Payment Choice and Currency Use: Insights from Two Billion Retail Transactions

Zhu Wang and Alexander L. Wolman

Federal Reserve Bank of Richmond

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Introduction

• How do consumers choose to pay at the point of sale?
  • Key to understanding transaction demand for money and the evolution of payments system
  • Rich data on non-cash payments from bank surveys
  • Cash? Mainly from small-sample consumer surveys

• We explore a unique merchant transaction dataset
  • 1 large discount chain, thousands of locations in U.S.
  • 2 billion retail transactions (≈ millions of consumers)
  • 3 full years, from April 1, 2010 to March 31, 2013
With this rich dataset we study three themes:
- payment variation across transaction sizes and locations
- payment variation at weekly and monthly frequencies
- payment variation over the longer term

We connect empirical findings to theories of money demand and payments:
- We show that cross-sectional and time-series payment patterns are consistent with a theoretical framework in which individual consumers choose between cash and non-cash payments based on a threshold transaction size.
- We evaluate factors that may determine the variation of threshold distributions across locations and time.
Outline

1. Data overview
2. Threshold hypothesis
3. Empirical analysis
   - Payment variation across payment sizes and locations
   - Payment variation at weekly and monthly frequencies
   - Payment variation over the longer term
4. Theoretical modeling
5. Conclusion
Transactions data

- Discount retailer, several ’000 stores, dozens of states across most of the U.S.
- Data covers April 1, 2010 - March 31, 2013.
- We restrict to cash, debit, credit, check (the four general purpose payment types).
- More than 1.75 million transactions per day.
- Median transaction size $\approx 7$. 
Payment variation across time

Fraction of Transactions by Payment Type

- cash, left axis
- debit, right axis
- credit, right axis
- check, right axis
Payment variation across locations, March 2013

Payment Composition Across Zip Codes
Kernel Density for Fraction of Each Payment Type

Fraction of Transactions
Density
cash
debit
credit
check

0.0 0.2 0.4 0.6 0.8 1.0
0 5 10 15 20
Payment variation across transaction sizes: level and dispersion, March 2013

A. Cash

B. Debit

5th Percentile
Median
95th Percentile
Transaction size distribution, March 2013

Transactions concentrated below $15
Distribution of Median Income Across Zip Codes

Our Sample

United States
Theories on money and payments

- Traditional money demand theories (e.g. Baumol 1952, Tobin 1956, Sidrauski 1967, Lucas 1982) emphasize opportunity cost, especially foregone interest, in households’ decisions of holding cash. Those models consider cash as the only means of payment.

- Later models (e.g. Prescott 1987, Freeman & Kydland 2000, Lucas & Nicolini 2015) introduce multiple payment means, where consumers choose payment means based on transaction sizes ($T_S$).

- Others (e.g. Alvarez & Lippi 2009, 2014) focus on the sequential interplay b/w payments and cash balances, allowing multiple payment means but assuming one transaction size ($C_H$).
Following Lucas & Nicolini (2015) and others, we assume that paying with cash incurs a cost proportional to the transaction size $z$, while paying with other means incurs a fixed cost per transaction.

This implies that a shopper has a threshold transaction size $z^*$ for choosing between cash and non-cash payment means.

In location $j$ on date $t$, there is a distribution of thresholds $G_{j,t}(z^*)$ across shoppers.

Each shopper draws a transaction size from a distribution $H_{j,t}(z)$. We assume that the draws from $G_{j,t}$ and $H_{j,t}$ are independent.
In location $j$ on date $t$, the cash share of size-$z$ transactions

$$S_{z,j,t} = \Pr(z^* > z) = 1 - G_{j,t}(z) \implies \frac{\partial S_{z,j,t}}{\partial z} < 0.$$

Accordingly, the cash share of all transactions

$$S_{j,t} = \int [1 - G_{j,t}(z)] dH_{j,t}(z).$$

We study how cash shares ($S_{j,t}$ and $S_{z,j,t}$) and the corresponding threshold distributions $G_{j,t}(z^*)$ vary across locations and time.
Explanatory variables

- Zip-code level variables, fixed across time.
  - Cash holding and payment choice considerations
    - bank concentration (HHI), bank branches per capita
    - robbery rate
  - Adoption of non-cash means of payment
    - median household income, deposits per capita
    - population density
  - Demographic variables: age, sex, race, education, housing status, family status
- State dummies, fixed across time.
- Time dummies: day-of-week, day-of-month, month-of-sample.
Empirical model (FMLogit, Mullahy 2010)

- Denote $s^k_{j,t} =$ share of payment type $k$ in zip-code $j$ on date $t$.
- Shares sum to one, can be zero or one $\Rightarrow$ FMLogit:

$$E[s^k | x] = G_k(x; \beta) = \frac{\exp(x\beta_k)}{\sum_{m=1}^{4} \exp(x\beta_m)}.$$

Normalize $\beta_{\text{cash}} = 0$ for identification:

$$G_k = \begin{cases} \frac{\exp(x\beta_k)}{1 + \sum_{m=1}^{3} \exp(x\beta_m)} & \text{for } k=1,2,3 \\ 1 & \text{for } k=\text{cash} \end{cases}, \quad G_{\text{cash}} = \frac{1}{1 + \sum_{m=1}^{3} \exp(x\beta_m)}.$$

- $X$ are zip-code level explanatory variables, state and time dummies.
Estimating overall payment mix

- Payment shares based on all transactions for a zip-code day, 4.5 million observations (zip-code days).

- Include median transaction size as an explanatory variable.

- For continuous $x$ variables, report marginal effects evaluated at the mean.

- For dummies, report “discrete effects” evaluated at mean.
## Findings: zip-code level variables (1)

<table>
<thead>
<tr>
<th>Economic Variables</th>
<th>Cash</th>
<th>Debit</th>
<th>Credit</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median transaction size</td>
<td>-0.018*</td>
<td>0.012*</td>
<td>0.005*</td>
<td>0.001*</td>
</tr>
<tr>
<td>HHI (bank concentration)</td>
<td>0.030*</td>
<td>-0.023*</td>
<td>-0.010*</td>
<td>0.003*</td>
</tr>
<tr>
<td>HHI*metro</td>
<td>-0.050*</td>
<td>0.032*</td>
<td>0.024*</td>
<td>-0.005*</td>
</tr>
<tr>
<td>Branches per capita</td>
<td>0.007*</td>
<td>-0.005*</td>
<td>-0.004*</td>
<td>0.001*</td>
</tr>
<tr>
<td>Robbery rate</td>
<td>-0.054*</td>
<td>0.063*</td>
<td>0.000</td>
<td>-0.010*</td>
</tr>
<tr>
<td>Median household income</td>
<td>-0.033*</td>
<td>0.005*</td>
<td>0.036*</td>
<td>-0.008*</td>
</tr>
<tr>
<td>Deposits per capita</td>
<td>-0.006*</td>
<td>0.016*</td>
<td>0.000</td>
<td>-0.010*</td>
</tr>
<tr>
<td>Population density</td>
<td>-0.038*</td>
<td>0.079*</td>
<td>0.091*</td>
<td>-0.131*</td>
</tr>
</tbody>
</table>

* significant at 1%.

Branches per capita = number of bank branches per 100 residents in a zip code. Median household income in $100,000 per household. HHI measured at county or MSA level, transformed to lie between 0 and 1. Deposits per capita in $10,000 deposits per resident in a zip code. Population density is measured in 100,000 residents per square mile in a zip code. Robbery rate = number of robberies per 100 residents in a county.
### Findings: zip-code level variables (2)

<table>
<thead>
<tr>
<th>Demographics</th>
<th>Cash</th>
<th>Debit</th>
<th>Credit</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>Family households</td>
<td>-0.098*</td>
<td>0.089*</td>
<td>0.016*</td>
<td>-0.006*</td>
</tr>
<tr>
<td>Female</td>
<td>-0.052*</td>
<td>0.080*</td>
<td>-0.005*</td>
<td>-0.023*</td>
</tr>
<tr>
<td>Age share: 15-34</td>
<td>-0.184*</td>
<td>0.163*</td>
<td>0.034*</td>
<td>-0.013*</td>
</tr>
<tr>
<td>35-54</td>
<td>-0.152*</td>
<td>0.115*</td>
<td>0.053*</td>
<td>-0.016*</td>
</tr>
<tr>
<td>55-69</td>
<td>0.031*</td>
<td>-0.000</td>
<td>-0.013*</td>
<td>-0.018*</td>
</tr>
<tr>
<td>≥ 70</td>
<td>-0.024*</td>
<td>-0.038*</td>
<td>0.054*</td>
<td>0.007*</td>
</tr>
</tbody>
</table>

* significant at 1%.
Findings: zip-code level variables (3)

<table>
<thead>
<tr>
<th>Demographics</th>
<th>Cash</th>
<th>Debit</th>
<th>Credit</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>Race: black</td>
<td>0.055*</td>
<td>-0.025*</td>
<td>-0.020*</td>
<td>-0.011*</td>
</tr>
<tr>
<td>hispanic</td>
<td>0.024*</td>
<td>-0.019*</td>
<td>0.003*</td>
<td>-0.007*</td>
</tr>
<tr>
<td>native</td>
<td>0.133*</td>
<td>-0.074*</td>
<td>-0.052*</td>
<td>-0.007*</td>
</tr>
<tr>
<td>asian</td>
<td>-0.018*</td>
<td>0.001</td>
<td>0.032*</td>
<td>-0.022*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Educ:</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>high school</td>
<td>-0.202*</td>
<td>0.138*</td>
<td>0.057*</td>
<td>0.007*</td>
</tr>
<tr>
<td>some college</td>
<td>-0.322*</td>
<td>0.233*</td>
<td>0.088*</td>
<td>0.001*</td>
</tr>
<tr>
<td>college</td>
<td>-0.225*</td>
<td>0.140*</td>
<td>0.079*</td>
<td>0.007*</td>
</tr>
</tbody>
</table>

* significant at 1%.
### State fixed effects

<table>
<thead>
<tr>
<th></th>
<th>Cash</th>
<th>Debit</th>
<th>Credit</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Top States</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NJ</td>
<td>AZ</td>
<td>MN</td>
<td>SD</td>
<td></td>
</tr>
<tr>
<td>NY</td>
<td>ID</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>MI</td>
<td>NV</td>
<td>SD</td>
<td>MN</td>
<td></td>
</tr>
<tr>
<td>VT</td>
<td>NM</td>
<td>OK</td>
<td>OK</td>
<td></td>
</tr>
<tr>
<td>DE</td>
<td>FL</td>
<td>OH</td>
<td>CO</td>
<td></td>
</tr>
<tr>
<td><strong>Bottom States</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL</td>
<td>MD</td>
<td>IA</td>
<td>NH</td>
<td></td>
</tr>
<tr>
<td>TX</td>
<td>NY</td>
<td>AR</td>
<td>NY</td>
<td></td>
</tr>
<tr>
<td>NM</td>
<td>ND</td>
<td>NV</td>
<td>AZ</td>
<td></td>
</tr>
<tr>
<td>ID</td>
<td>SD</td>
<td>MS</td>
<td>DE</td>
<td></td>
</tr>
<tr>
<td>AZ</td>
<td>MN</td>
<td>NJ</td>
<td>NJ</td>
<td></td>
</tr>
</tbody>
</table>
Separate models by transaction size

- The benchmark model provides a useful summary of consumer payment mix across locations and dates.

- For a given zip code in a given day, the overall payment mix depends on consumer payment choice at each transaction size combined with the transaction size distribution, through consumer characteristics, location & time fixed effects, and median transaction size.

- To better understand consumer payment choice at each transaction size, we run separate models by transaction size, which
  - take into account individual transaction sizes
  - allow transaction size to affect both coefficients and constants
Description, and summary of findings

- Similar number of observations to benchmark. Number of underlying transactions between 11 and 199 million.
- Same explanatory variables but allow their coefficients to differ across size class regressions.

The models fit data very well:

- Marginal effects amplify with transaction size
- Allowing coefficients to vary across transaction size is important for explaining variation in levels of shares, as well as dispersion
Amplification of marginal effects

Cash

HHI Income  Deposits  Pop Density  Robbery

Marginal effect

Value of sale

HHI Rural  HHI MSA  Branches

Marginal effect

Value of sale

Family  Homeowner  Vacant  Female

Marginal effect

Value of sale

Black  Hispanic  Native  Asian

Marginal effect

Value of sale

High School  Some College  College

Marginal effect

Value of sale
Payment variation across transaction sizes and locations (March 2013)

- Model does a good job at fitting data
- It helps to infer the underlying cash threshold distribution $G_{j,t}(Z^*)$
- It also explains how $X$ affects payment shares by transaction size
Model-implied threshold distribution

CDF of Cash Threshold

PMF of Cash Threshold
Decomposing the level and dispersion

- "x"-lines hold fixed coeffs on zip-code-level variables
- "o"-lines hold fixed all other terms: state/time/constant
Explaining the level and dispersion

- Our model estimates yield empirical counterparts to the cash threshold distributions $G_{j,t}(z^*)$ implied by theory.
- The level effect: for any location-specific distribution of thresholds, at a higher transaction size there will be a higher fraction of consumers using non-cash payments because their thresholds have been crossed.
- The dispersion effect: As transaction size increases, consumers in a location with easier access to non-cash options switch increasingly further away from cash compared to locations that do not.
- Quantitatively, both level and dispersion effects are almost entirely explained by zip-code-level variables!
Payment variation by day of week and month

Day of Week Marginal Effects

Mon  Tues  Weds  Thurs  Fri  Sat  Sun

-0.010  0.000  0.005  0.010

cash  debit  credit  check
Payment variation by day of week and month

A. Day of Week

solid = cash, dashed = debit

- $1 to $2
- $10 to $11
- $25 to $30
- Over $50
Payment variation by day of week and month

Day of Month Marginal Effects

- cash
- debit
- credit
- check
Payment variation by day of week and month

B. Day of Month

solid = cash, dashed = credit
The role of consumers’ financial positions

- A possible explanation is that consumers’ financial positions vary systematically over the week and the month.
- If true, we would expect supporting evidence in transaction volumes, e.g., some credit-constrained consumers would drop out of the pool of shoppers as time passes since their last payday.
- If paydays are correlated across consumers then the cash share would decrease because of systematically lower cash thresholds for the consumers who stay in the pool.
Weekly pattern of transaction volumes

A. Day of Week

$1 to $2

$10 to $11

$25 to $30

Over $50
Monthly pattern of transaction volumes

B. Day of Month

$1 to $2

$10 to $11

$25 to $30

Over $50

- Cash
- Noncash
- Total
Correlations: cash shares & transaction volumes

<table>
<thead>
<tr>
<th>Transaction Size</th>
<th>Days of Week</th>
<th>Days of Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1 to $2</td>
<td>-0.13</td>
<td>0.20</td>
</tr>
<tr>
<td>$2 to $3</td>
<td>0.29</td>
<td>0.31</td>
</tr>
<tr>
<td>$3 to $4</td>
<td>0.47</td>
<td>0.53</td>
</tr>
<tr>
<td>$4 to $5</td>
<td>0.54</td>
<td>0.55</td>
</tr>
<tr>
<td>$5 to $6</td>
<td>0.62</td>
<td>0.69</td>
</tr>
<tr>
<td>$6 to $7</td>
<td>0.63</td>
<td>0.65</td>
</tr>
<tr>
<td>$7 to $8</td>
<td>0.62</td>
<td>0.74</td>
</tr>
<tr>
<td>$8 to $9</td>
<td>0.65</td>
<td>0.73</td>
</tr>
<tr>
<td>$9 to $10</td>
<td>0.63</td>
<td>0.78</td>
</tr>
<tr>
<td>$10 to $11</td>
<td>0.66</td>
<td>0.77</td>
</tr>
<tr>
<td>$11 to $12</td>
<td>0.65</td>
<td>0.75</td>
</tr>
<tr>
<td>$12 to $13</td>
<td>0.66</td>
<td>0.80</td>
</tr>
<tr>
<td>$13 to $14</td>
<td>0.65</td>
<td>0.86</td>
</tr>
<tr>
<td>$14 to $15</td>
<td>0.62</td>
<td>0.82</td>
</tr>
<tr>
<td>$15 to $20</td>
<td>0.62</td>
<td>0.85</td>
</tr>
<tr>
<td>$20 to $25</td>
<td>0.54</td>
<td>0.83</td>
</tr>
<tr>
<td>$25 to $30</td>
<td>0.52</td>
<td>0.87</td>
</tr>
<tr>
<td>$30 to $35</td>
<td>0.51</td>
<td>0.88</td>
</tr>
<tr>
<td>$35 to $40</td>
<td>0.47</td>
<td>0.91</td>
</tr>
<tr>
<td>$40 to $45</td>
<td>0.41</td>
<td>0.93</td>
</tr>
<tr>
<td>$45 to $50</td>
<td>0.37</td>
<td>0.91</td>
</tr>
<tr>
<td>Over $50</td>
<td>0.31</td>
<td>0.93</td>
</tr>
</tbody>
</table>

There are several striking features of Figures 10A and 10B. First, the variation in number of transactions is enormous relative to the variation in payment shares; and, as with payment shares the variation tends to be amplified for larger transaction sizes. Over the week, for $1-$2 transactions volume varies by roughly 20 percent with the peak being Friday and Saturday, and for over $50 transactions this variation is almost 40 percent. Over the month, transaction volume is even more sensitive to transaction size: For $1-$2 transactions there is less than a ten percent difference between the highest...
Interpreting weekly and monthly variation

- Our findings suggest that financial position is likely driving both transaction volumes and the share of cash transactions.
- Credit-constrained consumers are likely to have high cash thresholds, so as they exit the pool of shoppers disproportionately, the fraction of cash payments may decline.
- For liquidity-constrained consumers, financial position may not affect shopping behavior, but their cash threshold may fall as their cash balances decline over the week or month (cf. Alvarez & Lippi).
- A successful theory may need to match the variation of both payment mix and shopping activities.
Payment variation over the longer term

Month of Sample Marginal Effects

- cash
- debit
- credit
- check

(grey lines demarcate 12 mos. from April through March)
Payment variation over the longer term

B. Regressions by Transaction Size

solid = cash, dashed = debit

- $1 to $2
- $10 to $11
- $25 to $30
- Over $50
Shifts in the predicted payment mix over time

Predicted Payment Fractions by Transaction Size

- Cash
- Debit
- Credit
- Check

- ○ March 2013
- × April 2010
Projecting currency use: zip-code variables

Zip–Code–Level Variables and Forecasts of Cash Fractions

*lines represent differences between forecasts based on indicated factors and estimated cash use fractions for March 2011*
Decline in the cash share

- Transitory shocks are unlikely to explain the decline in the cash share
  - recovery from the Great Recession
  - changes in store’s payment policy
  - changes in store’s goods and customers

- Longer-term economic and demographic factors
  - total effects of zip-code-level variables are small relative to the time trends (12%-15%)
  - among all zip-code-level variables, the majority of effects is due to the cohort effect (70%)

- Other factors shifting down the cash threshold distribution
  - the growth of debit at the expense of cash
  - technological progress and changing consumer perceptions
Our empirical findings show that cross-sectional and time-series payment patterns are consistent with a threshold-size framework.

A model like Lucas and Nicolini (2015) seems to be a natural starting point to interpret the cross-sectional payment pattern.

To match the data, the model needs to be adapted to allow for heterogeneity of consumers and locations.
A preliminary model

- Built on Lucas and Nicolini (2015), we consider a single-agent cash management model with two payment means (e.g. cash and deposit).
- A household consumes a continuum of different perishable goods in fixed proportions.
- Goods are in different sizes $z$. The size distribution is described by the cdf $F(z)$ and pdf $f(z)$.
- Denote $v = \int_0^\infty zf(z)\,dz$. Consuming $x$ means purchasing $x/v$ units of each good of size $z$.
- The household has the following preference over the composite good $X$:

$$\sum_{t=0}^\infty \beta^t U(x_t).$$
A preliminary model

- The household has one unit of labor each period to be divided between production and cash management.
- There are two payment means available to the household.
  - Money held as currency is subject to robbery and theft, so a fraction $\tau$ vanishes each period. Denote $\theta = \frac{1}{1-\tau}$, so $\theta c$ is the amount of currency needed for spending $c$ in cash.
  - Deposits pay an interest rate $r$, but payments by deposits incur a fixed cost $q$ per transaction (not varying with transaction value).
- At equilibrium, there exists a threshold transaction size $\gamma$, below which the household uses cash and above uses deposits.
A preliminary model

- The household chooses the number $n$ “trips to the bank” each period to replenish cash and deposits. Each trip requires a time cost $\phi$.
- The cash-in-advance constraints for the household:

\[
m \geq \theta c + d,
\]

\[
nc \geq px\Omega(\gamma),
\]

\[
nd \geq px[1 - \Omega(\gamma)],
\]

where $\Omega(\gamma)$ denotes the fraction of total consumption paid in cash

\[
\Omega(\gamma) = \frac{1}{\nu} \int_{0}^{\gamma} zf(z)dz.
\]
A preliminary model

- The household’s optimization problem is

\[
V(m) = \max_{x,c,d,\gamma,n} \{U(x) + \beta V(m')\}
\]

s.t. \( m' = m + T + rd - (\theta - 1)c + py(1 - \phi n) - px - qx(1 - F(\gamma)), \)
\[
m \geq \theta c + d,
\]
\[
n c \geq px \Omega(\gamma),
\]
\[
n d \geq px [1 - \Omega(\gamma)].
\]

- We evaluate the first order and envelope conditions at the steady state.
A preliminary model

- Five equations solve for five endogenous variables $x$, $c$, $d$, $\gamma$, $n$:

  $$x = \frac{n^2 \beta y \phi}{(\theta - \beta)\Omega(\gamma) + (1 - \beta - \beta r)[1 - \Omega(\gamma)]},$$

  $$c = \frac{px\Omega(\gamma)}{n},$$

  $$d = \frac{px[1 - \Omega(\gamma)]}{n},$$

  $$n\beta qv = (\theta + \beta r - 1)p\gamma,$$

  $$py(1 - \phi n) + T + rd = (\theta - 1)c + px + qx[1 - F(\gamma)].$$

- The cross-sectional variation of cash threshold $\gamma$ can be explained by the variation in $(y, T, \phi, q, r, \theta)$. 
Conclusion

- Data from a discount retailer: 3 years, thousands of locations ⇒ 2 billion transactions.
  - payment variation across transaction sizes and locations
  - payment variation at weekly and monthly frequencies
  - payment variation over the longer term
- We show that cross-sectional and time-series payment patterns are consistent with the threshold hypothesis.
- We evaluate factors that may determine the variation of threshold distributions across locations and time.