Greene and Stavins (2018) and Kumar and O’Brien (2019). Similar surveys are conducted by the Bank of Canada, see Henry, Huynh, and Welte (2018).
three-day diaries were evenly distributed throughout the months of October 2017 and October 2018 in a way that resembles a three-period overlapping generations model.\textsuperscript{2}

The DCPC has a large number of variables describing all sorts of demographics and transactions. For the purpose of this article, I will focus only on a subset of variables, some of which I describe below. In particular, I restrict the analysis to 16,951 “in-person” (in-person = 1) expenditure (“type” = 1) payments made by 2891 unique respondents; and then further restrict to 13,671 payments made by 2688 respondents in six merchant categories (merch = 1 to 6) using the five major payment methods (pi = 1 to 5): “cash,” “check,” “credit card,” “debit card,” and “prepaid card.”\textsuperscript{3} Other variables used include “amnt” (dollar amount of each payment), “age,” “income_hh” (household income), “hh_size” (number of persons in the household), “work,” “gender,” and “education.”

Finally, a note about the use of sampling weights. The data contain weights for all respondents that can be used to match the data with the U.S. adult population (18 and older). I indicate when the reported statistics are computed with weights either by (weighted) or (w) inside tables. In general, statistics on small subsamples or subgroups are reported without weights, because these subsamples may be correlated with some demographic variables upon which the weights are computed.

\section{Some statistics on ATM cash withdrawals}

In 2017, 131 diary respondents made 141 ATM cash withdrawals during their three diary days. In 2018, 119 diary respondents made 129 ATM cash withdrawals during their three diary days. These include respondents who participated in both the 2017 and the 2018 diary surveys. From the combined sample of respondents who withdrew cash from ATMs, 13 withdrew twice and 3 withdrew cash three times or more during their 3 diary days.

Focusing on ATM cash withdrawal dollar amounts, $5 was the lowest and $750 was the highest

\textsuperscript{2}Jonker and Kosse (2009) compare payment diaries with different time lengths and find that shorter diaries yield more accurate information due to “survey fatigue” that leads respondents to under report their payment activities.

\textsuperscript{3}The merchant categories are: 1. Grocery stores, convenience stores without gas stations, pharmacies, 2. gas stations, 3. sit-down restaurants and bars, 4. fast food restaurants, coffee shops, cafeterias, food trucks, 5. general merchandise stores, department stores, other stores, and 6. general services: hair dressers, auto repair, parking lots, laundry or dry cleaning, etc.
amount. The median amount was $80 and the mean was $115.6. The top panel in Figure 1 displays the number of ATM withdrawals for each dollar amount ignoring one $540, one $700, and one $750 ATM withdrawals. The bottom panel in Figure 1 is restricted to withdrawals not larger than $200. Both panels show that $20 was the most frequently withdrawn amount, followed by $200, $60, $80, and $300, in this order. All these amounts are multiples of $20 which provide the key motivation for this research. More precisely, out of all ATM withdrawals in this sample, 89.26 percent are in multiples of $20 where as the remaining 10.74 percent are not in $20 multiples. Note that the percentage of $20 bills in ATM withdrawals is higher than 89.26 percent because, for example, consumers who withdraw $50 from an ATM are most likely to get it as $20 bills and one $10 bill.

It should be mentioned that the ATM is not the only source of cash. In fact, by volume (by dollar value), 23.1 percent (24.7 percent) of cash received by respondents was obtained from ATMs, 35.3 percent (27.7 percent) obtained from family or friends, 11.5 percent (16.2 percent) from employers, 9.8 percent (26.5 percent) from a bank teller, 9.1 percent (2.6 percent) as store cash-back, and 10.0 percent (8.4 percent) from other sources. All these percentages are weighted. Note that we cannot make much use of non-ATM cash receipts because respondents do not record the denominations of the bills they received, only their total amounts. For a comprehensive analysis how and for what purpose consumers get cash see Greene and Shy (2019).

4. Empirical results

This section utilizes visual and statistical techniques to evaluate the effect of the $20 currency denomination supplied by ATMs on consumers’ decision whether to pay cash. The goal is to estimate the threshold payment values above which there are significant drops in cash payments relative to non-cash payments.

Using the data set described in Section 2, the vertical axis of Figure 2 displays the relative share of payments made with cash, checks, credit, debit, and prepaid cards. The horizontal axis measures actual payment dollar amounts in $1 intervals (total 45 intervals). The unequal spacing on the horizontal (Amount) axis reflects the relative number of transactions made at each payment
amount interval. Since the number of transactions declines very rapidly towards transaction values above $45, this figure is restricted to payment amounts up to $45 dollars.

Overall, Figure 2 shows how the share of cash use declines with the payment amount. But, perhaps, the most striking observations in Figure 2 are the sharp drops in the share of cash use in payment amounts between $20 and $21 and between $40 and $41. Other somewhat smaller drops in cash use are also observed in transactions values between $5 and $6, $10 and $11, $15 and $16, $25 and $26, and $30 and $31.

The top panel of Figure 3 shows that the share of cash payments peaks at the following payment amount intervals: $0–$1 (87.7%), $4–$5 (65.1%), $9–$10 (53.2%), $14–$15 (41.9%), $19–$20 (52.2%), $24–$25 (33.4%), $29–$30 (25.7%), and $39–$40 (42.3%).

The middle panel of Figure 3 depicts the difference (rise/fall) in the share of cash use associated with a $1 increase in the payment amount. More precisely, the middle part of Figure 3 shows a 9.2% drop in the share of cash use between $5 and $6 payment amounts, 15.4% drop between $10 and $11, 12.7% drop between $15 and $16, 27.4% drop between $20 and $21, 13.5% drop between $25 and $26, 13.7% drop between $30 and $31, and 33.9% drop between $40 and $41.

Perhaps the most striking observations in the middle panel of Figure 3 are the sharp drops in cash use in payment amounts between $20 and $21 (27.4%) and between $40 and $41 (33.9%). Both, the sharp increase in share of cash use and the sharp drop in cash use around the $20 and the $40 payment amounts make it clear that a large number of consumers use multiples of $20 payment amounts as thresholds above which they switch from paying cash to paying with cards. The following three subsections test this hypothesis using three statistical methods: (4.1) classification tree (4.2) logistic regression, and (4.3) de-trending with respect to payment dollar amounts.

### 4.1 Payment method classification tree

In the context of machine learning, a classification tree displays an optimized algorithm in the form of an upside-down tree. The tree illustrates how the machine (software) splits and classifies the payment methods with the objective of minimizing a function of the number of classification
errors among the predicted payment methods relative to the actually-used methods.⁴

Figure 4 displays an upside-down tree that classifies the use of the payment methods (cash, checks credit, debit, and prepaid cards) according to payment amount and payers’ demographic features that were described in Section 2. For the sake of illustration, the classification tree displayed in Figure 4 was pruned by setting the complexity parameter to generate only seven splits. The tree was constructed using 13,671 payments made by 2688 respondents using five payment methods: cash, checks, credit, debit, and prepaid cards. Because of their low use in the sample, check and prepaid card payments are not predicted by this tree.

Figure 4 shows that the $10 and $20 payment amount thresholds and $109,836 household income constitute the best predictors for cash payments. Note that the tree algorithm selects the splits on the top first because these thresholds reduce classification errors more than top splits according to age (that are pushed to lower branches of the tree). The exact top splitting amount ($10 in this sample) is determined by the error “majority rule” (or some function of it) in the sense that any other split would generate lower prediction accuracy as measured by a function of the number of prediction errors.

The $10 split on the top seems to capture low-value transactions especially transactions below $7 that are dominated by cash, see Figure 2. The $10 currency denomination has some effect the prevents the tree from splitting at payment values below $10. The top-left branch shows that 36 percent of all payments are classified as cash using this threshold.

The second layer of branches in Figure 4 consists of splits according to a very high household income because high income levels predict high use of credit cards. The third layer splits according to the $20 currency denomination threshold. The very left branch shows that 2 percent of the payments of exactly $20 were classified as cash. On the right branch, transactions over $20 were classified as either debit or credit depending on age and household income.

⁴The classification tree algorithm is designed and tuned with cross validation using the rpart R-package. The cross validation procedure partitions the training data into k folds, where the algorithm is constructed using k – 1 folds of data and tested on the retained k’s fold on which the classification errors are measured. The process repeats itself k times, each with a different retained k’s fold. The k error measurements are then averaged to produce the final tree algorithm. The advantage of this method is that all observations are used for both training and validation.
4.2 Logistic regression discontinuity design

Using the transaction data described in Section 2, define a binary variable “Cash” to take the value of 1 for cash payments and 0 for non-cash payments. Using 25 payment amount thresholds, the estimated model takes the form of\(^5\)

\[
\text{Cash}_i = \sum_{k=1}^{25} \delta_k I\{\text{Amount}_i > k\} + \beta_T \text{Amount}_i + \beta_W \text{Work}_i + \beta_S \text{HH.size}_i + \beta_I \text{HH.income}_i + \beta_M \text{Marital}_i + \beta_A \text{Age}_i + \beta_G \text{Gender}_i + \beta_E \text{Educ}_i + \epsilon_i. \quad (1)
\]

For each \(k = 1, \ldots, 25\) reflecting a $1 increment in dollar amount, \(I\) is the indicator function which takes a value \(I = 1\) if the payment amount is strictly greater than \(k\) and \(I = 0\) otherwise, where \(\delta_k\) is the corresponding dummy variable. The \(\beta\) coefficients correspond to dollar amount and some of the demographic variables described in Section 2. The index \(i\) corresponds to a single payment observation, \(i = 1, 2, \ldots, 13,638\), made by 2687 respondents. Note that payments made by the same respondent have the same demographic values.

Table 1 and Figure 5 display the estimated marginal effects and their confidence intervals. Both show that the largest drop in cash use occurs at the $20 threshold where the probability of paying cash drops by 31.3 percent. An equally striking result is the sharp increase in the probability of paying cash between $19 and $20. That is, the probability of paying cash increases by 26.2 percent for payment amounts above $19 to $20 (inclusive).

The marginal effects at other thresholds are substantially lower. The probability of cash use drops by 16.1 percent between $1 and $2 payment values and also between $2 and $3 which may reflect a switch from coin transactions to more currency note transactions. There is a 15.3 percent drop in the probability of cash use between $10 and $11, however, unlike the $19 to $20 threshold, the increase between $9 and $10 is only 8.1 percent. There is a 19.7 percent drop in in the probability of cash use between payment amounts $25 and $26.

Finally, looking at the demographic marginal effects in Table 1, the probability of using cash declines with education and increases with age.

\(^5\)A similar model was estimated in Chen, Huynh, and Shy (2019) using Bank of Canada’s 2013 Methods of Payment diary data.
4.3 De-trending according to payment amount

To further test the hypothesis that the $20 ATM and currency denominations have a significant impact on consumer payment choice, this subsection takes a different approach by separating the negative relationship between the share of cash use and payment amount from the local jumps and drops around the threshold payment amounts. More precisely, recall from Figure 2 and the top panel in Figure 3 that the share of cash use declines with the dollar amount. To separate this downward trend from the local jumps and drops, the analysis in this subsection ‘de-trends’ the share of cash use with respect to payment dollar amount.

The bottom panel in Figure 3 depicts the share of cash use for each payment amount after it is subtracted from the regression line depicted on the top panel of Figure 3. This procedure ‘de-trends’ the negative effect of dollar amount on the share of cash use and shows the jumps and drops in cash use relative to the trend in shares of cash use. The bottom panel shows that the highest de-trended share of cash use is at payment values between $19 and $20 followed by $39 to $40, and then $0 to $1. These findings provide additional support for the hypothesis that consumer choice of paying cash is influenced by payment dollar amounts closer to multiples of $20 bills.

5. Algebraic formulation of consumer preferences for paying cash

This section briefly sketches the analytics of consumer preferences for paying cash that are consistent with the empirical findings of the previous sections.

Consider a consumer who faces a decision whether to pay cash or with a non-cash payment instrument for an in-person purchase made at a retailer who accepts cash and non-cash (card) payments. Assume that the consumer carries multiples of a single denomination currency notes of $m (m > 0). For example, $m = 20, 2m = 40, km = k$20, and so on. The consumer enters a store, selects the items and finds the total payment amount (price) \( p \). Any price \( p \) must fall in one price range given by

\[(k - 1)m \leq p < km \quad \text{for one value of } k \in \{1, 2, \ldots\}. \tag{2}\]
A very low price is captured by $k = 1$, in which case $p \in [0, m)$. $k = 2$ implies that the payment amount lies in the range $p \in [m, 2m)$. When the consumer finds the payment amount $p$, the consumer can also figure out the value of the integer $k$ which determines the price range that $p$ belongs to.

After observing the payment value $p$ and $k$, the consumer decides on whether to pay cash (C) or with a non-cash payment instrument (NC) to maximize the utility function

$$U(p) = \begin{cases} 
  a - b(km - p) & \text{if pays cash (C)} \\
  c\sqrt{p} & \text{non-cash payment (NC) and } k = 1 \\
  U_{NC} & \text{non-cash payment (NC) and } k \geq 2.
\end{cases} \quad (3)$$

The utility function (3) is depicted in Figure 6 assuming that $b > 0$, $a > bm$, and $c > U_{NC}/\sqrt{m}$.

To derive the intuition behind the utility function (3) and Figure 6 it is easier to start with the case of $k \geq 2$ (larger payment amounts). In this case, the consumer chooses to pay cash if the first row in (3) is larger than the third row, formally, if $a - b(km - p) \geq U_{NC}$. The third row is a fixed utility derived from a non-cash payment. The first row corresponds to the upward sloping straight lines in Figure 6, which show that utility of paying cash rises as the payment amount $p$ gets closer to an exact multiple of $\$m$. This reflects consumer aversion to receiving and carrying change which diminishes as the price gets closer to $km$. At price levels $p_2, p_3, \ldots, p_k$, these lines cross $U_{NC}$ so the utility from paying cash becomes larger than the utility of making a non-cash payment.

The case of $k = 1$ (low payment amounts) is different as shown in Figure 6 for the range of payment amounts $p \in [0, m)$. This is formally captured by the second row in the utility function (3) to match the observations that cash is heavily used for payment amounts up to $\$6$, as shown in Figure 2. In this case, $a - b(km - p) > c\sqrt{p}$ for very low payment values in the range of $p \in [0, p_0]$ and for payment values close to the currency denomination $\$m$ defined by $p \in [p_1, m]$. For intermediate payment values $p \in (p_0, p_1)$ this consumer prefers to pay with a non-cash payment instrument.

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6It should be emphasized that the term utility refers to the net gain (benefit minus cost) consumers derive from the paying using a particular payment instrument. Here, the use of the term utility is substantially different from the common use of utility to measure the benefits derived from consuming a product or service.
Finally, it is clear that the utility function (3) and Figure 6 do not apply to all consumers. In fact, the data analyzed in previous sections reflect some variations across individuals. However, the type of preferences seems to capture perhaps the average behavior of consumers in deciding whether to pay cash or with a non-cash payment instrument.

6. Conclusion

This article identifies significant discontinuities in consumer payment choice between payment amounts $19 and $21 and also between $39 and $41. Whereas this research establishes a correlation between currency denomination and consumer payment choice, the exact cause of this behavior cannot be derived. What we can say is that the prevalence of $20 currency notes somehow enters consumers’ mind in the sense that it affects their choice among payment instruments used for in-person purchases.

This research has some policy implications for how optimal currency could be designed to minimize the burden of change. In fact, in the literature, there have been several attempts to compute the optimal currency denomination according to the “principle of least effort,” as discussed in Telser (1995), Van Hove (2001) and reference therein as well as in Shallit (2003) for the case of optimal coin denomination.

However, this literature does not take into consideration that even if central banks issue the effort-minimizing currency denominations, consumers may not be able to obtain all available currency denominations if ATMs provide mostly one type of currency ($20 bills in the United States). Some of this distortion is captured in the analysis of this paper.

Finally, the hypothesis analyzed in this paper is experimental in nature. It calls for randomized testing by providing buyers with different currency denominations and record their threshold payment amounts below which they pay only cash. One can think of field experiments where buyers who receive only $5, or $10, or even $50 dollar bills from the ATM. Obviously, such experiments are extremely costly to perform.
References


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</tbody>
</table>

Table 1: Cash use logistic regression marginal effects. Note: (***) , (**), (*), and (·) correspond to the 0.1, 1, 5, and 10 percent confidence thresholds, respectively.
Figure 1: Number of ATM cash withdrawals by dollar amount. Top: Withdrawals not exceeding $500. Bottom: Withdrawals not exceeding $200. Note: Red bars are withdrawals of exact multiples $20 bills.
Figure 2: Share of use of cash, check, credit, debit, and prepaid card payments made by 2551 respondents who made 11,181 payments between $0 and $45.

Note: Unequal spacing between each $1 increment reflects relative number of payments at this amount.
Figure 3: Top: Shares of cash use by 2551 respondents who made 11,181 payments between $0 and $45 and regression curve. Middle: Differences (jumps and drops) in share of cash use between two consecutive payment amounts. Bottom: Share of cash use de-trended around the regression curve.
Figure 4: Payment method classification tree using 13,671 payment observations made by 2688 respondents. Note: Check and prepaid card payments are not predicted because of their low use.
Figure 5: Marginal effects and 95-percent confidence intervals at each payment amount threshold.
Figure 6: Utility (net benefit) from paying cash or with a non-cash payment instrument as functions of the payment dollar amount $p$.

Note: The figure assumes that buyers carry only bills of $m$ ($20 as an example), and that buyers have no other forms of cash.