Cash or cards? A structural model of payment choices

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New microdata on cash management and payments

- Two ECB surveys: Study on the Use of Cash by Households (2015-16) and Study on the Payment Attitudes of Consumers in the Euro Area on 17 EA countries (W1 in 2019, W2 in 2021-22)
- Granular data on payment and cash management choices (daily diary) + additional information such as preferences and habits (survey questionnaires) and demographics/geographical info
- For any individual, we have detailed data on
  1. cash holdings and withdrawals
  2. transactions and payment method choices (cash/card)
- Information on the supply-side (card acceptance)

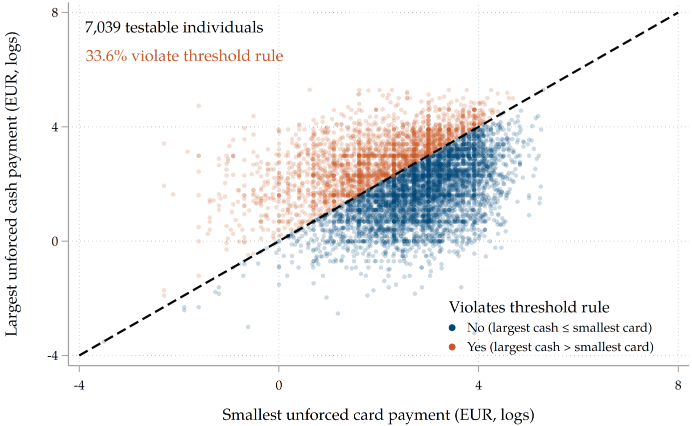
Summary statistics

	Data source								
	SUCH (2015-16)			SPACE I (2019)			SPACE II (2021-22)		
	Mean	Median	N_{obs}	Mean	Median	N_{obs}	Mean	Median	N_{obs}
Households' cash management									
Cash holdings (EUR)	59.99	32	64,632	82.79	40	40,990	90.69	50	39,543
$\Pr$(Withdraws cash)	0.11		64,632	0.13		41,155	0.22		39,343
Withdrawal size (EUR)	68.74	27	4,197	96.34	50	4,129	105.85	50	7,119
Sellers' acceptance of payment methods									
Card accepted	0.72		116,133	0.79		66,913	0.85		75,625
Features of transactions									
Card possible	0.70		115,368	0.77		66,523	0.83		73,180
Cash possible	0.90		132,548	0.87		80,029	0.79		83,376
Unforced (both possible)	0.60		115,368	0.62		66,523	0.61		73,180
Households' payment method choices									
$\Pr$(Card)	0.24		89,941	0.34		41,486	0.49		31,191
$\Pr$(Card | Unforced)	0.26		52,037	0.31		23,841	0.43		17,528

Note: Over the three waves, we observe a total of 263,530 transactions performed by 145,553 individuals.

Patterns of payment choice: data vs models (I)

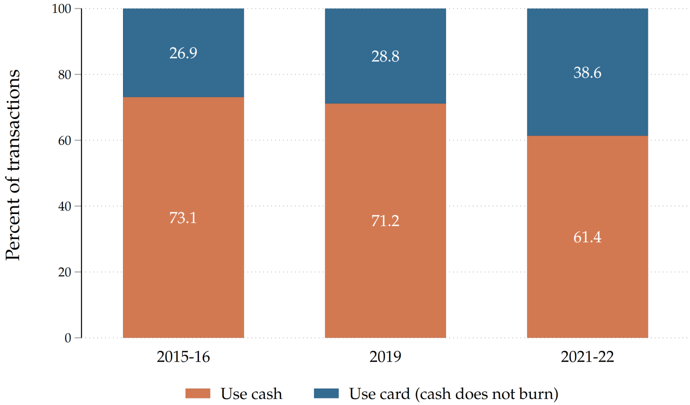
Whitesell (1989): pay cash when transaction size $s < \bar{s}$ and card otherwise



Note: Each dot corresponds to a SUCH/SPACE respondent. In total, we have 7,039 individuals that report both an unforced cash payment and an unforced card payment during the diary day. The black dashed line is the 45 degree line.
Source: Own calculations on data from ECB payment diaries: SUCH (2016) and SPACE (2019 and 2021-22).

Patterns of payment choice: data vs models (II)

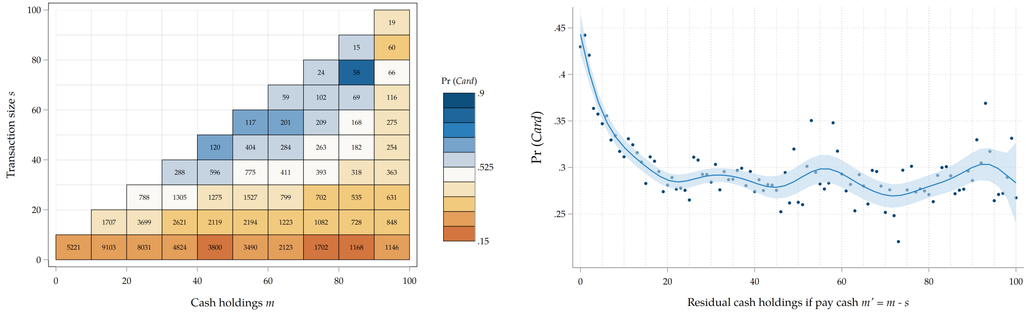
Alvarez and Lippi (2017): pay cash when you have enough $s \leq m$ (*cash burns*)



Note: The figure displays the distribution of payment method choices for *unforced* transactions, i.e., situations in which both cash and cashless methods were viable payment options. We say that *cash does not burn* in situations in which cash is not used despite the possibility to do so.
Source: Own calculations on data from ECB payment diaries: SUCH (2016) and SPACE (2019 and 2021-22).

Patterns of payment choice: interaction of m and s

Cards likely used as $s \to m$



Note: The left panel displays the share of payments settled using cards for bins defined in terms of cash holdings at payment (m) and transaction size faced (s). Numbers denote the number of observations falling in each bin. We focus on transactions where m and s are smaller or equal than 100 euros to avoid having cells with few observations. Only unforced transactions are considered, and transactions with $m = s$ are omitted. The right panel displays the shares of people paying using cashless methods for bins defined in terms of cash holdings remaining in case agents settle the payment using cash (*implied residual cash holdings* $m' = m - s$). A nonparametric fit ($h = 5$) with 95% confidence intervals is overlaid to the plot.

Source: Own calculations on data from ECB payment diaries: SUCH (2016) and SPACE (2019 and 2021-22). Regression

The model

- Purchase opportunities with arrival rate λ, size s, distributed with CDF $F(s)$
- Standard cash-inventory setup, with holding cost Rm, adjustment cost b (at times τ_i)
- Agents endowed with payment card, usage entails fixed cost κ (at times $\hat{\tau}_i$)
- Card acceptance: $\phi < 1$. If no card and $m < s$ then purchase is lost (cost u, times $\tilde{\tau}$)

$$v(m) = \min_{\{w_{\tau_i},\tau_i,\hat{\tau}_i,\tilde{\tau}_i\}_{i=0}^{\infty}} \mathbb{E}\left\{\int_0^{+\infty} e^{-\rho t} Rm(t)dt + \sum_{i=0}^{\infty}\left(e^{-\rho\tau_i} b + e^{-\rho\hat{\tau}_i}\kappa + e^{-\rho\tilde{\tau}_i}u\right) \,\middle|\, m(0) = m\right\}$$

subject to $\quad m(t) = m(0) + \sum_{\tau_i \le t} w_{\tau_i} - \sum_{i=0}^{N(t)} s_i \mathbb{1}\left(p_i = 0\right).$

HJB equation

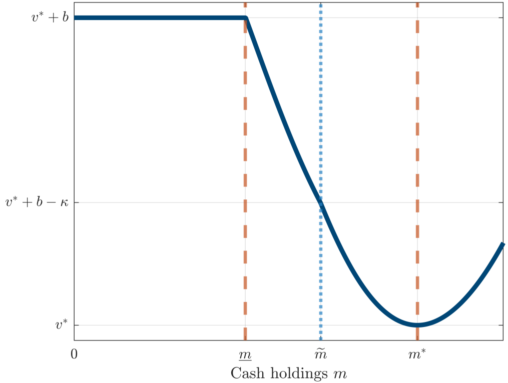
$$v^* = v(m^*), \quad \text{where } m^* = \arg\min v(\cdot).$$

$$\rho\, v(m) = \min \left\{ \rho(v^* + b) \;,\; Rm + \lambda\,(1 - F(m)) \left(\phi\kappa + \underbrace{(1-\phi)u}_{\text{value of lost purchase}} \right) + \right.$$
$$\left. + \lambda \int_0^m \left(\phi \underbrace{\min\left\{ v(m-s) - v(m) \,,\, \kappa \right\}}_{\text{cash or card? (unforced)}} + (1-\phi)\,(v(m-s) - v(m)) \right) dF(s) \right\}$$

- Outer min: withdrawal choice
- Inner min: payment choice for unforced purchases
- Primitives: 7 parameters $\{\rho, \phi, \lambda, \kappa, b, u, R\}$ and distribution $F(s)$

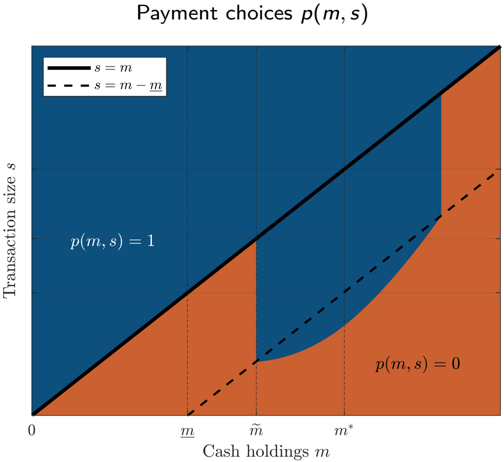
Withdrawal policy

Value function $v(m)$



- For continuous F, sS rule for withdrawals
- withdraw cash when $m < \underline{m}$ and replenish up to m^*
  (note: $\underline{m} > 0$)
- never use cards for $m < \tilde{m}$
  $v(\tilde{m}) = v^* + b - \kappa$
  (note: $\tilde{m} > \underline{m}$)

Payment policy: $p(m, s) = \{0, 1\}$ (0=cash,1= card)

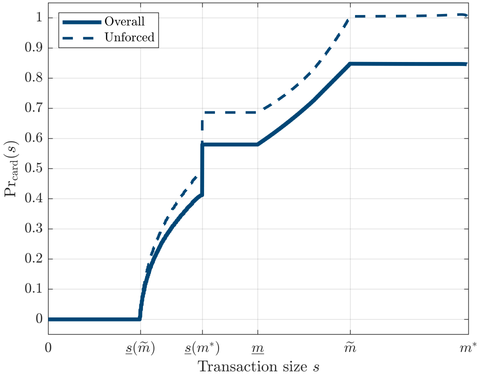


- Focus on the case $0 < \kappa < b$
- never use cards for $m < \tilde{m}$
- For $m \geq \tilde{m}$, use cards for relatively large purchases ($s \geq \underline{s}(m)$)
- if m very high ($m > \tilde{\tilde{m}} > m^*$) pure cash burn
- if $\kappa = 0$ counterfactual policy

More model predictions

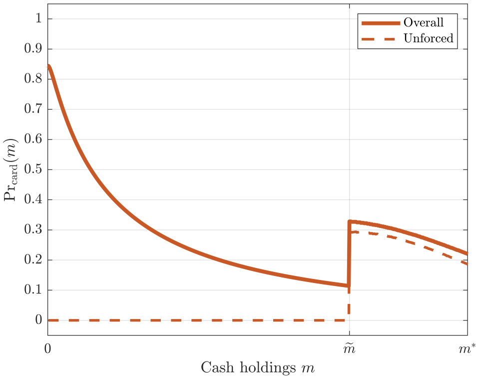
Payment choices, cash holdings and transaction sizes

Figure 2: $\Pr(\text{Card})$ and purchase size *s*



→ generalization of Whitesell's (1989) transaction-size threshold policy

Figure 3: $\Pr(\text{Card})$ and cash holdings *m*



→ generalization of Alvarez and Lippi's (2017) cash burns policy

Model-implied moments

- After solving for $(m^*, \overline{m}, p(m,s))$, we obtain the stationary distribution of cash holdings $h(m)$.
- From $h(m)$ and the optimal policy, we compute cash management statistics
  1. Average cash holdings M
  2. Average number of withdrawals n per unit of time
  3. Average withdrawal size W
  4. Average cash at withdrawals $\underline{M}$
- We also compute payment choice statistics:
  1. Card share of expenditure for unforced transactions $\tilde{\gamma}$
  2. Number of completed purchases $\hat{\lambda}$

Moments

Model calibration

- We calibrate the model at the yearly frequency
- The rate of time preference ρ, the purchase size distribution F $(LN(\mu_s, \sigma_s^2))$ and the rate of card acceptance ϕ are directly calibrated from the data
- Calibrate the 4 remaining parameters by matching four moments via minimum distance

Parameter	Description	Target
R	Opportunity cost of holding cash	Average cash holdings M
κ	Card usage cost	Card share of unforced expenditure $\tilde{\gamma}$
u	Lost purchase cost	Number of withdrawals per year n
λ	Arrival rate of purchase opportunities	Number of purchases per year $\hat{\lambda}$

$\rightarrow$ We cannot directly set λ equal to $\hat{\lambda}$ since some purchases are missed!
We find the λ such that $\hat{\lambda}_{\text{theory}} = \hat{\lambda}_{\text{data}}$

Calibration results and model fit

Calibration results		**Model fit**	Data (2021-22)	Model
Externally calibrated parameters		*Targeted moments*		
Size distribution F, location μ_s	-1.717	Cash balances, M/e	1.13	1.15
Size distribution F, scale σ_s^2	2.121	N. cash withdrawals per year, n	93.15	94.80
Card acceptance rate ϕ	0.845	Card share of unforced expenditure $\widetilde{\gamma}$	0.44	0.43
		N. purchases per day $\hat{\lambda}/365$	1.93	1.92
Internally calibrated parameters (minimum distance)		*Untargeted moments*		
Opportunity cost R	0.063	Cash balances, M/e (median)	0.75	1.15
Card usage cost κ/b	0.601	Cash balances, M/c	2.66	4.62
Purchase oppurt. per day $\lambda/365$	1.928	Cash at withdrawals, $\underline{M}/M$	0.84	0.41
Lost purchase cost u/b	80.341	Withdrawal size, W/M	1.29	0.83
		Card share of expenditure γ	0.57	0.75
		Share purchases lost		0.02

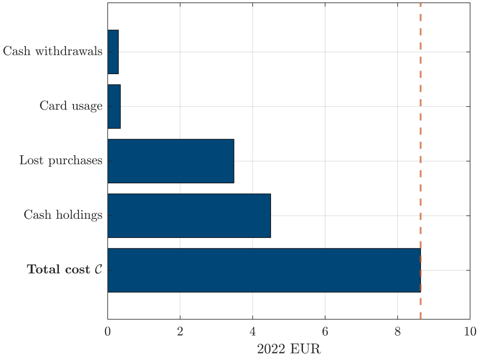
Note: This table contains our calibration results and information on the fit of the model to observed moments (SPACE data, wave 2, 2021-22). The parameter σ_s^2 is calibrated to match the coefficient of variation of purchase sizes $\widehat{\mathbb{CV}}_s$, and μ_s results from a normalization of total yearly expenditure to 365. Fixed withdrawal costs are normalized to $b = 0.5 \times 10^{-4}$. The cost κ of card usage and the cost u of lost purchases are reported as a fraction of b. The number of purchase opportunities per year λ is rescaled at the daily level. Cash balances are normalized by the overall daily expenditure e; we also display cash balances divided by daily *cash* expenditures c.

Application 1: the *cost of managing transactions*

Average household spends ≈ 8 EUR/year to manage consumption transactions

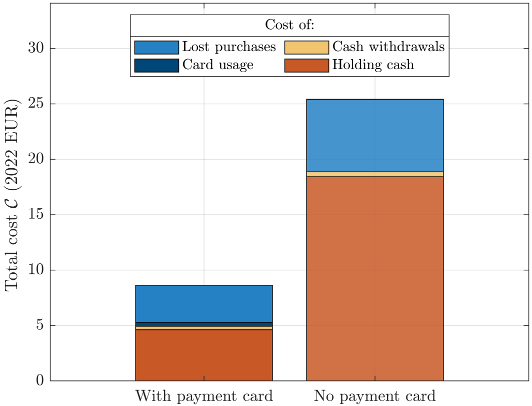
We use the *total cost of managing consumption transactions* in steady state as a welfare measure

$$\mathcal{C} = \underbrace{RM}_{\text{Cash holdings}} + \underbrace{bn}_{\text{Cash withdrawals}} + \underbrace{\kappa\gamma_n\hat{\lambda}}_{\text{Card usage}} + \underbrace{u\left(\lambda - \hat{\lambda}\right)}_{\text{Lost purchases}},$$



Application 2: the benefit of holding a payment card

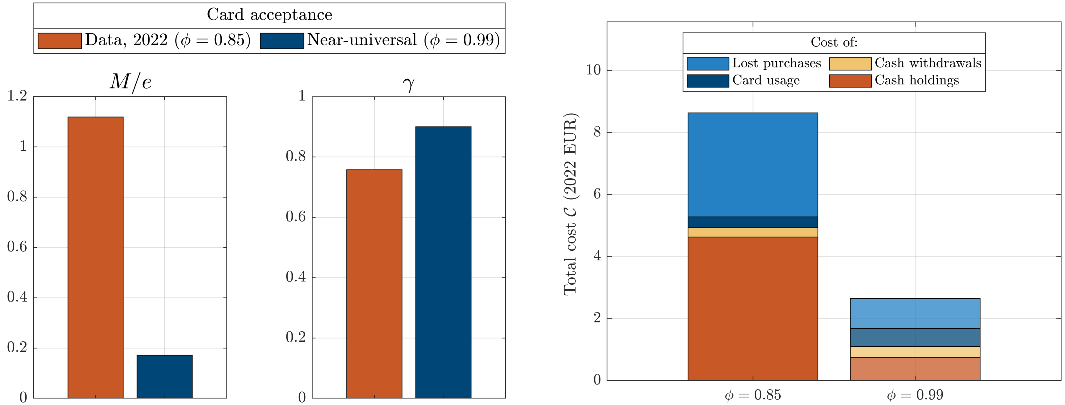
The value of a payment card is ≈ 17 EUR/year



Note: The graph compares the total cost of managing consumption transactions $\mathcal{C}$ for the estimated model with that obtained in an alternative scenario where we set $\phi = 0$, i.e., where the agent cannot use her payment card.

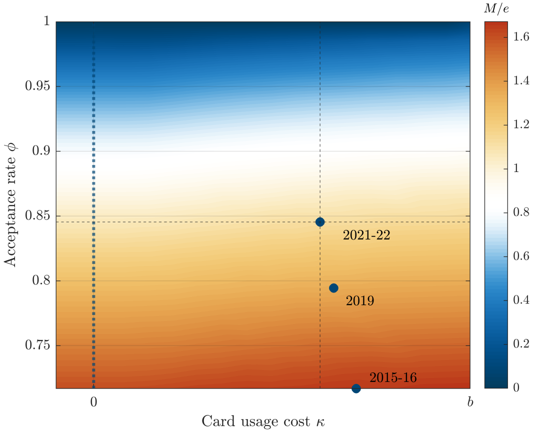
Application 3: near-universal acceptance ($\phi = .99$)

Cash declines but does not disappear; total costs fall by $\approx$ 70%



Note: The left panel compares counterfactual moments obtained by solving the estimated model for 2021-22 with $\phi = 0.99$ and their real-world counterparts under the true acceptance rate $\phi = \widehat{\phi} = 0.85$. Displayed moments are the average cash balances relative to daily expenditure M/e, and the share of expenditure settled using cards γ. The right panel shows the total cost of managing consumption transactions $\mathcal{C}$ (expressed in 2022 euros), both for the estimated model and for the alternative scenario with $\phi = 0.99$.

Application 4: a cashless economy?



Note: The graph displays the model-implied moment M/e, i.e., average cash holdings normalized by daily expenditure for goods and services, in a set of economies with all parameters except κ and ϕ set to their estimated levels for 2021-22. We solve the model for a rectangular array of $\{\kappa, \phi\}$, with $\kappa \in [-b/10, b]$ and $\phi \in [\hat{\phi}_{2015-16}, 1]$. The dashed blue line separate the right region, in which paying with cards is more expensive than using cash, from the left region, in which cards are a cheaper means of payment. The values of $\{\hat{\kappa}, \hat{\phi}\}$ estimated for 2015-16, 2019 and 2021-22 are overlaid to the plot. The dark blue area with $M/e = 0$ denotes the region in the space of (κ, ϕ) in which no-cash policies are optimal.

Supplementary material

Supplementary material

Regression evidence on payment choices

Table 1: Regression evidence on the joint importance of m and s.

Unit: EUR 100	Dependent variable: $PayCard_{it}$							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cash holdings m	-0.12***	-0.11***	-0.042***	-0.060***	-0.060***	-0.054***	-0.0079**	-0.026***
	(0.0017)	(0.0018)	(0.0024)	(0.0028)	(0.0022)	(0.0022)	(0.0029)	(0.0032)
Payment size s	0.68***	0.60***	0.40***	0.45***	0.90***	0.79***	0.64***	0.72***
	(0.0053)	(0.0055)	(0.0100)	(0.010)	(0.0084)	(0.0086)	(0.016)	(0.017)
Cash holdings m $\times$ Payment size s					-0.25***	-0.21***	-0.17***	-0.18***
					(0.0074)	(0.0071)	(0.0089)	(0.0095)
Observations	159359	144525	83412	91995	159359	144525	83412	91995
Unforced			✓	✓			✓	✓
Controls		✓	✓			✓	✓	
Random effects				✓				✓
Robust SEs	✓	✓	✓	✓	✓	✓	✓	✓

Note: Controls include demographic characteristics of individuals (region, country, year of the survey, sex, age group, income, education), as well as available characteristic of payments (type of store where the transaction was carried out, transaction number within diary day). Columns (2-3) and (6-7) include controls such as sex, age group, education and income of respondents. Columns (3-4) and (7-8) only take into account unforced transactions, i.e., transactions where both payments methods were available for the respondent. Columns (4) and (8) include individual-level random effects. Heteroskedasticity-robust standard errors are reported.

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Supplementary material

Model-implied moments I

- Stationary distribution $h(m)$ solves

$$h(m) = \frac{\int_{m}^{m^*} h(m')f(m'-m)\left(1-\phi p(m', m'-m)\right) dm' + h(m^*)f(m^*-m)\left(1-\phi p(m^*, m^*-m)\right)}{F(m) - \int_0^m f(s)\phi p(m,s)ds},$$

with $\int_{\underline{m}}^{m^*} h(m) + h(m^*) = 1$. **Average cash holdings** $M = \int_{\underline{m}}^{m^*} mh(m)dm + m^* h(m^*)$.

- **Card share of unforced expenditure**

$$\widetilde{\gamma} = \frac{\lambda\phi\left(\int_{\underline{m}}^{m^*} h(m)\left(\int_0^m sf(s)p(m,s)ds\right)dm + h(m^*)\left(\int_0^{m^*} sf(s)p(m^*,s)ds\right)\right)}{\lambda\phi\left(\int_{\underline{m}}^{m^*} h(m)\left(\int_0^m sf(s)ds\right)dm + h(m^*)\left(\int_0^{m^*} sf(s)ds\right)\right)}.$$

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- Expected time to withdrawal $t(m)$ solves

$$t(m) = \frac{1 + \lambda \int_0^{m-\underline{m}} f(s)\left(1 - \phi p(m,s)\right) t(m-s) ds}{\lambda \left[F(m) - \int_0^m f(s) \phi p(m,s) ds\right]},$$

and gives the **number of withdrawals per unit of time** $n = \frac{1}{t(m^*)}$

- **Number of completed purchases per unit of time**

$$\hat{\lambda} = \lambda \left(\int_{\underline{m}}^{m^*} h(m) \left(F(m) + (1 - F(m)) \phi\right) dm + h(m^*) \left(F(m^*) + (1 - F(m^*)) \phi\right) \right).$$

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