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Gabriele Camera
Chapman University, camera@chapman.edu

Marco Casari
University of Bologna

Stefania Bortolotti
University of Cologne

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Gabriele Camera
Chapman University
University of Basel

Marco Casari
University of Bologna
IZA

Stefania Bortolotti
University of Cologne

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Abstract

We develop a novel theoretical and experimental framework to study adoption and use of cash versus electronic payments in retail transactions. The design allows us to assess the behavioral impact of sellers' service fees and buyers' rewards from using electronic payments. In the experiment, buyers and sellers faced a coordination problem, independently choosing a payment method before trading. Sellers readily adopted electronic payments but buyers did not. Eliminating service fees or introducing rewards significantly increased adoption and use of electronic payments. Buyers' economic incentives played a pivotal role in the diffusion of electronic payments but cannot fully explain their adoption choices.

Keywords: money, coordination, pricing, transactions
JEL codes: E1, E4, E5

1 Introduction

In the last decades, electronic payments have gained a significant share of retail transactions, eroding the usage share of cash and checks. For example, debit cards have become the most used means of payment in one third of countries across the

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[*] Correspondence address: Gabriele Camera, Economic Science Institute, Chapman University, One University dr., Orange, CA 92866; Tel.: 714-628-2806; e-mail: camera@chapman.edu.
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world (World Bank, 2011). Convenience and reliability are among the suggested reasons for the growing popularity of electronic payments in retail transactions. Yet, significant differences in payment method adoption persist between developed and developing regions and several surveys show that cash enjoys a wide use also in developed economies.[1]

The open issue—and the objective of this study—is to understand the empirical determinants of the adoption of one payment method over another by consumers and retailers. Developing such an understanding is especially important for policymakers—central banks and government regulators—in assessing social costs and benefits associated with the diffusion of specific payment methods.[2] Unfortunately the available data have two limitations. First, estimates of cash usage are unreliable and it is difficult to characterize the relationship between relative payment costs and the adoption of a payment method (Humphrey, 2010). A second limitation is that the available data mostly come from survey answers that are not incentivized and therefore are subject to a number of biases and confounds. This study takes a step towards resolving such problems by constructing in the laboratory a prototypical retail market in which buyers and sellers must coordinate on using a payment method. We build on a literature that has successfully adopted experimental methodologies to empirically analyze the operation of market mechanisms (Smith, 1962), financial markets (in)efficiency (Noussair and Tucker, 2103), and coordination problems (Devetag and Ortmann, 2007; Arifovic et al., 2014; Arifovic and Jiang, 2014).

The primary goal of this study is to identify features of experimental markets that facilitate coordination on electronic payments as opposed to cash payments. We focus on the influence of service fees and rewards associated with electronic

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[1] See for instance World Bank (2011). For the US, Klee (2008) reports that cash captures 54 percent of all transactions collected from scanner data at 99 grocery stores. Survey data from Austria and Canada shows that more than 50 percent of all consumption purchases are paid for with cash (Huyn et al., 2013).

[2] For example, Humphrey (2010) ranks the overall unit cost of various payment methods based on US data and report that debit cards have the lowest cost while cash has the highest ($.90 versus $1.49). There can be also non-monetary considerations such as safety, convenience for record-keeping, privacy, tax evasion and counterfeiting, etc.; for a theoretical discussion of some of these issues see Camera (2001) and Kahn et al. (2005).

payments because these monetary components are at the forefront of the current debate (Board of Governors, 2011). In the experiment we manipulate the cost that sellers sustain from executing an electronic transaction. This cost represents the "merchant service fee" customarily paid by sellers to the service provider—the seller's financial institution.[3] We also manipulate the monetary benefit for buyers who use electronic payments, treating subjects with a monetary reward from electronic purchases, which commonly takes the form of dollars, miles, or other types of bonuses.

We construct a laboratory retail market for a homogeneous good. Before trading, buyers and sellers independently select cash or electronic payment methods, then meet in pairs to trade. In the pair the seller acts as a monopolist, posting a price, and then the buyer chooses a quantity. The payment methods adopted affect the ability to trade and, as a result of decentralized decision-making, payment methods' selections might be incompatible in some trading pairs. A transaction may fail to occur because the seller does not accept the buyer's payment method. The experimental design captures features that are central to the debate about the adoption of electronic versus cash payments. Specifically, the design assumes that cash is legal tender and that sellers cannot price discriminate based on the buyer's payment method. We also consider a design variation in which only sellers make an adoption choice, while buyers are *assumed* to have adopted both payment methods, and can costlessly switch between them in the middle of a transaction.

Analysis of the data suggests the existence of strong behavioral components in the patterns of payment method adoption. First, sellers' service fees on elec-

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[3] Sellers pay a service fee (or discount fee) to the service provider of the electronic payment, which generally takes the form of a percentage of amount transacted. The "interchange transaction fee," which is paid to the debit card issuer, makes up for the largest share of the service fee (U.S. Government Accountability Office, 2009). The Federal Reserve System has recently limited interchange fees for debit cards transactions to 21 cents plus 5 basis points times the transaction value, but only if the issuer of the debit card has more than $10 billion in assets; the average service fee is $0.43 for exempt institutions and dropped to $0.23 for non-exempt (Board of Governors, 2011). Credit card transactions are still exempted. Other components of the service fee are the cost of transaction processing, terminal rental and customer service, and the service provider's margin. There are other fees, such as the authorization fee, paid per authorization, communication fees, etc., but the service fee is the main one *directly* faced by the merchant.

tronic transactions influence payment methods' adoption through an unexpected channel: the presence of fees altered buyers' selection of payment methods significantly more than sellers'. Sellers readily adopted electronic payments and passed on to buyers the anticipated service fees, as theory predicts. Yet, a significant proportion of buyers selected cash payments. This miscoordination on payment methods was the source of trade frictions and, consequently, inefficiencies. This result is robust: when we endowed buyers with both payment methods, they still remained reluctant to pay electronically. A possible interpretation is that buyers hoped to induce sellers to post lower prices by revealing their readiness to pay cash. Second, the experimental data reveal that buyers' rewards from electronic purchases had a significant impact on their choice to pay electronically, and was effective at enhancing the diffusion of electronic payments in the market. The data also allow us to assess the efficiency loss generated by mismatch in adoption of payment systems, which we find to increase with the frequency of cash payments.

The rest of the paper is organized as follows. Section 2 reviews the literature on retail payments. Section 3 presents the experimental design and Section 4 illustrates the theoretical predictions. Section 5 reports the empirical results on payment methods' adoption and aggregate efficiency. Section 6 reports results for the case when only sellers have to make an adoption choice, which serve as a robustness check. Section 7 concludes.

2 Literature review

There is a vast literature on payment systems. Here, we focus on empirical studies that document how consumers' characteristics and payment methods attributes affect the diffusion and use of electronic payments relative to cash.

There is evidence that cash is still predominantly used in low-value transactions. The literature reports a significant correlation between consumers socio-demographic characteristics and the payment method adopted; for example, see Arango et al. (2015) for recent Canadian survey data. Field evidence also suggests that acceptability at the point of sale and monetary incentives are relevant variables. For instance, the study of Austrian and Canadian consumers in Huyn et al. (2013) has documented that acceptability is central to payment method frequency of use. Arango et al. (2015), Ching and Hayashi (2010), and Simon et al. (2010) report that monetary incentives such as buyer rewards and loyalty programs are significantly associated with payment choices. Another important consideration that emerges from field studies is the importance of the relative cost of use of payment methods for their adoption. Borzekowski et al. (2008) document this aspect for consumers, by looking at survey data. In addition, Humphrey et al. (2001) document the existence of a significant sensitivity to relative costs by looking at aggregate-level field data from Norway. There is also evidence that price discrimination plays a role: Bolt et al. (2010) consider survey data from the Netherlands where retailers can price discriminate depending on the payment method used and found that surcharges favor cash over card payments. Finally, some researchers have suggested that a possible reason for the under-utilization of electronic payments systems is the presence of network externalities: Gowrisankaran and Stavins (2004) study the automated clearinghouse electronic payments system of the Federal Reserve System and report the existence of network externalities.

3 Experimental design

This Section presents the set-up of the model and the experimental procedures, while the theoretical predictions are contained in Section 4.[4] The experiment has three main treatments—called Baseline, No-Fee, and Reward—each of which reproduces in the laboratory a prototypical retail market with an even number of homogeneous buyers and sellers, in which frequency of use and acceptability of different payment methods are endogenous. There is an additional treatment, called Switch, which serves as a robustness check and will be discussed in Section

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[4] A variety of models has been proposed to study payment methods. For instance, Camera (2001) studies competition between cash and electronic payments in a random matching model, Freeman (1996) studies payment systems in an overlapping generations model, and Kahn et al. (2005) study the problem of transactions' privacy in a model with spatial separation. The design we adopt is simple enough to be suitable for a laboratory investigation.

6; in that treatment buyers no longer had to make an adoption choice because they were *assumed* to have both payment methods at their disposal, and could switch between methods in the middle of a transaction. Table 1 presents an overview of the treatments.

	Treatment			
	Baseline	No-Fee	Reward	Switch
Parameters				
Service fee for electronic, $1-\varepsilon$	0.1	0	0.1	0.1
Rebate rate for electronic, r	0	0	0.05	0
Predictions and results				
Prices				
Theory $p^*_M, \max p^*_E$	120, 133	120, 120	120, 133	120, 133
Data p_M, p_E	180, 193	203, 190	192, 203	203, 221
Quantities				
Theory $q^*_M, \min q^*_E, \min \hat{q}^*_E$	2, 1.62, 1.62	2, 2, 2	2, 1.62, 1.79	2, 1.62, 1.62
Data q_M, q_{ME}, q_E	1.24, .97, .85	1.27, .93, 1.06	1.19, .95, .92	.99, .82, .94
Adoption of cash payments				
Sellers (% of choices)	14.4	2.5	6.2	29.1
Buyers (% of choices)	55.3	13.0	28.2	—
Cash use (% of all settlements)	54.9	11.9	27.6	52.0
Sessions (dd/mm/yy)				
	26/01/12	24/01/12	31/01/12	22/01/15
	26/01/12	24/01/12	0 2/02/12	23/01/15
	12/03/13	11/03/13	13/03/12	23/01/15
	12/03/13	11/03/13	13/03/12	24/01/15
N. participants	64	64	64	64

Table 1: Overview of the experiment

Notes: Prices: p^*_M = equilibrium price posted by sellers who only accept cash (M stands for manual, the word used in the experiment); p^*_E = upper bound of equilibrium price posted by sellers who accept both payment methods (E stands for electronic); p_M = average price posted by sellers who only accepted cash in the experiment; p_E = average price posted by sellers who accepted both payments in the experiment. Quantities: q^*_M = equilibrium demand for buyer who pays cash when price is p^*_M; $\min q^*_E$ = equilibrium demand for buyer who pays cash when price is p^*_E; $\min \hat{q}^*_E$ = equilibrium demand for buyer who pays electronically when price is p^*_E; q_M = average quantity purchased from sellers who only accepted cash; q_{ME} = average quantity purchased with cash from sellers who accepted electronic payments; q_E = average quantity purchased by buyers who paid electronically. Quantities refer to completed trades; prices are rounded to the nearest integer. In the Switch treatment, buyers had access to both payment methods; hence, no adoption choice is reported for them and quantities are calculated using buyers' preferred method of payment. Sessions were conducted at Purdue University in 2012, and at Chapman University in 2013 and 2015.

Overview of a session. In each session, sixteen subjects are randomly divided into two groups: eight buyers and eight sellers. Subjects interact anonymously and play 40 trading periods always in the same role but with changing trading partners. In each period, sellers are monopolists who can produce a non-storable good for buyers who are endowed with m transaction balances, called tokens. Sellers and buyers can remain idle or trade goods for tokens. Tokens have a fixed redemption value, while the value of a good to a buyer (or, seller) depends on the quantity consumed (or, produced).

A trading period includes six stages:

(1) Payment method choice: everyone independently selects a means to settle the current trade, cash or electronic, i.e., how to transfer tokens from buyer to seller;

(2) Pricing: each seller chooses a unit price $p \in [0, 400]$ for the good;

(3) Matching: buyer-seller pairs are randomly formed, according to a strangers matching protocol;

(4) Demand: each buyer observes the posted price p and demands $q \in [0, 4]$ goods;

(5) Payment: buyers complete the trade by transferring no less than pq tokens to the seller;

(6) Outcome: payoffs are realized.

The Baseline treatment captures two key empirical characteristics of retail payments. Sellers cannot refuse cash (called "manual payment" in the experimental instructions, see Supplementary Information). Electronic payments are more convenient and reliable than cash payments, but are also more costly for sellers.

In the experiment all sellers must accept cash and their choice is whether to also accept electronic payments. Buyers must select either cash or electronic payment for the period—a design feature that decreases complexity, as buyers do not have to make an additional portfolio choice. The choice of payment method is costless and remains private information until the outcome stage.

When everyone has selected a payment method, each seller chooses a price p. Then, in each round, buyer-seller matches are randomly formed with uniform probability among all possible matches. At this point, each buyer sees the seller's price and is given the opportunity to demand a quantity q. Choosing $q = 0$ amounts to choosing not to trade. Finally, buyers must pay, after which earnings are realized at the end of the period. The interaction is local: subjects observe only the outcome in their pair and have no information about the economy as a whole.

Furthermore, the interaction is anonymous: subjects cannot see the identity of the other person in their pair (experimental ID), hence there is no scope for reputation formation.

Payoffs. Subjects' instructions (see Supplementary Information) described the payoff functions in tokens, by means of tables and charts reporting tokens' earnings for given amounts $q \geq 0$ traded.

If there is no trade ($q = 0$), then the buyer's payoff corresponds to his transaction balance endowment for the period, m, which is a random integer uniformly distributed between 250 and 350 tokens. The seller's payoff corresponds to a fixed endowment $A = 350$, a parameter introduced to minimize differences in cash payments for subjects with different roles.

If there is trade (and the buyer earns no rebates), then the buyer's payoff is

$$m + u(q) - pq,$$

where $u(q) = 2\theta\sqrt{q}$ is the consumption utility, pq is the expenditure and $\theta = 169.5$. The seller's payoff is

$$A + q(\varepsilon p - g) - F.$$

Net earnings include the gross revenue pq minus production costs and possible service fees. Production costs have a fixed component $F = 15$ and a variable component gq, with $g = 60$. If payments are electronic, then the seller pays the *merchant service fee* $(1 - \varepsilon)pq$, where $1 - \varepsilon$ is called the *service fee.* The service fee is a treatment variable in the experiment (Table 1); it takes values 0.1 in Baseline and Reward, and 0 in No-Fee where the seller's payoff is thus simply $A + q(p - g) - F$.[5]

Settling a trade. A trade of quantity q and price p can take place only if the

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[5] In field economies, sellers who accept credit or debit cards pay a Merchant Discount Rate or Merchant Service Fee to the acquirer bank. Service fees range from a few basis points up to 3% or more, and account for costs for electronic payment processing, settling fees, interchange fees paid to the issuer, etc. In addition to explicit service fees, there may be implicit costs associated with tax-avoidance, which is more easily accomplished if payments are made in cash. Given these considerations, the 10% fee of the design—selected to better differentiate equilibrium prices across treatments— is therefore not so much unrealistic.

seller accepts the buyer's method of payment, and if the buyer has transaction balances $m \geq pq$. A buyer starts the period with m transaction balances in a cash or an electronic account (depending on the payment method chosen). Cash payments have an explicit manual component. A buyer's cash account displays the transaction balances as a set of tokens of different sizes (1, 5, 10, or 50-unit tokens) ordered from large to small. Large-size tokens can be broken down into smaller ones by clicking a button. To pay the amount pq, the buyer must manually select a suitable combination of tokens with a series of mouse clicks, and then must execute the payment by clicking a button (see Instructions). Electronic payments, instead, are executed with a mouse click, which immediately transfers pq tokens to the seller. Hence, electronic payments eliminate execution errors and minimize the effort and time to completion.

To induce differences in reliability and convenience of the two payment methods, subjects face a trading-time constraint. The entire trade sequence, from Pricing to Payment (stages 2-5), must be completed within 60 seconds.[6] A trading clock starts after everyone has selected their payment method and trade fails if payments are not completed in time.

Outcomes. A transaction (or trade) *succeeds* if the seller accepts the buyer's payment method, the trade is executed on time, and with a sufficient transfer of tokens. Otherwise the trade *fails*. At the end of each period, in the Outcome stage, buyer and seller are informed whether trade succeeded or failed. In the first case, they see the quantity traded, the earnings, and the payment method selected by their counterpart. Otherwise, they are informed about the reason for the failure. At each point in time, subjects can see their own trading history in the session. These rules and parameters are common knowledge.

The treatments No-Fee and Reward. Compared to the Baseline treatment, in the No-Fee treatment the sellers' service fee is set to zero, so $\varepsilon = 1$ in the seller's payoff function. In the Reward treatment, instead, half of the seller's service fee

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[6] To familiarize subjects with the experiment, in periods 1-6 the time constraint was 120 seconds and the payment method was exogenously imposed (electronic in periods 1-3, and cash in periods 4-6).

is rebated to the buyer. Hence, letting $r = \dfrac{1-\varepsilon}{2}$ denote the generic rebate rate in the Reward and No-Fee treatments, the buyer's payoff can be written as

$$m + u(q) - pq(1-r),$$

where the treatment variable $r = 0.05$ in Reward because $1-\varepsilon = 0.1$, while $r = 0$ in No-Fee because $1-\varepsilon = 0$ in which case the buyer's payoff is as in Baseline (see Table 1).

We recruited 256 undergraduate subjects, half at Purdue University and half at Chapman University for the three main treatments and all at Chapman University for the Switch treatment (Table 1). The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007). Instructions were read aloud at the start of the experiment and left on the subjects' desks. No eye contact was possible among subjects. Average earnings were \$22 per subject.[7] On average, a session lasted about 2 hours, including instruction reading, a quiz, and final payments.

4 Theoretical predictions

This section studies the symmetric Nash equilibria of the game for the three main treatments, which we have described in the previous section. To do so, we move backwards, starting with the derivation of the optimal demand schedule in a trade match, given a price p and rebate rate r. Then, we study the optimal price posted by sellers given a service fee $1-\epsilon$. Finally, given optimal pricing and demand schedules, the optimal payment method adoption strategy is studied.

Let $\mu_i \in [0,1]$ denote the probability that player $i = b, s$ ($b =$buyer, $s =$seller) selects cash payments. Hence, μ_s is the probability that a seller only accepts cash, $1-\mu_s$ is the probability that a seller also accepts electronic payments, while $1-\mu_b$ and μ_b are, respectively, the probabilities that a buyer pays electronically and with

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[7] The show up fee was \$5 for all treatments at Purdue (at Chapman, \$14 for No-Fee and \$7 for the other treatments) and the conversion rate was 7 cents for every 100 tokens at Purdue (at Chapman, \$0.07 for No-Fee and \$0.12 for the other treatments). Following local lab standards, Chapman students were paid more.

cash. The following definitions will be helpful in what follows:

- *Acceptability of electronic payments* is the probability that a seller accepts an electronic payment, $1-\mu_s$. Cash payments are always accepted.

- The *reliability* of a payment method is the probability of a successful trade conditional on the given payment method being accepted by the seller. In the experiment, reliability is endogenous. The (absolute) reliability of electronic payments is denoted R_e and the (absolute) reliability of cash payments is denoted R_m. Let $\sigma := R_m/R_e$ be the relative reliability of cash payments.

- *Trade risk* for a buyer is the probability of failing to trade with a given payment method because of acceptability or reliability problems. The trade risk of electronic payments is $\mu_s + (1-R_e)(1-\mu_s)$. The trade risk of cash payments is $1-R_m$.

- *Trade frictions* in the economy are the expected share of failed trades out of all possible trades, i.e., the expected failure rate of electronic transactions (due to mismatch and reliability problems) and of cash transactions (due to reliability problems). Normalizing trade frictions by the reliability of electronic transactions when R_e is close to one, trade frictions are approximately[8]

$$\tau := (1-\mu_b)\mu_s + (1-\sigma)\mu_b.$$

In the experimental data R_e is close to one, but R_m is not. Hence, theoretical predictions can be derived considering electronic transactions as being approximately always reliable, implying that σ approximates the reliability of cash payments, while $1-\sigma$ and μ_s approximate the trade risk of cash and electronic payments.

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[8] The expected share of failed trades out of all possible trades is

$$\tau^* := (1-\mu_b)\mu_s + (1-R_e)(1-\mu_b)(1-\mu_s) + (1-R_m)\mu_b,$$

i.e., the expected failure rate of electronic transactions (first two terms, capturing mismatch and reliability problems) plus that of cash transactions (third term). Normalized trade frictions are $\tau = \frac{\tau^*}{R_e}$. For $R_e \approx 1$—as in the experimental data (see later)—we have $\tau \approx (1-\mu_b)\mu_s + \mu_b(1-\sigma)$, where $\sigma = \frac{R_m}{R_e}$.

4.1 Prices and quantities

Optimal demand is characterized in the following lemma.

Lemma 1 (Optimal demand). *Given a price p and a rebate parameter r, the optimal demand of an unconstrained buyer satisfies*

$$q(p; r) := \left(\frac{\theta}{p}\right)^2 \times \frac{1}{(1-r)^2},$$

while a constrained buyer demands m/p.

Proof. See Appendix. ☐

If the buyer's transaction balances are insufficient to satisfy her demand, $m < p \times q(p; r)$, then the optimal quantity demanded is simply m/p. Otherwise, if the buyer is unconstrained, she optimally demands $q(p; r)$ goods. This quantity decreases with the price p and increases with the rebate rate r.

The model is parameterized so that in equilibrium demand is always interior (see Supplementary Information). The quantity demanded is unaffected by the seller's payment method because sellers cannot price-discriminate. It depends on the buyer's payment method if there are rewards from electronic payments. The quantity *traded*, instead, depends on the payments methods of both parties.

To derive the optimal pricing schedule, recall that sellers are monopolists with linear payoffs over tokens. They choose a price p to maximize expected profits. A trade succeeds only if the seller accepts the buyer's payment method and, conditional on that, if the trade can be executed on time.

Lemma 2 (Optimal posted price). *Consider the treatment parameters (ε, r) and the endogenous probabilities (μ_b, σ). The profit-maximizing prices for a seller who, respectively, refuses and accepts electronic payments are*

$$p_M := 2g \qquad \text{and} \qquad p_E := p_M \times \frac{\mu_b \sigma (1-r)^2 + (1-\mu_b)}{\mu_b \sigma (1-r)^2 + (1-\mu_b)\varepsilon}.$$

Proof. See Appendix. ☐

A seller who does not anticipate receiving electronic payments posts a price p_M, which is below the price p_E posted if some electronic payments are expected, where

$$p_M \leq p_E \leq \frac{p_M}{\varepsilon},$$

Sellers who expect some electronic payments charge premium prices to recoup the expected service fees. The premium depends on the anticipated incidence of electronic transactions, and therefore is bounded above (approximately) by the service fee $1-\varepsilon$; it falls in μ_b and converges to zero as $\mu_b \to 1$.[9]

To summarize, the design ensures that if sellers pay a service fee to receive electronic payments (Baseline), then they charge premium prices, where the premium is roughly equal to the service fee $1-\varepsilon$. If buyers earn rewards from electronic purchases (Reward), then they increase their demand by a percentage roughly equal to the service fee. If electronic payments have neither costs nor benefits (No-Fee), then prices and quantities are independent of the payment method adopted.

4.2 Payment methods' adoption

Given optimal prices and quantities, we determine the choice of payment methods in symmetric Nash equilibrium. In doing so, we differentiate *use* from *adoption* of a payment method. Use refers to the payment method utilized in a successful trade. Adoption refers to the individual choice of payment method.

Using Lemma 1, let $q(p) := q(p; 0)$ when $r = 0$, hence let $q_E := q(p_E)$ and $q_M = q(p_M)$ denote the (optimal) quantity demanded by a buyer who pays cash and faces, respectively, prices p_E and p_M. In contrast, let

$$\hat{q}_E := \frac{q(p_E)}{(1-r)^2}$$

denote the quantity demanded by a buyer who pays electronically; clearly, the buyer cannot trade with sellers posting p_M, because they only accept cash. Using a linear approximation around $\varepsilon = 1$, observe that $\hat{q}_E/q_E \approx 1-\varepsilon$ when ε is small. To summarize, all else equal, buyers demand an identical quantity unless rewards are given for electronic payments; in that case, buyers who have selected electronic payments demand more than other buyers.

Let μ_i denote the probability that any player i selects cash payments in sym-

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[9] Due to the fixed cost F, sellers trade only if their expected profit is non-negative. The design parameters ensure that equilibrium profits are positive, i.e., F is below net earnings $q(p;r)(\varepsilon p - g)$ and $q(p)(p-g)$. See Supplementary Information.

metric Nash equilibrium. The equilibrium payoff $\mathcal{V}^b_j$ to a buyer who pays using method $j = E, M$ and has m transaction balances is

$$\begin{aligned} \mathcal{V}^b_E &= m + (1-\mu_s)[u(\hat{q}_E) - p_E(1-r)\hat{q}_E], \\ \mathcal{V}^b_M &= m + \sigma\left\{(1-\mu_s)\left[u(q_E) - p_E q_E\right] + \mu_s\left[u(q_M) - p_M q_M\right]\right\}. \end{aligned} \tag{1}$$

Sellers who, respectively, accept and refuse electronic payments have payoffs

$$\begin{aligned} \mathcal{V}^s_E = \quad & A + \mu_b\sigma[q_E(p_E - g) - F] + (1-\mu_b)[\hat{q}_E(\varepsilon p_E - g) - F], \\ \mathcal{V}^s_M = \quad & A + \mu_b\sigma[q_M(p_M - g) - F]. \end{aligned}$$

The payoff-maximizing choice of payments method μ'_j for player $j = b, s$ satisfies

$$\mu'_j = \begin{cases} 1 & \text{if } \mathcal{V}^j_M - \mathcal{V}^j_E > 0 \\ [0,1] & \text{if } \mathcal{V}^j_M - \mathcal{V}^j_E = 0 \\ 0 & \text{if } \mathcal{V}^j_M - \mathcal{V}^j_E < 0. \end{cases}$$

Traders evaluate the expected relative benefits of paying with cash and electronically. Everyone benefits from the greater reliability of electronic payments. However, buyers and sellers face different incentives. For buyers, electronic payments generate rewards but may also carry the risk of being declined. The opposite is true for sellers; accepting electronic payments resolves coordination problems in payment methods, but using them may generate costs. This generates coordination problems.

Proposition 1 (Equilibria). *Let prices and quantities satisfy Lemmas 1-2. Every treatment supports two symmetric pure-strategy Nash equilibria characterized by homogeneous adoption of a single payment method.*

Proof. See Appendix. ☐

The design ensures that in all treatments two Nash equilibria coexist, which are characterized by the uniform adoption of one payment method. The two pure strategy equilibria $\mu_j = 0, 1$ for $j = b, s$ coexist in each treatment (Table 1).[10] These equilibria always coexist because payment method choices are strate-

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[10] The Appendix reports the complete set of symmetric equilibria. In particular, there exists a symmetric equilibrium in which sellers mix, while buyers adopt cash payments. This equilibrium is not robust to trembles as it introduces mismatch risk; hence, sellers have an incentive to accept both payments since there is no cost from doing so.

gic complements. If sellers refuse electronic payments, then a buyer's dominant action is to pay cash, hence $\mu_b = \mu_s = 0$. If every seller accepts both payment methods, then buyers prefer electronic payments when these generate rewards or are more reliable; otherwise, buyers are indifferent. Hence, $\mu_b = \mu_s = 1$ is always a symmetric equilibrium. It follows that, in each treatment, subjects face a coordination problem, which by design cannot be solved through communication.

Note that payment methods' adoption choices have implications for the level of trade frictions τ in the economy. Although cash payments are less reliable than electronic, buyers' adoption of cash payments is not necessarily a source of trade frictions. In fact, an increase in buyers' frequency of adoption of electronic payments reduces trade frictions τ only when electronic payments have a lower relative trading risk, $\mu_s < 1 - \sigma$. Therefore, this design ensures an endogenous association between relative diffusion of electronic payments and trade frictions. This, and the pricing associated with different adoption modes, has implications for efficiency, as we explain next.

4.3 Efficiency

The economy may exhibit inefficiencies because of pricing distortions, which lead to inefficient quantities, and because of frictions due to failed transactions.

Consider the first inefficiency, which is along the intensive margin. Let q^* satisfy $u'(q^*) = g$, where $q^* := \left(\frac{\theta}{g}\right)^2$. From Lemmas 1-2, the quantities traded in each of the two pure strategy equilibria are

$$q = \begin{cases} q_M = q^*/4 & \text{if } \mu_b = \mu_s = 1, \\ \hat{q}_E = (q^*/4) \times \left(\frac{\varepsilon}{1-r}\right)^2 < q_M & \text{if } \mu_b = \mu_s = 0. \end{cases}$$

Traded quantities are inefficiently low when all transactions involve costly electronic payments because service fees amount to a distortionary tax. Minimum equilibrium consumption occurs when buyers earn no rewards, $r = 0$. It follows that trade surplus is the lowest when costly electronic payments are adopted, because

$$\begin{aligned} u(\hat{q}_E) - g\hat{q}_E \qquad &= \frac{3\theta^2}{4g} \times \frac{\varepsilon}{1-r}\Big[1 - \frac{\varepsilon}{4(1-r)}\Big] - F \\ &< \frac{3\theta^2}{4g} - F = u(q_M) - gq_M. \end{aligned} \tag{2}$$

Now consider the extensive margin inefficiency. We measure aggregate efficiency by ex-ante social welfare $\mathcal{W}$, defined as the sum of payoffs to buyer and seller, net of fixed payments, plus un-rebated service fees, i.e.,

$$\mathcal{W} := \sum_{i=b,s} [\mu_i \mathcal{V}^i_M + (1-\mu_i)\mathcal{V}^i_E] + (1-\mu_b)(1-\mu_s)p_E q(p_E; r)(1-\varepsilon-r) - (A+m),$$

Here, service fees are not a deadweight loss because they either compensate buyers (rewards) or some unmodeled service providers. In the expression $\mathcal{W}$ service fees are net of rewards, $p_E q(p_E; r)(1-\varepsilon-r)$, and are multiplied by $(1-\mu_b)(1-\mu_s)$, which is the expected frequency of electronic purchases. Substituting for $\mathcal{V}^i_E, \mathcal{V}^i_M$ we obtain

$$\begin{aligned} \mathcal{W} = (1-\mu_b)(1-\mu_s)[u(\hat{q}_E) - g\hat{q}_E - F] + \mu_b(1-\mu_s)\sigma[u(q_E) - gq_E - F] \\ + \mu_b\mu_s\sigma[u(q_M) - gq_M - F]. \end{aligned} \tag{3}$$

The expression above indicates that a planner would impose the uniform adoption of the highest-return payment method to avoid mismatch in payment preferences, and note that

$$\mathcal{W} = \begin{cases} \mathcal{W}_M := \sigma[u(q_M) - gq_M - F] & \text{if } \mu_b = \mu_s = 1, \\ \mathcal{W}_E := u(\hat{q}_E) - g\hat{q}_E - F & \text{if } \mu_b = \mu_s = 0. \end{cases}$$

What payment system would the planner adopt, then?

		Sellers	
		Cash	Cash+Electronic
Buyers	Cash	$\sigma[u(q_M) - gq_M - F]$	$\sigma[u(q_E) - gq_E - F]$
	Electronic	0	$u(\hat{q}_E) - g\hat{q}_E - F$

Table 2: Efficiency as a function of adoption choices

Notes: Each cell reports the ex-ante social welfare $\mathcal{W}$ from (3) for all combinations (μ_b, μ_s).

Proposition 2 (Efficiency). *Let prices and quantities satisfy Lemmas 1-2. If the relative reliability of cash payments is*

$$\sigma \leq \sigma^* := \frac{u(\hat{q}_E) - g\hat{q}_E - F}{u(q_M) - gq_M - F},$$

then social welfare $\mathcal{W}$ is maximized by common adoption of electronic payments.

To prove it, note that cash trades are associated with the greatest trading efficiency, $\hat{q}_E \leq q_M$, but are unreliable—trade succeeds only with probability σ. The planner selects electronic payments if $\mathcal{W}_M \leq \mathcal{W}_E$, i.e., when cash payments are sufficiently unreliable. This occurs if $\sigma \leq \sigma^*$ where $\sigma^* < 1$ whenever $\varepsilon < 1$; see (2). Given the design parameters we have $\sigma^* = .93$ in Baseline and $\sigma^* = .96$ in Reward. It is immediate that $\sigma^* = 1$ in No-Fee since quantities are independent of the payment method used; coordinating on the use of electronic payments is always optimal in this treatment since there are no price distortions. For the other treatments, it depends on the realized value of σ.

5 Results: main treatments

This section focuses on two questions: did our experimental markets succeed in coordinating on using a common payment method? And how did service fees and rewards associated with electronic payments alter trade patterns and efficiency? We report four main results. Results 1-3 concern the diffusion of the payment methods. Result 4 reports the relationship between payment methods and trade frictions and efficiency.

All analyses focus on the three main treatments and exclude the initial six periods, where, in order to familiarize participants with the task, only one payment method was made available. Hence, *adoption* refers to the individual choice of payment method, and *use* refers to the payment method employed in a successful transaction. Section 6 will subsequently discuss the robustness of the results to the alternative design adopted in the Switch treatment—where buyers were assumed to be able to pay with either method.

Result 1 (Use of payment methods). *There was mixed use of payment methods in the Baseline treatment. The use of electronic payments prevailed in the No-Fee and Reward treatments.*

Tables 1 and 3 provide support for Result 1. Among all trades that are successfully completed, 45.1 percent were settled with an electronic payment in Baseline, 72.4 in Reward and 88.1 in No-Fee (Table 1). A Wilcoxon rank-sum test reveals that both the difference between Baseline and No-Fee and between Baseline and Reward are significant ($p = 0.021$ and $p = 0.083$ respectively, two-sided, $N_1 = N_2 = 4$). Further support is provided by a probit regression, where the dependent variable is the use of payment methods and takes value 1 for electronic trades and 0 for cash trades (Table 3, Model 1). The econometric analysis shows that introducing rewards for buyers or eliminating sellers' service fees significantly raised overall use of electronic payments.

Recall that in all treatments the equilibrium where everybody trades with cash coexists with the one where all trades are electronic. A possible interpretation of Result 1 is that the cost associated with electronic payments serves as a coordination device for payment methods' selection.

To shed further light on Result 1, we separately study the adoption choices of sellers and buyers.

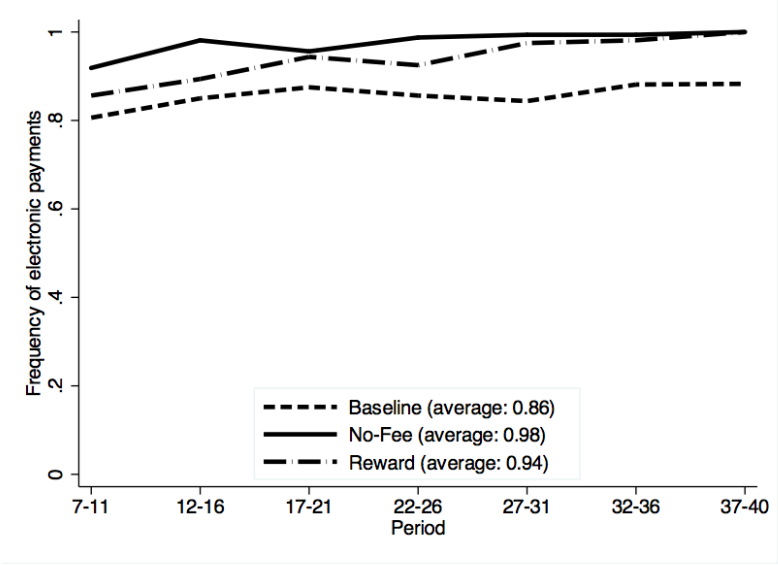
Result 2 (Adoption choices). *In all treatments, sellers were more likely to adopt electronic payments than buyers.*

Figure 1 shows adoption rates by type of trader. Pooling all treatments, sellers chose electronic payments in 92 percent of cases, while buyers adopted electronic payments in 68 percent of instances; such difference is significant according to a Wilcoxon rank-sum test ($p < .001$, two-sided, $N_B = N_S = 12$). Buyers were significantly more reluctant to adopt electronic payments than sellers in each treatment ($p = .043, .020, .021$ in Baseline, No-Fee, and Reward, respectively; two-sided Wilcoxon rank-sum, $N_B = N_S = 4$). This significance is confirmed by a probit regression where the dependent variable is the payment method adopted by a trader (Table 3, Model 2); the disparities in adoption rates between buyers and sellers (Buyer role dummy) remain significant even after controlling for treatment effects.

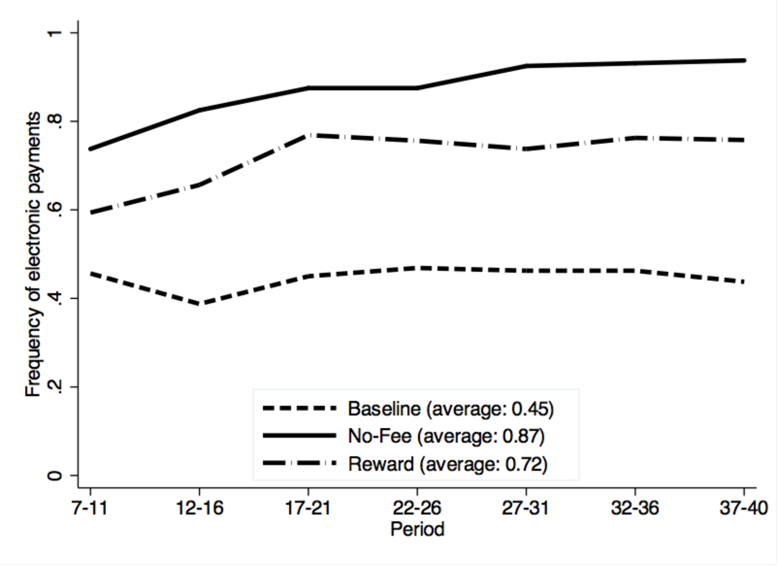
Dependent variable:	**Use**		**Adoption**	
Payment method		Pooled	Buyers	Sellers
(1=electronic, 0=cash)	Model 1	Model 2	Model 3	Model 4
No-Fee treatment	2.831 ***	1.677 ***	2.391 ***	0.918 ***
	(0.473)	(0.261)	(0.406)	(0.301)
Reward treatment	1.507 ***	0.721 ***	1.390 ***	0.134
	(0.469)	(0.246)	(0.395)	(0.276)
Buyer role		-1.346 ***		
		(0.208)		
Period	0.025 ***	0.029 ***	0.024 ***	0.039 ***
	(0.004)	(0.003)	(0.003)	(0.005)
Purdue location	-0.599	-0.553 ***	-0.438	-0.622 ***
	(0.375)	(0.207)	(0.323)	(0.236)
Constant	-0.650 *	1.024 ***	-0.683 **	1.159 ***
	(0.393)	(0.240)	(0.332)	(0.257)
N.obs.	2986	6528	3264	3264
Log likelihood	-904.833	-1698.241	-1112.420	-573.073

Table 3: Use and adoption of electronic payments

Notes: Probit regression with individual random effects. The dependent variable takes value 1 if electronic payments are chosen and 0 otherwise. Model 1 studies the use of payment methods considering only observations corresponding to buyers who successfully traded. Models 2—4 study the adoption of payment methods; model 1 pools adoption choices of sellers and buyers, while models 3 and 4 separately consider adoption choices of buyers and sellers, respectively. The default treatment is Baseline. The explanatory variable *Buyer role* equals 1 for a buyer and 0 for a seller, while the dummy *Purdue* assumes value 1 for sessions carried out at Purdue University and 0 for sessions at Chapman University. Periods 7-40 and main treatments only. Symbols $***$, $**$, and $*$ indicate significance at the 1%, 5% and 10% level, respectively.



(a) Sellers



(b) Buyers

Figure 1: Adoption of electronic payments

It is surprising that buyers were reluctant to adopt electronic payments, and sellers were not, because buyers never suffered a direct cost, while sellers did. Hence, one would imagine that buyers would readily adopt the most convenient method, while sellers might not. Instead, the opposite holds true. Introducing buyers' rewards from electronic purchases or eliminating sellers' service fees boosts the diffusion of electronic payments primarily because it alters buyers' behavior. On average, 45 percent of buyers chose electronic payments in Baseline, a rate that increased to 72 percent if rewards were added and to 87 percent if fees were removed. The increases relative to Baseline are significant as shown by a probit regression (Model 3 in Table 3) and by non-parametric tests ($p = 0.021$ and $p = 0.083$ for No-Fee vs. Baseline and Reward vs. Baseline, respectively; two-sided Wilcoxon rank-sum, $N_1 = N_2 = 4$). In contrast, sellers' adoption choices are less sensitive to changes across treatments. Average adoption rates of electronic payments for sellers were 86, 94 and 98 percent in Baseline, Reward, and No-Fee. The only significant difference is between No-Fee and Baseline according to a probit regression (Model 4 in Table 3); the magnitude of the effect is also smaller for sellers than buyers.[11] This is interesting because it implies that subjects' dollar costs and revenues from using electronic payments cannot entirely explain adoption choices in the experiment.[12]

A referee noted that some of our findings may hinge on the existence of feedback effects between the two sides of the market—some form of network externality. Buyers will more readily adopt electronic payments when many sellers adopt electronic payments, for instance. To test this hypothesis, we estimated sellers and buyers' decisions jointly using a bivariate probit model (see Supplementary Information). In one model we also included lagged regressors that capture the counterparts' past behavior because in the experiment individuals on each side

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[11] According to non-parametric analysis, the only significant difference is between No-Fee and Reward ($p = 0.042$, two-sided Wilcoxon rank-sum, $N_{NF} = N_R = 4$).

[12] All else equal, a decrease in ε from 1 to 0.9 generates lower dollar earnings for subjects who sell electronically, because now they are charged a service fee. The data reveal that altering the subjects' monetary incentives by eliminating this service fee in the No-Fee treatment does not significantly increase the seller's frequency of electronic payments' adoption relative to the Baseline treatment. Hence, this variation in dollar earnings is not sufficient to significantly alter the subjects' behavior.

of the market slowly learn about behavior of the other side through personal experience. We find support for the notion that past experience influences present behavior, but the correlations of residuals—although positive—are insignificant, suggesting that network externalities do not play a role.

Result 3 (Buyers' adoption choices). *Regular users of cash payments emerged only in Baseline. Removing service fees and adding rewards greatly increased the number of regular users of electronic payments.*

	Treatment		
Share of buyers	Baseline	No-Fee	Reward
Regular users			
Cash payment	0.22	0.00	0.00
Electronic payment	0.06	0.44	0.22
Occasional users			
1 or 2 switches	0.13	0.25	0.16
3 or more switches	0.59	0.31	0.63

Table 4: Buyers' adoption of payment methods

Table 4 provides support for Result 3. Buyers who always adopted cash payments, which we call "regular users," were 22 percent in Baseline and none in the other treatments. There also exists a group of buyers who regularly adopted electronic payments; this group grew from 6 to 44 percent when the service fee was removed. Most buyers were occasional users who switched payment systems. The switching probability significantly declined with experience and increased whenever a buyer experienced a trade failure. It made no difference whether the failed trade involved an attempt to pay electronically or with cash.[13] Such disparities in adoption choices contributed to generate endogenous trade frictions and inefficiencies, as discussed below.

Result 4 (Trade frictions and efficiency). *There is a positive association between buyers' adoption of cash payments, trade frictions, and efficiency losses.*

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[13] Evidence comes from a probit regression on individual changes in payment methods (Table B-1 in Supplementary Information), where we controlled for buyers' types according to their prevalent adoption of payment methods, electronic or cash.

Tables 5-6 provide support for Result 4. Trade frictions are measured as the frequency of failed transaction in the economy (see Section 4). Frictions endogenously emerged in every treatment and were positively associated with the diffusion of cash payments in the experimental retail markets. The highest incidence of trade frictions is found in Baseline, followed by Reward, and No-Fee (Jonckheere-Terpstra test; p-value= 0.012, N=12, two-sided). Tobit regressions show a positive, significant association between trade frictions and buyers' adoption of cash payments also after controlling for treatments effects (Table 5).

Dependent variable: *Share of buyers who adopted cash*	Model 1		Model 2	
Trade frictions	0.257	***	0.253	***
	(0.064)		(0.063)	
No-Fee treatment			-0.436	***
			(0.089)	
Reward treatment			-0.273	***
			(0.089)	
Purdue location			0.135	*
			(0.073)	
Constant	0.288	***	0.457	***
	(0.067)		(0.073)	
N.obs.	408		408	
Log. Likelihood	151.347		158.555	

Table 5: Buyers' adoption of cash payments

Notes: Tobit regressions with session random effects, censored at 0. The dependent variable is the share of buyers who chose cash payments in each period of each treatment. The unit of observation is the period average within a session. Trade frictions are per-period session averages. Symbols $***$, $**$, and $*$ indicate significance at the 1%, 5% and 10% level, respectively.

Buyers were pivotal in determining the diffusion of payment methods in our experimental retail markets, and trade frictions largely depended on their adoption choices. The data allow us to separately measure trade frictions that are due to reliability problems and to acceptability problems (Table 6). Buyers who adopted cash payments were exposed to trade risk that was entirely due to reliability issues because by design cash was always accepted. On the other hand, buyers who adopted electronic payments, were primarily exposed to trade risk due to acceptability issues because electronic payments were very reliable.

In the experiment, reliability and acceptability of payment methods were endogenous. Cash payments had about 85 percent reliability, which means that a buyer who intended to pay cash faced a 15 percent probability of being unable to complete the trade. In contrast, electronic payments were very reliable (97-98 percent) but their acceptability varied between 86 and 98 percent, depending on the treatment.[14] As a result , buyers who adopted electronic payments faced a trade risk that was between 3.9 and 10.5 percent.

Overall, the two payment methods exhibited similar trade risk in Baseline, while electronic payments minimized trade risk when service fees were removed or buyers' rewards added. This suggests that relative trade risk considerations could well be the driving force behind buyers' adoption of payment methods.

Trade frictions, together with price and quantity distortions gave rise to substantial inefficiencies. Table 7 reports theoretical and realized efficiency measures. The highest theoretical efficiency level is $\mathcal{W} = 344.13$ (Equation 3) but it cannot be achieved in every treatment. It can be achieved either when everyone adopts cash payments that are fully reliable ($\mu_b = \mu_s = 1$ and $\sigma = 1$), or when everyone adopts electronic payments that carry no costs for sellers ($\mu_b = \mu_s = 0$ and $\epsilon = 1$). We use this upper bound to normalize all values in Table 6 so that our efficiency measures are reported as a fraction of the highest theoretical value.

Table 7 reports the *theoretical* efficiency for a treatment as the highest (normalized) value $\mathcal{W}$ that is feasible in that treatment.[15] According to Proposition 2, the highest feasible value implies uniform adoption of electronic payments, because in the experiment they were sufficiently more reliable than cash payments, $\sigma < \sigma^*$ (Table 6). Differences in theoretical efficiency across treatments were due to price and quantity distortions from service-fees and rewards (Lemma 1 and 2).

Realized efficiency is the (normalized) value $\mathcal{W}$ observed in the experiment.

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[14] The data reveal that cash trades failed primarily due to time constraints and not underpayment, while the reverse is true for electronic trades, which primarily failed due to underpayment and not time constraints (see also Table B-2 in Supplementary Information).

[15] For instance, in the Baseline treatment the theoretical highest value is $\mathcal{W} = 320.04$, which is based on $p_e^* = 133$ and $q_e^* = 1.62$. This value is then normalized, dividing it by 344.13.

	Treatment		
	Baseline	No-Fee	Reward
Trade frictions τ	.114	.051	.091
Buyers' choice of payment: cash			
Fraction of choices μ_b	.553	.130	.282
Trade risk	.103	.154	.127
Reliability R_m	.869	.846	.873
Acceptability	1	1	1
Buyers' choice of payment: electronic			
Fraction of choices $1 - \mu_b$	.447	.870	.718
Trade risk	.105	.039	.083
Reliability R_e	.973	.985	.977
Acceptability	.859	.976	.935
Performance of cash relative to electronic payments			
Relative reliability σ	.893	.859	.893
Relative acceptability	1.2	1.0	1.1

Table 6: Endogenous trade frictions: acceptability, reliability, and trade risk

Notes: Average incidence of trade failures unconditional and conditional on the buyer's payment. *Trade frictions* are the incidence of failed trades as a percentage of all possible trades. *Trade risk* for a buyer using payment method $i = E, M$ is the incidence of trade failures either due to reliability or acceptability by the seller. *Reliability* is the percentage of successful trades, conditional on the payment method being accepted. *Acceptability* is the percentage of times the buyer's payment method is accepted by the seller. Reliability and acceptability measures are an average of session averages. All numbers are rounded up to the closest decimal point.

	Treatment		
Normalized efficiency $\mathcal{W}$	Baseline	No-Fee	Reward
Theoretical	0.93	1.00	0.96
Realized	0.59	0.69	0.62
Breakdown of efficiency losses			
a. Sub-optimal adoption	19.7%	11.5%	19.8%
b. Sub-optimal prices	37.2%	68.5%	46.8%
c. Sub-optimal consumption	43.1%	20.0%	29.7%

Table 7: Measures of aggregate efficiency

The ordering of treatments in terms of their theoretical efficiency corresponds to their ordering in terms of realized efficiency. In all treatments there are efficiency losses, which range from .41 to .34 of the highest possible efficiency. These losses originate from three sources: (a) sub-optimal adoption of payment methods; (b) price departures from theoretical predictions; (c) quantities traded that differ from theoretical predictions.

The greatest source of inefficiency is associated with quantities and prices that departed from equilibrium. Average prices movements across treatments are consistent with the theoretical comparative statics. In particular, the mean price posted by sellers who did not accept electronic payments was similar across treatments; in the Baseline treatment this price was significantly below the mean price of sellers who accepted electronic payments. However, in the remaining treatments, prices were not significantly affected by the seller's payment method choice.[16] Average price levels, instead, were higher than theoretical equilibrium predictions (Table 1) and such pricing distortion was responsible for a significant efficiency loss because average quantities traded were below the theoretical equilibrium quantities.

All treatments had some inefficiency resulting from mis-coordination in payment method adoption. Yet, the inefficient adoption of payment methods accounted for twice as much efficiency loss in the Baseline and Reward treatments compared to the No-Fee treatment, where there was the highest adoption of electronic payments.

6 What if buyers carry cash and payment cards?

In this section we study the case where buyers are *no longer constrained* to carry only one method of payment.[17] In an additional treatment, called Switch, we modify the Baseline design to facilitate coordination on use and adoption of electronic payment methods. Specifically, we assume that buyers have adopted both payment methods and always carry in their wallets a card for electronic payments

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[16] Statistical evidence is reported in the Supplementary Information, see Table B-3.

[17] We thank an anonymous referee for suggesting this line of inquiry to us.

as well as cash. Hence, while sellers must make an adoption choice as in the previous analysis, buyers can now switch from one method to the other *at no cost*, in the middle of a transaction. We study the robustness of our results to this new design, and in particular with respect to the effect on sellers' adoption choices and on the use of payment methods that results in the market.

In the Switch treatment buyers no longer face acceptability risks because they always carry a payment method that is accepted by the seller. At the start of each trading round buyers must simply select how to initiate a payment in that round. If they select electronic and this is refused by the seller, then the buyer can promptly switch to pay with cash. Similarly, buyers who initiate a payment with cash and for some reason cannot complete it before the trading clock runs out can promptly switch to using electronic payments. In this manner, the design allows us to differentiate the buyer's *preferred* payment method—the one initially selected—from the method that is *used* to settle the transaction.

Dependent variable: *Payment method (1=electronic, 0=cash)*	Use Model 1	Preference (buyers) Model 2	Adoption (sellers) Model 3
Switch treatment	0.347	0.729	-0.911 **
	(0.466)	(0.470)	(0.357)
Period	0.004	0.012 ***	0.008 **
	(0.004)	(0.004)	(0.004)
Constant	-0.464	-0.684 **	1.621 ***
	(0.344)	(0.343)	(0.278)
N.obs.	1872	2176	2176
Log likelihood	-782.718	-871.538	-747.520

Table 8: Choice and use of payments methods in Baseline and Switch

Notes: Probit regression with individual random effects. The dependent variable takes value 1 if electronic payments are chosen (or used) and 0 otherwise. Model 1 studies the use of payment methods considering only observations corresponding to buyers who successfully traded. Model 2 studies the buyers' preferred payment method, i.e., the method selected to initiate a payment. Model 3 studies adoption choices of sellers. The default treatment is Baseline; only data from periods 7-40 in Baseline and in Switch are included. Symbols $***$, $**$, and $*$ indicate significance at the 1%, 5% and 10% level, respectively.

Analysis of the data from the Switch treatment confirms the robustness of the results reported in Section 5. Table 8 allows us to compare choice and use of payment methods in the Switch and Baseline treatments.

The data from successful transactions shows that the *use* of electronic payments in Switch was similar to Baseline (48% vs 45% of all successful trades); this difference is not statistically significant (Wilcoxon rank-sum test, $p = 1.00$, two-sided $N_1 = N_2 = 4$; Model 1 in Table 8). To understand this similarity in use between Baseline and Switch we study buyers' preference for a payment method and sellers' adoption.

Recall that buyers carried both payment methods at all times and could pay either way in every transaction. Yet, they remained as reluctant to pay electronically as in the Baseline treatment. In the Switch treatment 59% of all transactions were initiated with an offer to pay electronically, which is not significantly different from the 45% adoption rate recorded in Baseline (see Model 2 of Table 8).[18] In fact, no buyer regularly initiated a transaction with electronic payments, while a group of regular cash users emerged (about 12.5%), much as it happened in the Baseline treatment. The data also reveals that when buyers could not pay using the method initially selected—which occurred in 20% of all trades—they took advantage of the opportunity to switch to the other method (77% of all cases). The switch was mostly to time-consuming cash payments, which probably explains why in a few cases buyers did not even attempt a switch, but simply gave up on the idea of trading in that round.

Imposing adoption of both payment methods for buyers changed sellers' incentives. Sellers adopted electronic payments less frequently in the Switch treatment compared to Baseline (71%, vs 86%), a decline that is statistically significant (see the *Switch treatment* dummy variable in Model 3 of Table 8). This is an interesting, and perhaps surprising, result: one would imagine that giving buyers' costless access to both payment methods would foster coordination on adopting electronic payments in the whole market. Yet, the sellers' greater reliance on cash

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[18] It is interesting to note that 59% is below the buyers' adoption rate of electronic payments observed in the No-Fee and Reward treatments, which was 87% and 72%, respectively.

observed in the Switch treatment can be easily explained by cost-mitigation considerations: now that buyers can switch to pay cash, sellers can safely decrease their trade costs by forestalling any initial attempt at paying electronically. As a consequence, the fraction of sellers who *adopted* electronic payments in the Switch treatment was not significantly different than the fraction of buyers who *initiated* a transaction with electronic payments (71% vs. 59%, respectively; $p = 0.2482$, two-sided Wilcoxon rank-sum test, $N_1 = N_2 = 4$).

Finally, we again find a link between efficiency and use of cash, similarly to what we previously found in the Baseline treatment.[19] Overall, these considerations confirm the robustness of our Baseline results to the case when buyers can costlessly carry both payment methods.

7 Discussion and conclusions

This study has developed a novel experimental framework to advance research and to inform policies about payment methods adoption. There are many reasons why the experimental methodology is useful to advance the study of retail payments. In the lab, one can construct model economies where agents have perfect information about the institutions under study. One can also manipulate exogenously the variables of interest, hence uncovering the relationship between payment systems' attributes—such as service fees or reward programs—and their diffusion in the economy. Experiments grant the ability to combine data on use and cost of payment systems, and to test theoretical predictions, also.

The laboratory platform we have developed is simple, is flexible, and it captures basic features of two basic retail payment methods, cash and electronic. We have used it to investigate the payment method's adoption decisions of individual consumers and retailers who are motivated by actual incentives. Our aim is to shed light on the association between features of the economy and individual payment method's adoption choices on the one hand, and endogenous trading frictions

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[19] Support comes from a tobit regression, censored at 0, using Switch treatment data. We regress the share of buyers who chose cash payments in a period on "Trade frictions" in a period; the unit of observation is the period average within a session. The coefficient is positive and highly significative.

and social efficiency on the other hand. In this manner, we complement existing survey-based studies about consumers and retailers' adoption decisions.

We have constructed economies in which there always exist an equilibrium where trade is only executed using cash, and another where all payments are electronic. Coordinating on using electronic payments maximizes social welfare. The design captures empirically-relevant features of retail markets and, in particular, that buyers and sellers face different incentives. For buyers, electronic payments generate benefits but may carry the risk of being declined. The opposite is true for sellers; accepting electronic payments reduces the risk of trade failures but using electronic payments generates costs.

The experiment includes three main treatments—Baseline, No-Fee, and Reward—each of which reproduces in the laboratory a prototypical retail market in which use and acceptability of payment methods are endogenous. In the Baseline treatment, sellers suffer a cost from executing an electronic transaction, which is proportional to the revenue. Service fees are removed in No-Fee, while buyers' rewards are introduced in Reward. As a robustness check, we also study use and sellers' adoption choices when buyers are *assumed* to have adopted both payment methods, in the Switch treatment. There are two main lessons.

First, analysis of the data suggests that buyers are pivotal in the diffusion of electronic payments. Sellers readily adopted electronic payments in all of the main treatments, and did so significantly more than buyers. This is particularly interesting given that in our set-up only sellers suffered electronic payments' usage costs, and could not price-discriminate based on the buyer's choice of payment method. When sellers had to pay a service fee, a sizeable group of buyers regularly adopted cash payments. Buyers remained reluctant to pay electronically even when we imposed adoption of both payment methods to buyers. This behavior was no longer observed when service fees were removed or rewards added; under these conditions, a new group of buyers emerged, which regularly adopted electronic payments. The relative use of payments methods did not significantly change when we imposed adoption of both payment methods to buyers.

Second, the data suggest that regulatory policies aimed at fostering competition among providers or at increasing reward programs could boost the diffusion of electronic payments among consumers in retail markets. The experimental data collected allows us to measure the endogenous extent of trade frictions, to pin down their source, and to assess their impact in terms of efficiency loss for the entire market. We find that trade frictions, together with price and quantity distortions, gave rise to substantial inefficiencies. Interestingly, inefficient diffusion of payment methods accounted for twice as much efficiency loss in Baseline and Reward, compared to the No-Fee treatment, where there was the highest adoption of electronic payments.

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Appendix

A Proof of Lemma 1

Consider an economy with a population composed of equal numbers of anonymous, homogeneous sellers and buyers. We use M to denote cash as opposed to electronic payments, denoted E.

At the beginning of the period the buyer receives a random amount of tokens $m \in [m_L, m_H]$, with uniform pdf. These transaction balances can either be spent to purchase goods or simply consumed. Buyers have quasilinear preferences defined over transaction balances and goods. If we normalize the price of tokens to one (the numeraire), then the utility (in tokens) of a buyer who has m transaction balances and purchases $q > 0$ goods at price $p > 0$ is

$$m + u(q) - pq(1 - r).$$

Here $u(q)$ is the utility from consuming q gods, with $u' > 0$, $u'' < 0$, and $u(0) = 0$. The expenditure is pq and r denotes a possible reward rate to the buyer, which can be positive or zero. The reward is earned *after* the purchase has been executed—it takes the form of a rebate—and so it is simply "consumed;" the reward cannot be used to relax the expenditure constraint, i.e., we have $pq \leq m$.

The buyer chooses $q \geq 0$ to solve the problem

$$\max[m + u(q) - pq(1 - r) + \lambda(m - pq)]$$

where λ is the Kühn-Tucker multiplier on the expenditure constraint. The first order condition is

$$u'(q) - p(1 - r) - \lambda p \leq 0.$$

We can thus define the buyer's inverse demand function by

$$\begin{cases} 0 & \text{if } u'(0) \leq p(1-r), \\ q(p(1-r)) := (u')^{-1}(p(1-r)) & \text{if } u'(0) > p(1-r) \text{ and } pq \leq m, \\ \dfrac{m}{p} & \text{otherwise .} \end{cases} \tag{4}$$

Demand depends on the price p posted by the seller, the transaction balances m, and the rebate rate r, which may be zero or positive, depending on the treatment. The demand does not directly depend on the payment method because the seller cannot price-discriminate based on the payment method, and neither method generates a cost to the buyer. If demand is positive, then $u(q) - pq(1 - r) > 0$.

We parameterize the model such that the decomposition $q(p(1-r)) = k(r)q(p) \geq q(p)$ holds, where $k(0) = 1$, $k'(r) > 0$, and $q'(p) < 0 < q''(p)$. When $r = 0$ we have

$q(p(1-r)) = q(p)$. In the experiment we assume $u(q) = 2\theta\sqrt{q}$, which implies

$$\begin{aligned} q(p) &= \left(\frac{\theta}{p}\right)^2, \\ q(p(1-r)) &= k(r)q(p) = \frac{q(p)}{(1-r)^2}, \\ \frac{\partial q(p(1-r))}{\partial p} &= q'(p)k(r) = -\frac{2q(p)}{p}k(r) < 0. \end{aligned}$$

That is, for a buyer who encounters a seller posting a price p, $q(p)$ is quantity purchased if the buyer pays cash, and $q(p(1-r))$ is quantity purchased if the buyer pays electronically and there is a proportional rebate r on electronic purchases. □

B Proof of Lemma 2

Each seller is a monopolist who has linear preferences over tokens and chooses the price p to maximize expected profits, given expected demand. If $q = q(p(1-r))$ for all $m \in [m_L, m_H]$, then expected demand is simply $q(p(1-r))$. We will work under this conjecture because, under the parametrization selected, this is true in equilibrium (see Supplementary Information).

A seller who accepts electronic payments must accept also cash, and cannot price discriminate. Given that the buyer demands q goods when the price is p and the rebate rate is r, the transaction can be completed only if the seller accepts the buyer's chosen payment method, and if the buyer transfers at least pq tokens to the seller. Assume that cash transactions are settled with probability σ. If a transaction cannot be settled, then nothing is produced. The expected profit $\mathcal{V}_E^s(p)$ of a seller who accepts electronic payments and posts price p is

$$\mathcal{V}_E^s(p) := A + \mu_b\sigma[q(p)(p-g) - F] + (1-\mu_b)[k(r)q(p)(\varepsilon p - g) - F],$$

where μ_b denotes the (endogenous) probability that the buyer encountered uses cash payments and we have used the fact that $q(p(1-r)) = k(r)q(p)$.

The seller always receives the fixed payment A, and may have earnings from trading with the buyer. With probability $1-\mu_b$ the seller meets a buyer who uses electronic payments; here, demand is $k(r)q(p)$, so the seller's profits are $k(r)q(p)(\varepsilon p - g) - F$. With probability μ_b the seller meets a buyer who uses cash, in which case demand is $q(p)$, and expected profits are $\sigma q(p)(p-g) - F$.

The FOC for an interior solution is

$$\mu_b\sigma[q'(p)(p-g) + q(p)] + (1-\mu_b)k(r)[q'(p)(\varepsilon p - g) + \varepsilon q(p)] = 0.$$

Define

$$\eta_0 := \mu_b\sigma + (1-\mu_b)k(r)\varepsilon \qquad \text{and} \qquad \eta_1 := \mu_b\sigma + (1-\mu_b)k(r). \tag{5}$$

Let p_E be the profit-maximizing price for a seller who accepts electronic payments;

$p_E > 0$ uniquely solves

$$q'(p)\,(p\eta_0 - g\eta_1) + q(p)\eta_0 = 0,$$

so we have the identity

$$p_E = \frac{g\eta_1}{\eta_0} - \frac{q(p_E)}{q'(p_E)}$$

where $p_E > g$ since $\eta_0 < \eta_1$ and $q' < 0$.

A seller who does not accept electronic payments trades with probability $\mu_b\sigma$, i.e., when she meets a buyer who has adopted a cash payment method. The expected profit is

$$\mathcal{V}^s_M(p) := A + \mu_b\sigma[q(p)(p-g) - F].$$

The profit-maximizing price p_M uniquely satisfies $Q'(p)(p-g) + Q(p) = 0$, hence

$$p_M = g - \frac{q(p_M)}{q'(p_M)}.$$

p_M is independent of μ_b, $p_M \leq p_E$, and $p_E = p_M$ only if $\mu_b = 1$ or $\varepsilon = 1$ (which is when $\eta_1 = \eta_0$). Given the optimal demand function in (4) we have

$$p_M := 2g \qquad \text{and} \qquad p_E := p_M\frac{\eta_1}{\eta_0}. \tag{6}$$

We have $p_M \leq p_E \leq \dfrac{p_M}{\varepsilon}$ since $\dfrac{\eta_1}{\eta_0}$ falls in μ_b, equalling 1 when $\mu_b = 1$ and $\dfrac{1}{\varepsilon}$ when $\mu_b = 0$. Note that p_M is invariant to μ_b while $\dfrac{\partial p_E}{\partial \mu_b} \propto \sigma k(r)(1-\varepsilon) < 0$.

Due to the fixed cost F, sellers trade only if their expected profit is nonnegative for any choice of payment selected by the buyer. We choose parameters so that sellers are never inactive, i.e., F is below then net earnings $q(p)(\varepsilon p - g)$ and $q(p)(p-g)$. To do so, we need to ensure that

$$F < q(p_E)(\varepsilon p_E - g)$$

in which case $F < q(p_M)(p_M - g)$. To see this, note that $p = p_M$ is the unique maximizer of $q(p)(p-g)$; it follows that $q(p_M)(p_M - g) > q(p_E)(p_E - g)$ for all $p_M < p_E$.We have $q(p_E)(p_E - g) > q(p_E)(\varepsilon p_E - g)$. So, if $q(p_E)(\varepsilon p_E - g) - F > 0$, then $q(p_M)(p_M - g) - F > 0$; notice also that this implies $k(r)q(p_E)(\varepsilon p_E - g) - F > 0$ since $k(r) > 0$. For the parameters used in the experiment $F < q(p_E)(\varepsilon p_E - g)$ holds in all symmetric equilibria (see Supplementary Information). □

C Proof of Proposition 1

Proposition 1 is a special case of proposition 3 which we next present and prove.

Proposition 3. *Let prices and quantities satisfy Lemmas 1-2. Each treatment*

		No-Fee			Baseline			Reward		
$\mu_s =$		0	x	1	0	x	1	0	x	1
	0	$\checkmark$			$\checkmark$			$\checkmark$		
$\mu_b =$	y	$\checkmark^{-}$			$\checkmark^{-}$					
	1	$\checkmark^{-}$	$\checkmark^{--}$	$\checkmark$		$\checkmark^{--}$	$\checkmark$		$\checkmark^{--}$	$\checkmark$

Table 9: Multiplicity of equilibria

Notes: The Table reports all the possible symmetric equilibria. $^{-}$ indicates that the equilibrium exists only if $\sigma = 1$ (cash and electronic payments are equally reliable). $^{--}$ indicates that the equilibrium is not robust to trembles in buyers' choice. We let $y = (0, 1)$, i.e., any number in the open unit interval, and $x = (1 - \sigma(1 - r), 1)$.

supports multiple symmetric Nash equilibria:

$$(\mu_b, \mu_s) = \begin{cases} (0,0), (y,0)^\star, (1,0)^\star, (1,x), (1,1) & \textit{if } (\varepsilon, r) = (1, 0); \\ (0,0), (y,0)^\star, (1,x), (1,1) & \textit{if } (\varepsilon, r) = (.9, 0); \\ (0,0), (1,x), (1,1) & \textit{if } (\varepsilon, r) = (.9, .05), \end{cases}$$

for $y = (0, 1)$*, and* $x = (1 - \sigma(1 - r), 1)$*. The notation* * *indicates the equilibrium exists only if* $\sigma = 1$*.*

Table 9 summarizes the possible equilibria, by treatment. Consider a symmetric stationary outcome. Let $\mu_i \in [0, 1]$ denote the probability that a player of type $i = b, s$ (b =buyer, s =seller) adopts cash payments. Hence, $1 - \mu_s$ is the probability that a seller accepts both electronic and cash payments, while $1 - \mu_b$ is the probability that a buyer uses the electronic payment method.

A buyer who adopts electronic payments can only make a purchase if the seller accepts them. A buyer who adopts cash payments can buy from any seller. Conjecturing that the buyer is unconstrained in his purchases, let

$$\hat{q}_E = q(p_E(1 - r))$$

denote the equilibrium quantity demanded when the price is p_E and the rebate rate is r. There is never a reward for a buyer who trades using cash, so we let $q_E = q(p_E)$ and $q_M = q(p_M)$ denote the equilibrium quantity demanded, when the price is p_E and p_M, respectively, and the buyer pays cash.

The payoff $\mathcal{V}^b_j$ to a buyer who has adopted payment method $j = M, E$ and has m transaction balances is thus

$$\begin{aligned} \mathcal{V}^b_M \quad &= m + \sigma \left\{ (1 - \mu_s) \left[u(q_E) - p_E q_E \right) \right] + \mu_s \left[u(q_M) - p_M q_M \right] \right\}, \\ \mathcal{V}^b_E \quad &= m + (1 - \mu_s)[u(\hat{q}_E) - p_E(1 - r)\hat{q}_E]. \end{aligned}$$

Here q_j satisfies (4), p_j satisfy (6) and $\sigma \in (0, 1]$ denotes the probability that a cash payments is completed in the time allocated to transact. It follows that

$$\mathcal{V}^b_M - \mathcal{V}^b_E = \mu_s \sigma [u(q_M) - p_M q_M] - (1 - \mu_s)[u(q_E) - p_E q_E] \Big(\frac{1}{1 - r} - \sigma \Big).$$

The second term in the equality above follows from $\hat{q}_E = k(r)q(p_E) = \frac{q(p_E)}{(1-r)^2}$ so we have $u(\hat{q}_E) = u(q_E)\frac{1}{1-r}$ since $u(q) = \sqrt{q}$.

The choice of payment method μ_b' of the generic buyer must satisfy:

$$\mu_b' = \begin{cases} 1 & \text{if } \mathcal{V}_M^b - \mathcal{V}_E^b > 0, \\ [0,1] & \text{if } \mathcal{V}_M^b - \mathcal{V}_E^b = 0, \\ 0 & \text{if } \mathcal{V}_M^b - \mathcal{V}_E^b = 0. \end{cases} \tag{7}$$

The buyer evaluates the difference between expected surplus earned when sellers accept only cash $\mu_s\sigma[u(q_M) - p_M q_M]$ and the opportunity cost of using cash, which is simply the expected surplus from using cash with a seller who accepts electronic payments, $(1-\mu_s)[u(q_E) - p_E q_E]$; this terms is adjusted for the loss of the rebate rate r and the possibility that the cash transaction is not completed, σ.

Let $\mathcal{V}_j^s$ denote the payoff to a seller who adopts payment method $j = M, E$. In an outcome where buyers are not constrained in their purchases, we have

$$\begin{aligned} \mathcal{V}_M^s = &\quad A + \mu_b\sigma[q_M(p_M - g) - F], \\ \mathcal{V}_E^s = &\quad A + \mu_b\sigma[q_E(p_E - g) - F] + (1-\mu_b)[\hat{q}_E(\varepsilon p_E - g) - F], \end{aligned} \tag{8}$$

Seller j does not see the buyers' method of payment before choosing the price p_j.

Clearly, $\hat{q}_E = q_E k(r) = \dfrac{q_E}{(1-r)^2}$, hence

$$\begin{aligned} \mathcal{V}_M^s - \mathcal{V}_E^s = &\quad \mu_b\sigma\{q_M(p_M - g) - [q_E(p_E - g)]\} \\ &\quad -(1-\mu_b)\left\{\frac{q_E}{(1-r)^2}(\varepsilon p_E - g) - F\right\}. \end{aligned}$$

The choice of payment method μ_s' of the generic seller must satisfy

$$\mu_s' = \begin{cases} 1 & \text{if } \mathcal{V}_M^s - \mathcal{V}_E^s > 0 \\ [0,1] & \text{if } \mathcal{V}_M^s - \mathcal{V}_E^s = 0 \\ 0 & \text{if } \mathcal{V}_M^s - \mathcal{V}_E^s < 0. \end{cases} \tag{9}$$

Two remarks are in order. First, we choose parameters so that $q_E(\varepsilon p_E - g) > F$. This not only implies $\dfrac{q_E}{(1-r)^2}(\varepsilon p_E - g) > F$ for all $r \geq 1$ but also $q_E(p_E - g) > F$; that is a seller who accepts electronic payments makes positive profits when he engages either in an electronic or in a cash transaction (see Supplementary Information). Second, when p_j satisfy (6), we have:

- If $\mu_b = 0$, then $\mathcal{V}_M^s - \mathcal{V}_E^s < 0$;
- If $\mu_b = 1$, then $\mathcal{V}_M^s - \mathcal{V}_E^s = 0$ (because $p_M = p_E = g$), and
- If $\mu_b \in (0,1)$, then $\mathcal{V}_M^s - \mathcal{V}_E^s < 0$ for $\varepsilon < 1$ sufficiently large.

To prove the last bullet point recall that $q_M(p_M - g) > q_E(p_E - g)$ for all $p_M < p_E$. The price p_E monotonically falls to p_M as μ_b grows to 1, while p_M is invariant to μ_b. Hence, $q_M(p_M - g) > q_E(p_E - g)$ when $\varepsilon < 1$ or $r > 0$ and the first term of the expression $\mathcal{V}_M^s - \mathcal{V}_E^s$ is positive for all $\mu_b \in (0,1)$. If $\mu_b = 0$, then $\mathcal{V}_M^s - \mathcal{V}_E^s < 0$; if $\mu_b = 1$, then $\mathcal{V}_M^s - \mathcal{V}_E^s = 0$. In principle we could have $\mathcal{V}_M^s - \mathcal{V}_E^s < 0$ for $0 < \mu_b \leq \bar{\mu}_b < 1$, and $\mathcal{V}_M^s - \mathcal{V}_E^s > 0$ otherwise. However, $\bar{\mu}_b < 1$ only if ε is sufficiently small; otherwise, there is no $\mu_b \in (0,1)$ that satisfies $\mathcal{V}_M^s - \mathcal{V}_E^s = 0$. To see this note that for $\varepsilon = 1$ we have $p_E = p_M$, in which case $\mathcal{V}_M^s - \mathcal{V}_E^s$ is negative and increasing in μ_b. By continuity, this holds also for some $\varepsilon < 1$ sufficiently close to 1. In the experiments we set parameters such that this was always the case. It follows that $\mathcal{V}_M^s - \mathcal{V}_E^s < 0$ for all $\mu_b < 1$.

It is now a matter of algebra to verify that the existence of equilibria in Proposition 3. The procedure is constructive. First, we conjecture that a given value of μ_b is an equilibrium. Given this, we find the optimal value for μ_s' using (9). Imposing symmetry, $\mu_s' = \mu_s$, we confirm whether the conjecture is correct for some parameters by considering (7). If no parameters support the conjectured value μ_b The details can be found in the Supplementary Materials. $\square$