Explaining the Interplay Between Merchant Acceptance and Consumer Adoption in Two-Sided Markets for Payment Methods*

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Abstract

Markets for payment cards are inherently two-sided, where consumers benefit from increased merchant acceptance of payment cards and vice-versa. This interdependence is known as a network externality. We build and estimate a structural two-sided model of a payment choice to quantify network externalities. We utilize a unique data set consisting of the Bank of Canada's consumer payment diary data and retailer survey of cost of payments. The model estimates are used to conduct counterfactual simulations of an increase in the usage cost of credit cards for merchants. We find that consumer adoption of payment cards is inelastic but usage of credit cards declines in favor of cash, while merchants reduce the acceptance of credit and opt to accepting only cash.

Keywords: Cash Usage, Network Externalities, Structural Models.
JEL Classifications: L15, L13, L82, L96, C51.

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1 Introduction

Despite the dire warnings, the use of cash, especially at the point-of-sale (POS), still remains strong in most industrialized countries, see Bagnall et al. (2016). The main alternatives, debit and credit cards, have a large market share but have still not supplanted cash. Understanding the usage of cash is of first-order responsibility for central banks as they are usually the sole issuer of banknotes. However, the increasing digitization of payment innovations by private entities require that public authorities monitor these new developments and understand the implications for provision of an efficient payment system.

There are many reasons for the resilience of cash; from the demand-side or consumers there is a preference for cash, especially at small-value transactions, see Arango et al. (2015) and Wakamori and Welte (2017). The supply-side has shown that consumer adoption of payment cards is ubiquitous, see Arango et al. (2012) and Fung et al. (2015). However, merchant acceptance is not universal; for example in Canada about a third of small- and medium-sized businesses do not accept any type of payment card, see Fung et al. (2017). One of the major reason for merchant non-acceptance of payment cards is due to costs of cash, see European Commission (2015) and Fung et al. (2018). Since merchant acceptance is not universal, consumers must hold cash in cases that merchants do not accept cards. Arango et al. (2015) and Wakamori and Welte (2017) illustrate that consumer perception of merchant non-acceptance of payment cards plays a large role for the continued use of cash. Further, Huynh et al. (2014) demonstrate that the lack of universal acceptance of payment cards is a determinant for the continual holding of cash by consumers. This interplay between consumers and merchants is known as two-sided markets for payment cards while the feedback between consumer and merchants are known as network externalities, see Rysman (2009) and Rysman and Wright (2014) for further details.

Much of the early work on two-sided markets focused on theoretical modeling of platform competition and how this relates to the setting of fees, (see Rochet and Tirole 2003), inter alia. Examples of empirical work on payment markets include Rysman (2007) establishes a feedback loop between consumer usage and merchant acceptance, a necessary condition for the two-sidedness of a market. Carbó-Valverde et al. (2016) and Bounie et al. (2016) are examples of papers that estimate an empirical model based on survey data from both consumers and merchants in Spain and France, respectively. These empirical models utilize simultaneous equations with instrumental variables to estimate the the cross-partial elasticities of consumer adoption and merchant acceptance. However, these methodologies are unable to quantify or identify the equilibrium source of network externalities. McAndrews and Wang (2012) articulate that there are two types of network externalities present: (1) adoption externality and (2) usage externality. In the first case, for a payment system to work – consumers require that merchants accept payment card and merchants require that consumer have a payment card. In the second case, the increase in the usage of payment cards by consumers will have implications on merchants costs (fees) of acceptance of cards versus cash.

The contribution of this paper is that we develop a structural equilibrium model of interactions between consumers and merchants in two-sided markets for payment methods. We utilize rich micro data for consumers from the Bank of Canada's 2013 Method-Of-Payments (MOP) Survey and for merchants the 2014 Retailer Survey on the Cost of Payment Methods (RSCPM). The 2013 MOP data contains consumer adoption and usage of payment instruments while the 2014 RSCPM contains detailed cost data and merchant acceptance of payment methods. Using this unique data and the model, we are able to estimate the structural parameters so that we can decompose the network externalities into the extensive (adoption) and intensive (usage) margin.

In our framework, the interaction between consumers and merchants is modeled as a two-stage game that is played every period. In the first stage, consumers and merchants simultaneously and independently make adoption and acceptance decisions of which methods of payments to be able to use in the following stage. In the second stage, consumers and merchants are randomly matched to conduct transactions. Merged parties can transact by using payment methods they chose previously. Two-sided nature of the payment methods emphasizes the role of network effects, where consumers benefits from the increased acceptance decisions of merchants and vice versa. The benefit to consumers is the reduction in expected costs of transacting because they can choose from a wider set of payment methods with heterogeneous usage costs, i.e., they minimize over larger set of options. In our model, a rational consumer conditions their adoption decisions on the expected probabilities of acceptance for each mean of payment. If a given payment method is widely accepted by merchants, consumers expect to be able to use it more frequently. Similarly, merchants condition their acceptance decisions on the expected adoption probabilities by consumers of various types.

We find that in equilibrium some merchants choose to accept all means of payment in order to attract more customers. By doing so they can generate additional revenues that can contribute about 2 to 3 percent into total revenue of the merchants. Debit cards are the most costly for consumers and the cost can be as high as $33 per month while adoption of credit card generate benefits of up to $7 per month. We find that the network effects originating on the consumer side of the market due to changes in the adoption or usage costs. This effect can have larger short-run impact on the usage probabilities than the effect originating on the merchant side. In the long-run, as the per-value cost of credit for merchant increases there is much stronger response on the merchant side in terms of reduced acceptance probabilities than on the consumer side where adoption probabilities are inelastic.

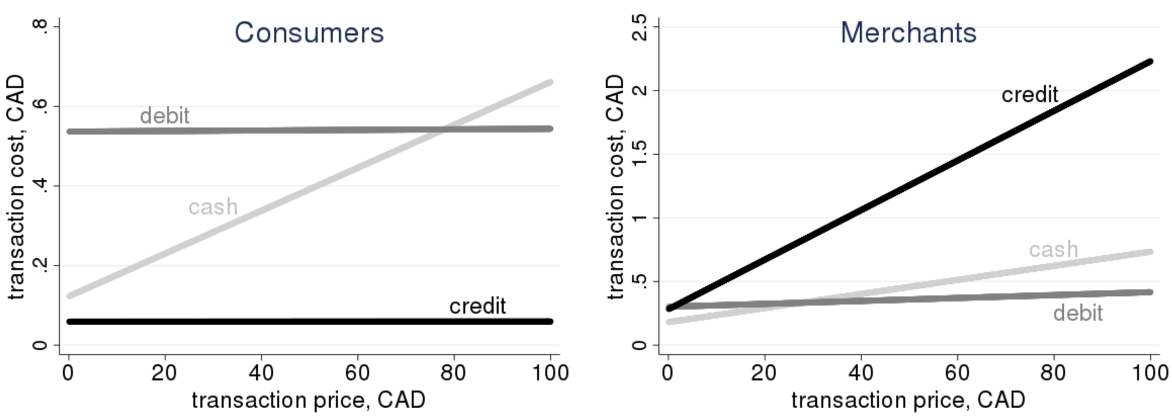
The rest of the paper is organized as follows. Section 2 provides institutional details and describes our data. This section also provides reduced form evidence for network effects in our sample. We describe our theoretical model in Section 3 while the empirical specifications and details of the estimation algorithm are provided in Section 4. Section 5 contains discussion of the results including an analysis of the determinants of adoption and acceptance decisions at observed equilibrium. Section 6 discusses the equilibrium effect of consumer and merchant costs in a counterfactual simulations that involve varying per-value usage cost of credit for merchants. Finally, Section 7 concludes.

2 Consumer and Merchant Payment Data

This study makes use of both consumer-side and merchant-side surveys developed by the Bank of Canada. The former is the 2013 Methods of Payment (MOP) survey, which includes two components, see Henry et al. (2015). The first component is the survey questionnaire (SQ), containing information on individuals' demographics and payment card ownership. The second component is the diary survey instrument (DSI), which asked respondents to report transactions they made over a three day period, along with many key characteristics including: method used to complete the transaction, value of transaction, and type of store the transaction was made at. The merchant-side survey used is the 2014 Retailer Survey on the Cost of Payment Methods (RSCPM), which included questions about perceptions of payment method costs and benefits, payment method acceptance, and revenue and fees broken down by payment method. More details of the 2014 RSCPM is available in Kosse et al. (2017).

Data analysis suggests that consumers and merchants view payment methods very differently in terms of their usage costs. Figure 1, based on results from Kosse et al. (2017), can be used to rank the usage costs for consumers and merchants for a given transaction size. Most glaringly, for all price points, consumers find credit cards the least costly while merchants find them the most costly. Further, both consumers and merchants find cash cheaper than debit for smaller transactions, but more costly for larger transactions.

Figure 1: Consumer (left) and merchant (right) costs of transacting



Source: Figure 13 of Kosse et al. (2017).

Consumers almost always (99.8 percent) have a payment card of some kind, with 83 percent owning both a debt and credit card (Table 1). On the other hand, about a fifth (22 percent) of merchants accept only cash, while 70 percent accept both types of cards. This suggests that while merchants can always expect consumers to carry a payment card the consumers may not always have a payment card at their disposal.

Table 1: Summary consumer adoption and merchant acceptance decisions.

variable	consumers		merchants	
	frequency	percent	frequency	percent
cash only	24	1.23	162	22.10
cash and debit	197	10.08	31	4.23
cash and credit	118	6.04	24	3.27
all methods	1,616	82.66	516	70.40
Total	1,955	100.00	733	100.00

Transactions between consumers and merchants are captured from the consumer-side diary data[1], and can be characterized by their price. On average, transactions were priced at about $33 and each consumer on average provided details on 7 transaction over the study period. (Table 2). Cash was the most common method of payment (44% of transactions) followed by credit card (33%) and debit card (23%).

Table 2: Summary statistic for transactions and usage of payment methods

variable	mean	p50	min	max	s.d.
transaction price	32.97	18.48	0.00	300.00	41.57
transactions per consumer	7.05	6.00	3.00	18.00	3.13
usage of cash	0.44	0.00	0.00	1.00	0.50
usage of debit	0.23	0.00	0.00	1.00	0.42
usage of credit	0.33	0.00	0.00	1.00	0.47

3 Empirical Model

Koulayev et al. (2016) develop a rich structural model of the two-step payment choice and use it to determine the response of consumers to a change in payment card fees. Our model advances this by adding the merchant adoption decision structurally to the consumer side model, meaning that the feedback loop between consumer and merchant decisions is taken into account when policy changes are simulated. Further, using consumer diary data, our consumer usage model is able to take into account the individual discrete choice of usage, and models usage as a function of transaction price. This is important as consumer rewards and merchant interchange fees being important drivers in the theory of two-sided payments markets are functions of transaction price.

Consider a market populated by merchants, s, who sell various products, and consumers, b, who purchase these products. Let N_s denote the number of merchants and N_b denote the number of consumers in the market. Consumers and merchants interact with each other with the purpose of completing day-to-day transactions. These transactions can be made by using one of the three available means of payment: (1) cash, ca, (2)

[1]Note that only focus on cash, debit, and credit transactions that are $300 or less. Further, we exclude consumers who have reported less than 3 transactions during the period of their diary.

debit card, de, and (3) credit card, cr.[2] Let $\mathcal{M} = (\{ca\}, \{ca, de\}, \{ca, cr\}, \{ca, de, cr\})$ denote the set of all possible adoption/acceptance decisions available to consumers and merchants. Let $\mathcal{M}_b \in \mathcal{M}$ and $\mathcal{M}_s \in \mathcal{M}$ denote sets of payment methods available to consumer b and merchant s, respectively. We assume that every merchant and every consumer can use cash, i.e., $ca \in \mathcal{M}_b$ and $ca \in \mathcal{M}_s$ $\forall b, s$.

Consumers and merchants represent two sides of the market and we assume their interaction takes form of a two-stage game played every time period. In the first stage, consumers and merchants simultaneously and independently decide about the combination of payment methods to adopt/accept. In the second stage, consumers and merchants are randomly matched with each other for every transaction. We provide detailed discussion of the optimization problem for each side and define equilibrium below.

Consumers. Consumers can be of two types: informed and uninformed. The informed consumers know acceptance decisions of each seller. The uninformed consumers only know average probability of acceptance among the merchants. In what follows, we structurally model interactions between merchants and uninformed consumers and estimate the size of the informed market in a reduced form. In the remaining part of the paper we will use the term "consumers" to reference the uninformed group of consumers, unless explicitly stated otherwise.

In our model consumers make two decisions: first stage decision to adopt particular combination of payment methods to use in the second stage, $\mathcal{M}_b$; and second stage usage decision, which depends both on $\mathcal{M}_b$ and the first stage acceptance decision of the merchant the consumers are matched with. We begin with the second stage decision.

Each consumer is exogenously endowed with a set of transactions to complete, $\mathcal{J}_b$. We assume inelastic demand for transactions, which is summarized in the following assumption.

Assumption 1: *Every consumer b is endowed with a set of transactions $\mathcal{J}_b$, all of which must be completed. The number of transactions (cardinality of $\mathcal{J}_b$) and their prices, p_{bj}, $j \in \mathcal{J}_b$, are exogenous.*

Transacting is costly and the cost depends on both the number of transactions and their values. Each consumer type b is characterized by observable demographics, X_b, which maps into a pair of cost function parameters per payment method, m, $c_{0bm}(X_b)$, and $c_{1bm}(X_b)$, such that the cost of a transaction with price p_j is given by

$$c_{bmj}(p_j) = c_{0bm} + c_{1bm} p_j + \varepsilon_{bmj}, \tag{1}$$

where ε_{bmj} is a cost innovation at the point of sale. We assume consumers don't observe realizations of ε_{bmj} when making first stage decision, but they know their distribution

[2] We assumed away other means of payment, like checks, money orders, and e-transfers because in our survey we have very limited information on the usage of these methods and because they are more likely to be used for utility payments rather than for day-to-day transactions.

F_ε, i.e.,

Assumption 2: *A vector of consumer usage cost innovations* $\varepsilon_b = (\varepsilon_{b,ca,j}, \varepsilon_{b,de,j}, \varepsilon_{b,cr,j})$ *is given by random draws from joint distribution* $F_\varepsilon(\cdot|\theta^{b2})$ *known up to a parameter vector,* θ^{b2}*, i.e.,*

$$\varepsilon_b \overset{iid}{\sim} F_\varepsilon(\cdot|\theta^{b2}).$$

Consumers then choose method m^* for transaction j by choosing the cheapest method from the intersection $\mathcal{M}_b \cap \mathcal{M}_s$. Note that in the first stage, when the adoption decision has to be made, consumer can only evaluate the expected minimum, i.e., prior to the realization of the second stage errors,

$$\mathbb{E}_\varepsilon \left[\min_{m' \in \mathcal{M}_b \cap \mathcal{M}_s} \{c_{bm'j}(p_j)\} \right]. \tag{2}$$

Since consumers and merchants make their first stage decisions simultaneously, both must form expectations about the likely choices of the other side of the market. Let $EP(\mathcal{M}_s)$ denote consumer belief that a randomly chosen merchant accepts $\mathcal{M}_s \subset \mathcal{M}$. Then, a consumer can calculate expected cost of transacting in the second stage as a function of own adoption decision and the likely decisions of merchants as follows. Let $EC_b(\mathcal{J}_b, \mathcal{M}_b)$ denote expected second stage cost to complete $\mathcal{J}_b$ transactions if the consumer chooses $\mathcal{M}_b$ in the first stage. For example, if the consumer chooses $\mathcal{M}_b = ca$, then the expected cost is given simply by

$$EC_b\left(\mathcal{M}_b = \{ca\}\right) = \sum_{j \in \mathcal{J}_b} c_{b,ca,j}(p_j)$$

If, instead, the consumer chooses $\mathcal{M}_b = \{ca, de\}$, then the expected cost consists of several terms as shown in equation (3). The first and second terms measure expected cost when the intersection of $\mathcal{M}_b$ and $\mathcal{M}_s$ is given by a singleton. This may happen if merchants accept cash only or if they accept cash and credit, but not debit card. The third and fourth terms describe situations where both of the payment methods adopted by the consumer are accepted by the merchant ($\mathcal{M}_s = \mathcal{M}_b$ in the third line and $\mathcal{M}_b \subset \mathcal{M}_s$ in the fourth one.

$$EC_b(\mathcal{M}_b = ca, de) = \sum_{j \in \mathcal{J}_b} \begin{pmatrix} EP(\mathcal{M}_s = \{ca\}) \times c_{b,ca,j}(p_j) \\ + EP(\mathcal{M}_s = \{ca, cr\}) \times c_{b,ca,j}(p_j) \\ + EP(\mathcal{M}_s = \{ca, de\}) \times \mathbb{E}\left[\min_{m' \in \{ca, de\}} c_{b,m',j}(p_j) \right] \\ + EP(\mathcal{M}_s = \{ca, de, cr\}) \times \mathbb{E}\left[\min_{m' \in \{ca, de\}} c_{b,m',j}(p_j) \right] \end{pmatrix} \tag{3}$$

Note that given consumer perceptions of $EP(\mathcal{M}_s = \{ca\})$, $EP(\mathcal{M}_s = \{ca, cr\})$, $EP(\mathcal{M}_s = \{ca, de\})$, and $EP(\mathcal{M}_s = \{ca, de, cr\})$, the expected total transaction cost is defined for any $\mathcal{M}_b \in \mathcal{M}$. As we discuss later, these perceptions must be consistent with the actual realizations of individual merchants' decisions.

In the first stage, consumers choose a combination of payment methods to adopt. In order to adopt a particular payment method, consumers must pay adoption cost, $\tilde{F}_{b\mathcal{M}_b}$, and may receive adoption benefits, $B_{b\mathcal{M}_b}$, which is given by loyalty programs. The net cost (benefit) from adoption is thus $F_{b\mathcal{M}_b} \equiv B_{b\mathcal{M}_b} - \tilde{f}_{b\mathcal{M}_b}$. Note that $F_{b\mathcal{M}_b}$ can be both positive (if the benefit from adoption is greater than cost) or negative (if the cost of adoption exceeds its benefit).

Then we can describe consumer decision in the first stage as

$$\min_{\mathcal{M}'_b} \left\{ EC_b(\mathcal{M}'_b) - F_{b\mathcal{M}'_b} \right\}, \tag{4}$$

where total cost is the sum of expected transaction cost in the second stage and the fixed adoption cost net of fixed adoption benefits.

Assumption 3: *A vector of consumer fixed adoption cost components (one for each possible combination of payment methods) is given by draws from the joint distribution known up to a parameter vector, θ^b, i.e.,*

$$\left(\tilde{f}_{b,\{ca\}}, \tilde{f}_{b,\{ca,de\}}, \tilde{f}_{b,\{ca,cr\}}, \tilde{f}_{b,\{ca,de,cr\}} \right) \overset{iid}{\sim} F_{1b}(\cdot|\theta^b).$$

Note that the distribution of $f_{b\mathcal{M}_b}$'s determines the distribution of $F_{b\mathcal{M}_b}$'s, i.e., the distribution of the adoption costs (benefits) is F_{1b} with mean shifted by $B_{b\mathcal{M}_b}$. Ex ante adoption probability for combination of payment methods $\mathcal{M}_b$ is then,

$$\Pr(\mathcal{M}_b) = \Pr\left(EC_b(\mathcal{M}_b) - F_{b\mathcal{M}_b} \leq EC_b(\mathcal{M}'_b) - F_{b\mathcal{M}'_b} \; \forall \mathcal{M}'_b \subset \mathcal{M} \right) \tag{5}$$

where we assume that cash is included into every $\mathcal{M}_b$ at no cost. For a given parameter vector we can use $F_{1b}(\cdot|\theta^b)$ to evaluate equation (5).

Merchants. Each merchant is characterized by a pair of usage cost function parameters per method of payment, $c_{sm0}(X_s)$ and $c_{sm1}(X_s)$, $m \in \mathcal{M}_s$, where c_{sm0} denotes cost per transaction and c_{sm1} denotes cost per value of the transaction, and X_s is a vector of observable merchant characteristics, e.g., size, location, industry, etc. Similarly to the consumer side of the market, per transaction cost for merchant s is given by

$$c_{smj}(p_j) = c_{0sm} + c_{1sm} p_j + \varepsilon_{smj}. \tag{6}$$

Note that due to the linearity of the merchants' payoff function and our assumption that it is the consumer who decides on the method to use in the second stage, the distribution of ε_{smj} is irrelevant for the merchants' first stage decisions.

The key distinction from the consumer side is that in the second stage, when merchants and consumers are randomly matched with each other, it is the consumer decision as to which method of payment to use from $\mathcal{M}_b \cap \mathcal{M}_s$. Merchants cannot refuse to accept any method of payment provided they are in $\mathcal{M}_s$, i.e., were chosen for acceptance in the first stage of the game. This is summarized in the following assumption.

Assumption 4: *If a merchant s accepting $\mathcal{M}_s$ meets a consumer b, who chose to adopt $\mathcal{M}_b$ in the first stage, the usage decision is made by the consumer from the set $\mathcal{M}_b \cap \mathcal{M}_s$.*

In other words, the merchant payoffs are completely determined by their first stage acceptance decisions. For example, if a merchant decides to accept $\mathcal{M}_s = \{ca, de\}$, its expected cost *per transaction* in the second stage is given by

$$\begin{aligned} ETC_{bj}(\mathcal{M}_s = \{ca, de\}) = & P(\mathcal{M}_b = \{ca\}) \times c_{s,ca,j}(p_j) \\ & + P(\mathcal{M}_b = \{ca, cr\}) \times c_{s,ca,j}(p_j) \\ & + P(\mathcal{M}_b = \{ca, de\}) \times \begin{bmatrix} \Pr\left(c_{b,ca,j}(p_j) \leq c_{b,de,j}(p_j)\right) \times c_{s,ca,j} \\ \left(1 - \Pr\left(c_{b,ca,j}(p_j) \leq c_{b,de,j}(p_j)\right)\right) \times c_{s,de,j} \end{bmatrix} \\ & + P(\mathcal{M}_b = \{ca, de, cr\}) \times \begin{bmatrix} \Pr\left(c_{b,ca,j}(p_j) \leq c_{b,de,j}(p_j)\right) \times c_{s,ca,j} \\ \left(1 - \Pr\left(c_{b,ca,j}(p_j) \leq c_{b,de,j}(p_j)\right)\right) \times c_{s,de,j} \end{bmatrix}. \end{aligned}$$

The expected cost from participating in the market given acceptance combination $\mathcal{M}_s = \{ca, de\}$ is then

$$EC_s\Big(\mathcal{M}_s = \{ca, de\}\Big) = \frac{1}{N_s} \sum_{i=1}^{N_b} \sum_{j \in \mathcal{J}_b} ETC_{bj}(\mathcal{M}_s = \{ca, de\}). \tag{7}$$

Note that merchants form beliefs about adoption probabilities, $P(\mathcal{M}_b)$, for each consumer type b in the market.

In the first stage, merchants decide which means of payment to accept. Similar to consumer side, each combination of payment methods has acceptance cost, $\tilde{f}_{s\mathcal{M}_s}$, and acceptance benefit, $B_{s\mathcal{M}_s}$. Then, merchant's decision can be expressed as the following cost minimization problem,

$$\min_{\mathcal{M}'_s} \left\{ EC_s(\mathcal{M}'_s) - F_{s\mathcal{M}_s} \right\}, \tag{8}$$

where $F_{s\mathcal{M}_s} = B_{s\mathcal{M}_s} - \tilde{f}_{s\mathcal{M}_s}$. We assume that the first stage innovations $\tilde{f}_{s\mathcal{M}_s}$ are draws from a joint distribution known up to a parameter vector.

Assumption 5: *A vector of consumer fixed acceptance cost components (one for each possible combination of payment methods) is given by draws from the joint distribution known up to a parameter vector, θ, i.e.,*

$$\left(\tilde{f}_{s,\{ca\}}, \tilde{f}_{s,\{ca,de\}}, \tilde{f}_{s,\{ca,cr\}}, \tilde{f}_{s,\{ca,de,cr\}}\right) \overset{iid}{\sim} F_{1s}(\cdot|\theta^s).$$

We assume that, differently from consumers, merchants' benefit component is given by extra profit generated by the group of informed consumers, which we discuss next.

Informed consumers. Thus far our discussion was concerned with the uninformed group of consumers, whose decisions are based on their perceptions of the average merchants' acceptance probabilities for each payment method. We also assume that there is another group of consumers who know exactly the realizations of each merchant's acceptance decision. These consumers may live in the neighborhood, use online information, or learn from the experience of others. What is important is that these consumers can direct their purchases towards stores accepting their favorite mean of payment for each transaction.

It is very hard to model directed search and we don't have any data on the proportions of the informed and uninformed consumers in population. Therefore, we will model this group of consumers in reduced form. More specifically, we assume that the data is generated by equilibrium discussed below. In this equilibrium, the informed consumers distribute their purchases among the merchants who accept their favorite mean of payment for the transaction.

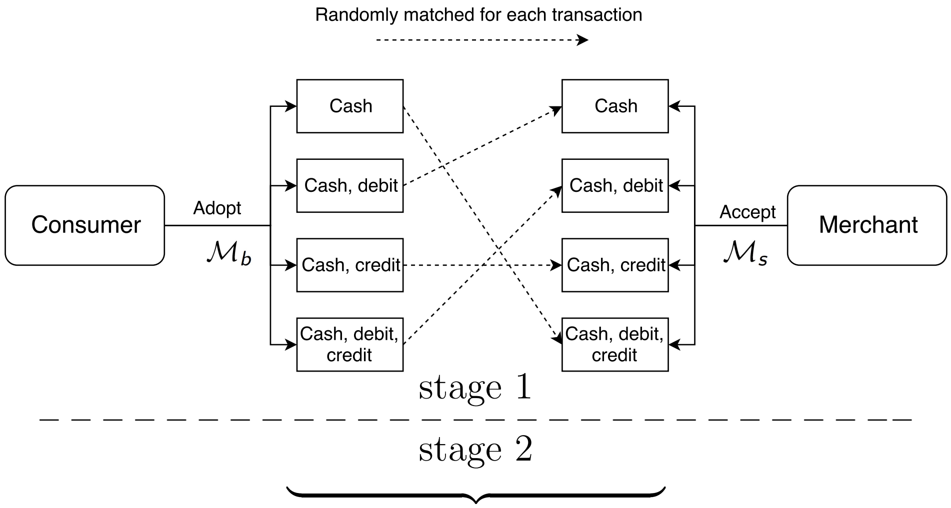
Let $\Pi(\mathcal{M}_s)$ denote total profit from transacting with informed consumers who patronize payment combination $\mathcal{M}_s$. If there are $n^*_{\mathcal{M}_s}$ merchants accepting combination $\mathcal{M}_s$, each of them in equilibrium receives

$$B_{s\mathcal{M}_s} = \frac{1}{n^*_{\mathcal{M}_s}} \Pi(\mathcal{M}_s) \tag{9}$$

In estimation we will recover $F_{s\mathcal{M}_s} = B_{s\mathcal{M}_s} - \tilde{F}_{s\mathcal{M}_s}$. Then, by using external information on the cost component $\tilde{F}_{s\mathcal{M}_s}$ reported as the cost of payment processing terminal, we can extract the pure benefit component, $B_{s\mathcal{M}_s}$. This will be important in the counterfactual analysis when the merchant acceptance probabilities change. For example, if more merchants begin accepting a given combination of payment methods, the estimated benefit must be divided between larger number of merchants, which would reduce per merchant benefit and vice versa. We will return to the discussion of informed consumers in Section 5.

Equilibrium. Our equilibrium concept is subgame perfect Nash equilibrium (SPNE). Figure 2 provides a sketch of the two-stage game.

Figure 2: Two-stage model of interactions between merchants and uninformed consumers



$$\min_{m' \in \mathcal{M}_b \cap \mathcal{M}_s} c_{bm'j}(p_{bj}),$$

where $c_{bm'j}(p_{bj})$ is the consumer usage cost for method m for transaction price p_{bj}.

Equilibrium of the game is defined in terms of merchant acceptance probabilities, $\Pr(\mathcal{M}_s)$, and consumer adoption probabilities, $\Pr(\mathcal{M}_b)$. In equilibrium, individual (uninformed) consumer decisions based on the consumers' perceptions of $EP(\mathcal{M}_s)$ result in consumer adoption probabilities, $\Pr(\mathcal{M}_b)$. The realizations of consumer adoption probabilities, in turn, must be consistent with the merchants' perceptions, $P(\mathcal{M}_b)$'s. In other words, in equilibrium we have consumer and merchant adoption/acceptance probabilities consistent with the expectation of the other side of the market and resulting second stage usage probabilities, i.e.,

$$\begin{cases} \text{Consumers:} & EP(\mathcal{M}_s) = \frac{1}{N_s}\sum_{s=1}^{N_s} \Pr(\mathcal{M}_s) \\ \text{Merchants:} & P(\mathcal{M}_b) = \Pr(\mathcal{M}_b)\ \forall \mathcal{M}_b, b \\ \text{Usage:} & \Pr\left(m|j, \mathcal{M}_b, \mathcal{M}_s\right) = \Pr\left(m = \arg\min_{m' \in \mathcal{M}_b \cap \mathcal{M}_s} c_{bm'j}(p_{bj})\right) \end{cases} \tag{10}$$

We now move to the discussion of our empirical specification and estimation method.

4 Specification and Estimation

In our model we estimate the parameters of three distributions of cost innovations. The first distribution of cost shocks is $F_\varepsilon(\cdot|\theta^{b2})$, which describes second stage consumer usage cost innovations. The second set of parameters characterizes the distribution of the first stage consumer adoption cost innovations, $F_{1b}(\cdot|\theta^{b1})$. Finally, parameters of the merchant first stage acceptance cost innovations, $F_{1s}(\cdot|\theta^{s1})$, describe the distribution of the first stage merchant acceptance cost innovation.

In what follows we will provide estimation results for several alternative specifications of the distributions. In our main specification, we assume that F_ε is type 1 extreme value (T1EV), while F_{1b} and F_{1s} belong to normal distributions. We also experiment with all distributions defined as T1EVs. Finally, for robustness analysis we estimate a specification where all three distributions are assumed normal.

4.1 Solution algorithm

We estimate parameters of the model using maximum simulated likelihood. Our nested fixed point algorithm computes one equilibrium for a given vector of parameter values $(\theta^{2b}, \theta^{1b}, \theta^{1s})$ characterizing the distributions of cost innovations. It begins with an initial guess for consumer adoption and merchant acceptance probabilities. Given beliefs about average merchant acceptance probabilities, $EP(\mathcal{M}_s)\ \forall \mathcal{M}_s$, a consumer's expected total second stage usage cost function can be computed as

$$EC_b(\mathcal{M}_b) = \sum_{j \in \mathcal{J}_b} \left[\sum_{\mathcal{M}_s} EP(\mathcal{M}_s) \times \int \cdots \int \left(\max_{m \in \mathcal{M}_b \cap \mathcal{M}_s} c_{0bm} + c_{1bm} p_{bj} + \varepsilon_{bmj} \right) dF_\varepsilon \right] \tag{11}$$

For example, if F_ε is T1EV, equation (11) becomes

$$EC_b(\mathcal{M}_b) = -\sum_{j \in \mathcal{J}_b} \left[\sum_{\mathcal{M}_s} EP(\mathcal{M}_s) \times \log \left(\sum_{m \in \mathcal{M}_b \cap \mathcal{M}_s} \exp(-c_{0bm} - c_{1bm} p_{bj}) \right) \right]$$

which makes it very convenient for numerical optimization.

Parameter values for the first stage distribution of consumer adoption cost innovations, θ^{b1}, and the vector of $EC_b(\mathcal{M}_b)$ computed above can be used to update type-specific consumer adoption probabilities,

$$\Pr(\mathcal{M}_b) = \int \cdots \int \mathbb{1} \left(EC_b(\mathcal{M}_b) - F_{b\mathcal{M}_b} \leq EC_b(\mathcal{M}_b') - F_{b\mathcal{M}_b'}\ \forall \mathcal{M}_b' \right) dF_{1b}. \tag{12}$$

We update the merchant side of the market by setting beliefs equal to the current iteration values of consumer adoption probabilities, i.e., $P(\mathcal{M}_b) = \Pr(\mathcal{M}_b)$. Expected usage cost to merchants for a particular transaction in the second stage can be computed as

$$ETC_{bj}(\mathcal{M}_s) = \sum_{\mathcal{M}_b \in \mathcal{M}} P(\mathcal{M}_b) \times \Pr\left(c_{bmj}(p_{bj}) \leq c_{bm'j}(p_{bj})\ \forall m' \in \mathcal{M}_b \cap \mathcal{M}_s \right) \times (c_{0sm} + c_{1sm} p_{bj}).$$

Note that, similar to the expected maximum property, we can compute second stage usage probabilities analytically, i.e., per consumer-transaction expected merchant usage cost is

$$ETC_{bj}(\mathcal{M}_s) = \sum_{\mathcal{M}_b \in \mathcal{M}} P(\mathcal{M}_b) \times \frac{\exp(-c_{0bm} - c_{1bm} p_{bj})}{\sum_{m' \in \mathcal{M}_s \cap \mathcal{M}_b} \exp(-c_{0bm} - c_{1bm} p_{bj})} \times (c_{0sm} + c_{1sm} p_{bj}), \tag{13}$$

so the expected total stage 2 cost for merchants is

$$EC_s(\mathcal{M}_s) = \frac{1}{N_s} \sum_{i=1}^{N_b} \sum_{j \in \mathcal{J}_b} ETC_{bj}(\mathcal{M}_s). \tag{14}$$

Given parameter values for the distribution of stage one cost innovations, θ^{1s}, we can calculate acceptance probabilities for each merchant as follows,

$$\Pr(\mathcal{M}_s) = \int \cdots \int \mathbb{1}\left(EC_s(\mathcal{M}_s) - F_{s\mathcal{M}_s} \leq EC_s(\mathcal{M}'_s) - F_{s\mathcal{M}'_s}\ \forall \mathcal{M}'_s\right) dF_{1s}. \tag{15}$$

Consumer perceptions are updated by setting

$$EP(\mathcal{M}_s) = \frac{1}{N} \sum_{s=1}^{N_s} \Pr(\mathcal{M}_s)\ \forall \mathcal{M}_s.$$

This operation completes one iteration of our solution algorithm. We then return to equation (11) and repeat iterations until convergence is reached for both adoption and acceptance probabilities.

4.2 Model predictions and observed data

Our model generates three sets of policy functions: (1) optimal usage probabilities in the second stage, (2) optimal consumer first stage adoption probabilities, and (3) optimal merchant first stage acceptance probabilities.

In the data, for each consumer we observe a set of transactions with prices as well as the point-of-sale payment method decision. We denote these data as $(U_{bj1}, U_{bj2}, U_{bj3})$ such that $U_{bjm} \in \{0, 1\}\ \forall m$ and $U_{bj1} + U_{bj2} + U_{bj3} = 1$. We also see the realization of the first stage consumer adoption decisions. Let these data be denoted with the following vector $\left(A_{b,\{ca\}}, A_{b,\{ca,de\}}, A_{b,\{ca,cr\}}, A_{b,\{ca,de,cr\}}\right)$ per consumer type. Finally, on the merchant side we see first stage merchant acceptance decisions denoted as $\left(A_{s,\{ca\}}, A_{s,\{ca,de\}}, A_{s,\{ca,cr\}}, A_{s,\{ca,de,cr\}}\right)$ per merchant type.

Using our model predictions and available data on both sides of the market, we construct the following likelihood function for estimation,

$$\begin{aligned} \mathcal{L}(\theta) = & \prod_{b=1}^{N_b} \Pr(\mathcal{M}_b)^{A_{b\mathcal{M}_b}} \times \\ & \prod_{b=1}^{N_b} \times \prod_{j \in \mathcal{J}_b} \prod_{m \in \{ca,de,cr\}} \Pr(c_{bmj} = \min_{m' \in \mathcal{M}_s \cap \mathcal{M}_b} c_{bm'j})^{U_{bjm}} \times \\ & \prod_{s=1}^{N_s} \prod_{\mathcal{M}_s \subset \mathcal{M}} \Pr(\mathcal{M}_s)^{A_{s\mathcal{M}_s}}, \end{aligned} \tag{16}$$

where the first line is for consumer adoption probabilities, the second line matches usage decisions, and the third line is for merchants' acceptance decisions.

5 Estimation Results

Table 3 summarizes parameter estimates for five alternative specifications. We estimated several versions of the model. Our first specification (column (LL) in Table 3) assumes that all cost innovations are independent and identically distributed type 1 extreme value (T1EV) deviates. This version of the empirical model is simplistic but numerically stable, so we use it to find starting values for our more complex specifications. In our second specification (column NN (1)), we assume normally distributed errors for consumers and merchants in both stages. In this specification, we impose several restrictions on the parameters. In particular, we restrict consumer first stage variances of the *cash-debit* and *cash-debit-credit* combinations to be equal. The same restriction is imposed on buyers' second stage variances of usage costs, and for the variances of the *cash-debit* and *cash-debit-credit* combinations on the merchant side. The specification reported in column NN (2) allows for different first stage variances for both consumer and merchants, while maintaining second stage buyer usage cost equal to each other. Specification in column NN (3) is similar to NN (2), but allows buyer second stage usage cost variances to be different for debit and credit and fixes variance of cash usage to zero. Finally, our richest specification (column NN (4)) relaxes all restrictions on first and second stage variances.

Results suggest that an average consumer in our sample spends about $33 a month to have cash and debit card in her wallet relative to holding only cash.[3] Consumers who adopt all means of payment instead receive a relative benefit of about $8 a month. For merchants, accepting cash and debit costs about $90 per year on average relative to accepting only cash. By choosing to accept all means of payment a typical merchant receives gross benefits equivalent to about $6,090 per year.

The presence of negative fixed costs in our results suggests that we are estimating an amalgamation of fixed costs and benefits. Using data from the merchant survey, we estimate fixed acceptance costs using merchants' self-reported costs for owning or renting debit and credit card terminals. Table 4 summarizes these data by size of merchant and reports the implied net benefits of acceptance as the difference between self-reported costs and the cost estimates from our model. Benefits from the informed group of consumers increase as a function of merchant size. For example, a large merchant (sales of about 8 million dollars) can receive a net benefit of 158 thousand dollars per year for accepting all methods of payment. On the other hand, for small merchants having annual sales of 50,000 dollars, accepting all means of payment can generate about $1,000 in gross benefits, which leaves about $800 in net benefits after paying for terminals.

[3] Recall that our sample records consumer purchases over a 3-day period. To pro-rate our estimates to the monthly level we multiply by 10.

Table 3: Preliminary estimation results, joint estimation

	(LL)	NN (1)	NN (2)	NN (3)	NN (4)
Buyers					
mean cost: $F_{b,\{ca,de\}}$	-0.17	-0.30	-0.09	0.95	3.29
	(0.22)	(0.43)	(0.47)	(2.56)	(1.89)
mean cost: $F_{b,\{ca,de,cr\}}$	-0.37	-7.44	-2.56	-3.70	-0.77
	(0.21)	(2.58)	(0.76)	(0.92)	(0.15)
variance of $F_{b,\{ca,de\}}$			2.54	14.08	13.62
	1.64	22.56	(3.30)	(18.69)	(11.55)
variance of $F_{b,\{ca,de,cr\}}$		(12.63)	6.18	6.37	0.84
			(4.38)	(2.91)	(0.09)
variance of usage cost, cash				0.00	0.10
					(0.02)
variance of usage cost, debit	1.64	0.25	0.27	0.34	0.37
		(0.01)	(0.01)	(0.02)	(0.02)
variance of usage cost, credit				0.13	0.00
				(0.02)	(0.02)
Sellers					
mean cost: $F_{s,\{ca,de\}}$	1.01	0.58	-0.21	0.21	0.09
	(0.06)	(0.13)	(0.04)	(0.07)	(0.06)
mean cost: $F_{s,\{ca,de,cr\}}$	-3.77	-6.72	-6.07	-5.94	-6.09
	(0.03)	(0.26)	(0.16)	(0.09)	(0.10)
variance of $F_{s,\{ca,de\}}$			1.86	2.76	2.76
	1.64	49.50	(0.38)	(0.78)	(0.71)
variance of $F_{s,\{ca,de,cr\}}$		(5.58)	27.43	14.77	14.33
			(3.18)	(1.16)	(1.18)
F-value	-12,897.92	-12,629.29	-12,634.76	-12,525.05	-12,460.51

Notes: Specification *LL* assume T1EV deviates in both stages for both sides of the market. Specifications NN (1) through NN (4) report estimation results for normally distributed errors in both stages for both sides of the market. Every next specification relaxes some of the restrictions on the parameter values where specification NN (4) is the richest model.

Table 4: Summary of fixed cost estimates, self-reported costs, and implied benefits, CAD

size, sales	CA&DE			CA&DE&CR		
	reported cost	estimate	benefit	reported cost	estimate	benefit
50k	50.4	11.9	38.5	213.4	-807.5	1,020.9
175k	147.2	41.8	105.4	1,077.7	-2,826.4	3,904.1
375k	1,229.9	89.5	1,140.3	6,041.3	-6,056.5	12,097.9
625k	684.5	149.2	535.3	5,274.4	-10,094.2	15,368.7
875k	740.5	208.8	531.6	7,589.8	-14,131.9	21,721.8
3,000k	1,291.4	716.0	575.4	15,818.6	-48,452.4	64,270.9
7,500k	1,152.1	1,790.1	-638.0	36,888.4	-121,131.0	158,019.3

As an indicator of model fit, we predict merchant acceptance as a function of sales (Figure 3) and consumer adoption as a function of total expenditure (Figure 4), and compare to estimates from their respective samples. We find that consumer adoption is predicted remarkably well. On the other hand, merchant acceptance is predicted well for larger merchant sizes, but acceptance of cash-only and cash-debit bundles are respectively under- and over-estimated.

Figure 3: Model fit for three acceptance combinations, merchants

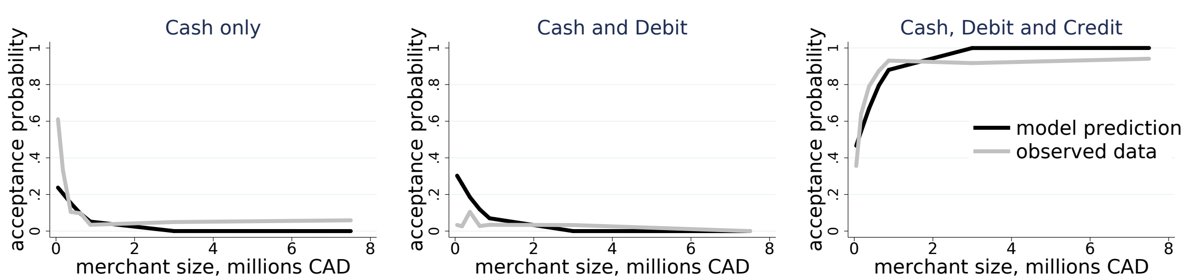
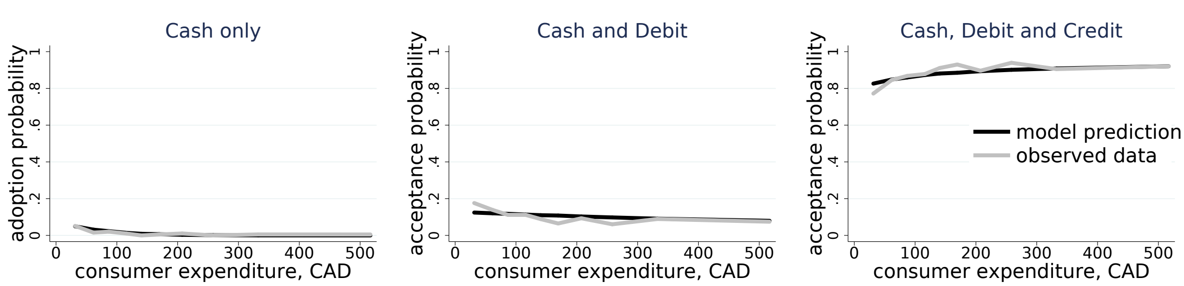


Figure 4: Model fit for three adoption combinations, consumers



5.1 Usage costs

To identify the key drivers of consumer adoption and merchant acceptance decisions we calculate local responses to small perturbations in the second stage usage costs for consumers and merchants.

Table 5 (top three rows) summarizes elasticity of buyer adoption probabilities to usage costs in the second stage. In other words, we compute the following elasticity measure for consumers:

$$\mathcal{E}_{\Pr(\mathcal{M}_b),C_{bm}} \equiv \frac{\partial \mathbb{E}\Pr(\mathcal{M}_b)}{\partial C_{mb,\cdot}} \frac{C_{mb,\cdot}}{\mathbb{E}\Pr(\mathcal{M}_b)} \;\forall m, \mathcal{M}_b.$$

Bottom three rows of Table 5 list measures of merchant responsiveness to increase in consumer usage costs. Our goal is to quantify merchant response to an exogenous change in consumer adoption probabilities. To do this we define our "elasticity-like" measure of sensitivity. Note that consumer adoption probabilities must add up to one. Therefore, we first compute one-step consumer response to an increase in own usage costs, i.e., $\frac{\partial \mathbb{E}\Pr(\mathcal{M}_b)}{\partial C_{b,m}}$, and then use this "exogenous variation" to calculate one-step merchant response.[4] In other words, we calculate the following measure of merchant responsiveness to changes in consumer usage cost and subsequent change in consumer adoption probabilities,

$$\mathcal{E}_{\Pr(\mathcal{M}_s=x),C_{b,m}} \equiv \left[\sum_{y\in\mathcal{M}} \frac{\partial \mathbb{E}\Pr(\mathcal{M}_s=x)}{\partial \mathbb{E}\Pr(\mathcal{M}_b=y)} \times \frac{\partial \mathbb{E}\Pr(\mathcal{M}_b=y)}{\partial C_{b,m}}\right] \times \frac{C_{b,m}}{\mathbb{E}\Pr(\mathcal{M}_s=x)} \;\forall m, \mathcal{M}_s.$$

Obtained results are reported in Table 5 below.

Table 5: Consumer and merchant response to increased buyer usage costs

	$\partial C_{b,cash}$	$\partial C_{b,debit}$	$\partial C_{b,credit}$
$\partial \mathbb{E}\Pr(\mathcal{M}_b = \{ca\})/\cdots$	-1.701	1.062	0.219
$\partial \mathbb{E}\Pr(\mathcal{M}_b = \{ca, de\})/\cdots$	-0.206	-0.171	0.060
$\partial \mathbb{E}\Pr(\mathcal{M}_b = \{ca, de, cr\})/\cdots$	0.050	0.004	-0.010
$\partial \mathbb{E}\Pr(\mathcal{M}_s = \{ca\})/\cdots$	0.234	0.290	-0.081
$\partial \mathbb{E}\Pr(\mathcal{M}_s = \{ca, de\})/\cdots$	0.622	0.672	-0.205
$\partial \mathbb{E}\Pr(\mathcal{M}_s = \{ca, de, cr\}/\cdots)$	-0.216	-0.239	0.072

Notes: Each element of the matrix illustrate elasticity of the variable defined in the first column with respect to a variable defined in the first row. For the merchant acceptance probabilities, we compute elasticity using $\mathcal{E}_{\Pr(\mathcal{M}_s=x),C_{b,m}} \equiv \left[\sum_{y\in\mathcal{M}} \frac{\partial \mathbb{E}\Pr(\mathcal{M}_s=x)}{\partial \mathbb{E}\Pr(\mathcal{M}_b=y)} \times \frac{\partial \mathbb{E}\Pr(\mathcal{M}_b=y)}{\partial C_{b,m}}\right] \times \frac{C_{b,m}}{\mathbb{E}\Pr(\mathcal{M}_s=x)} \;\forall m, \mathcal{M}_s$, where the change in $\Pr(\mathcal{M}_b)$ is induced by an increase in buyer usage costs (see discussion above).

We also conduct a similar exercise to illustrate responsiveness of consumer adoption and merchant acceptance probabilities to changes in the usage cost of sellers. First three rows in Table 6 summarizes own elasticity, calculated as

$$\mathcal{E}_{\Pr(\mathcal{M}_s),C_{sm}} \equiv \frac{\partial \mathbb{E}\Pr(\mathcal{M}_s)}{\partial C_{sm}} \frac{C_{sm}}{\mathbb{E}\Pr(\mathcal{M}_s)} \;\forall m, \mathcal{M}_s,$$

[4] Note that our measure is not identical to a usual price elasticity because the change in usage costs will affect the entire distribution of consumer adoption probabilities. Therefore, merchants respond to the change in the distribution instead of change in an isolated adoption probability for a single mean of payment.

while the bottom three rows report cross-cost elasticity, i.e., consumer short-run response to change in merchant usage cost in the second stage,

$$\mathcal{E}_{\Pr(\mathcal{M}_b=x),C_{s,m}} \equiv \left[\sum_{y\in\mathcal{M}} \frac{\partial \mathbb{E}\Pr(\mathcal{M}_b = x)}{\partial \mathbb{E}\Pr(\mathcal{M}_s = y)} \times \frac{\partial \mathbb{E}\Pr(\mathcal{M}_s = y)}{\partial C_{s,m}}\right] \times \frac{C_{s,m}}{\mathbb{E}\Pr(\mathcal{M}_b = x)} \; \forall m, \mathcal{M}_b.$$

Table 6: Consumer and merchant response to increased merchant usage costs

	$\partial C_{s,cash}$	$\partial C_{s,debit}$	$\partial C_{s,credit}$
$\partial\mathbb{E}\Pr(\mathcal{M}_s = \{ca\})/\cdots$	-1.151	0.670	1.101
$\partial\mathbb{E}\Pr(\mathcal{M}_s = \{ca, de\})/\cdots$	-0.296	-0.521	2.171
$\partial\mathbb{E}\Pr(\mathcal{M}_s = \{ca, de, cr\}/\cdots)$	0.270	0.041	-0.799
$\partial\mathbb{E}\Pr(\mathcal{M}_b = \{ca\})/\cdots$	-0.458	0.078	0.991
$\partial\mathbb{E}\Pr(\mathcal{M}_b = \{ca, de\})/\cdots$	-0.081	-0.010	0.241
$\partial\mathbb{E}\Pr(\mathcal{M}_b = \{ca, de, cr\})/\cdots$	0.017	-0.000	-0.044

Notes: Each element of the matrix illustrate elasticity of the variable defined in the first column with respect to a variable defined in the first row. For the consumer adoption probabilities, we compute elasticity using $\mathcal{E}_{\Pr(\mathcal{M}_b=x),C_{s,m}} \equiv \left[\sum_{y\in\mathcal{M}} \frac{\partial \mathbb{E}\Pr(\mathcal{M}_b=x)}{\partial \mathbb{E}\Pr(\mathcal{M}_s=y)} \times \frac{\partial \mathbb{E}\Pr(\mathcal{M}_s=y)}{\partial C_{s,m}}\right] \times \frac{C_{s,m}}{\mathbb{E}\Pr(\mathcal{M}_b=x)} \; \forall m, \mathcal{M}_b.$, where the change in $\Pr(\mathcal{M}_s)$ is induced by an increase in seller usage costs.

Our empirical analysis reveals that consumer adoption probabilities and merchant acceptance probabilities are decreasing in own usage costs (negative elements on the diagonal in the top rows of Table 5 and Table 6). Consumer has elastic demand for cash ($\mathcal{E}_{\Pr(\mathcal{M}_b=\{ca\}),C_{b,cash}} = -1.7$) and consumer adoption of cash increases by about 1.06 percent if usage cost of debit increases by 1 percent, i.e., the cross-partial elasticity measure $\mathcal{E}_{\Pr(\mathcal{M}_b=\{ca,de\}),C_{b,debit}} = 1.062$. Other measures of responsiveness of consumer adoption probabilities to increase in own usage costs turn out to be inelastic.

Similar observation can be made for the merchant side of the market. In particular, merchant responds by reducing probability of cash-only acceptance decisions by 1.15 percent when own usage cost of cash increases by 1 percent. Interestingly, cross-partial elasticity of merchant all-methods acceptance decisions with respect to increase in own usage cost of credit are larger than 1. For example, a 1 percent increase in usage cost of credit would result in 1.1% increase in cash-only acceptance probabilities, and in 2.2% increase in cash-and-debit acceptance probabilities.

Finally, as discussed above, the bottom three rows of Table 5 and Table 6 present measures of responsiveness of adoption/acceptance decisions on one side of the market to the increase in usage costs on the other side of the market. We find that consumer response to increases in merchant usage cost of cash is stronger when adjusting adoption probability of cash-only option. The same observation applies to the consumer response to increases in the merchant usage cost of credit, i.e., consumer responds more to merchant increase in usage costs than vice versa, i.e.,

$$\left|\mathcal{E}_{\Pr(\mathcal{M}_b=\{ca\}),C_{s,credit}}\right| > \left|\mathcal{E}_{\Pr(\mathcal{M}_s=\{ca\}),C_{b,credit}}\right|$$
$$\text{and}$$
$$\left|\mathcal{E}_{\Pr(\mathcal{M}_b=\{ca\}),C_{s,credit}}\right| > \left|\mathcal{E}_{\Pr(\mathcal{M}_s=\{ca\}),C_{b,credit}}\right|$$

Merchants respond more to the change in consumer usage costs of cash and debit with the exception of $\left|\mathcal{E}_{\Pr(\mathcal{M}_b=\{ca\}),C_{s,cash}}\right| > \left|\mathcal{E}_{\Pr(\mathcal{M}_s=\{ca\}),C_{b,cash}}\right|$.

5.2 Adoption and acceptance costs

To illustrate the effects of changes in the fixed adoption or acceptance costs for the first-stage consumer and merchant decisions we calculate elasticity-like measures for each side of the market. These calculations are analogous to the one conducted for usage costs in the previous section. Results for the change in adoption (buyer side) costs are summarized in Table 7, while results for the change in acceptance (seller side) costs are summarized in Table 8

Table 7: Consumer and merchant response to increase in consumer adoption costs

	$\partial F_{b,\{ca,de\}}$	$\partial F_{b,\{ca,de,cr\}}$
$\partial \Pr(\mathcal{M}_b = \{ca\})/\ldots$	0.34	1.85
$\partial \Pr(\mathcal{M}_b = \{ca, de\})/\ldots$	-1.49	0.34
$\partial \Pr(\mathcal{M}_b = \{ca, de, cr\})/\ldots$	0.17	-0.07
$\partial \Pr(\mathcal{M}_s = \{ca\})/\ldots$	0.14	-0.05
$\partial \Pr(\mathcal{M}_s = \{ca, de\})/\ldots$	0.35	-0.11
$\partial \Pr(\mathcal{M}_s = \{ca, de, cr\})/\ldots$	-0.12	0.04

On the consumer side, as expected, increase in adoption costs for combination $m \in \mathcal{M}$ decreases probability of adopting this combination, with the effect being more pronounced for combination $\mathcal{M}_b = \{ca, de\}$ (about 1.5% decline) than for combination $\mathcal{M}_b = \{ca, de, cr\}$ (about 0.07% decline). While merchants does respond to the innovations in the consumer adoption costs, this response is inelastic and ranges between 0.04% and 0.35% for a one percent increase in the adoption costs.

Table 8: Consumer and merchant response to increase in merchant acceptance costs

	$\partial F_{s,\{ca,de\}}$	$\partial F_{s,\{ca,de,cr\}}$
$\partial \Pr(\mathcal{M}_s = \{ca\})/\ldots$	0.03	1.23
$\partial \Pr(\mathcal{M}_s = \{ca, de\})/\ldots$	-0.06	2.42
$\partial \Pr(\mathcal{M}_s = \{ca, de, cr\})/\ldots$	0.01	-0.89
$\partial \Pr(\mathcal{M}_b = \{ca\})/\ldots$	-0.01	0.02
$\partial \Pr(\mathcal{M}_b = \{ca, de\})/\ldots$	-0.00	0.00
$\partial \Pr(\mathcal{M}_b = \{ca, de, cr\})/\ldots$	0.00	-0.00

When perturbing acceptance costs on the merchant side, we find that increase in own acceptance costs reduces acceptance probability of that combination, though the response is inelastic. In particular, one percent increase in acceptance cost for cash and debit reduces probability of accepting this combination by only 0.06%. While the decline in own acceptance probabilities is stronger for combination $\mathcal{M}_s = \{ca, de, cr\}$, it is still only about 0.89%. Interestingly, when own acceptance cost for merchant combination $\mathcal{M}_s = \{ca, de, cr\}$ increases, the merchants respond by increasing acceptance of $\mathcal{M}_s = \{ca, de\}$ by 2.4%, and also by increasing acceptance of $\mathcal{M}_s = \{ca\}$ by 1.23%. Consumer (cross-partial) responses to a one-percent increase in acceptance costs for merchants are much smaller and stay below 0.02%.

5.3 Equilibrium usage probabilities

Thus far we have discussed the determinants of consumer adoption and merchant acceptance decisions. Similar analysis can be done for the equilibrium usage probabilities. Figures 5 and 6 illustrates several elasticity-like measures of responsiveness of each side of the market to small increases in the cost structure. Table 9 in Appendix A provides additional details on own- and cross-cost elasticities with respect to key structural parameters in the model.

First, we define $\mathcal{E}^{\text{IM}}_{\text{Pr(use m)},\theta}$ $m \in \mathcal{M}$ as an immediate response of equilibrium usage probability to change in parameter θ. Note that this measure is only defined for buyer usage costs $C_{b,m}$ $m \in \mathcal{M}$ as neither adoption nor acceptance probabilities change. In other words, the immediate response is a partial derivative of the consumer second stage usage decisions with respect to own usage costs. We normalize the derivative by the ratio of usage cost level and current equilibrium usage probability. Let $\overline{PM}_s$ and $\overline{PM}_b$ denote vectors of *ex ante* (prior to realization of random innovations) acceptance and adoption probabilities, respectively. Let $\text{Pr}(\text{use m}, \overline{PM}_b, \overline{PM}_s)$ denote joint probability of first and second stage choices, such that $\overline{PM}_s = \left(PM_{s,\{ca\}}, PM_{s,\{ca,de\}}, PM_{s,\{ca,de,cr\}}\right)$ and $PM_{s,\{ca\}}$ is a shortcut for $\text{Pr}(\mathcal{M}_s = \{ca\})$ and $\overline{PM}_b$ defined similarly. Then, with an abuse of notation we can describe our measure of an immediate response as follows

$$\mathcal{E}^{IM}_{\text{Pr(use m)},\theta^{IM}} = \mathbb{E}_{b,j}\left[\frac{\partial\,\text{Pr}(\text{use m}, \overline{PM}_b, \overline{PM}_s)}{\partial\theta^{IM}}\right] \times \frac{\theta^{IM}}{\text{Pr(use m)}}, \qquad \theta^{IM} \in (C_{b,ca}, C_{b,de}, C_{b,cr})\ \forall b. \tag{17}$$

This measure of an immediate response measures adjustments on the intensive margin as neither buyers nor sellers can adjust their adoption and acceptance decisions. Other elasticity-like measures discussed above allow changes on the extensive margin on one or both sides of the market.

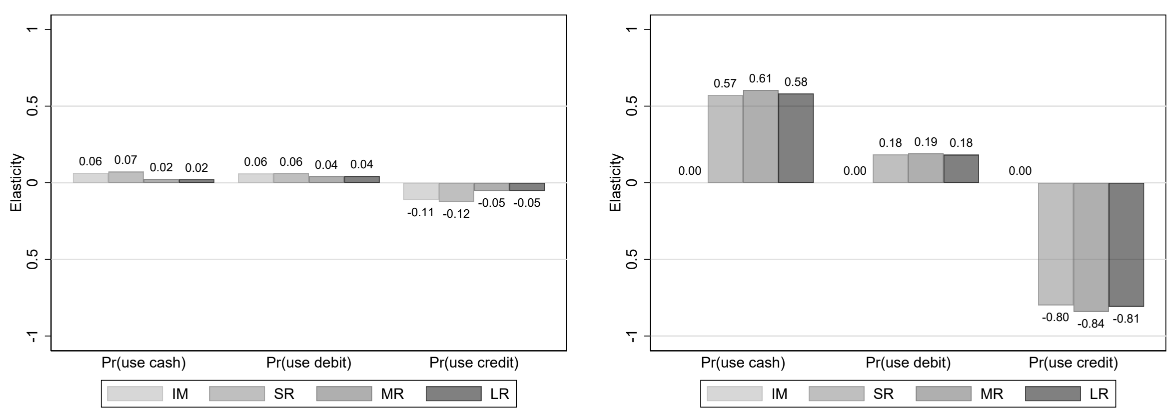
Next we study change in the usage probability in the short run, when only the side whose parameter is perturbed has time to adjust its adoption/acceptance decisions, $\mathcal{E}^{\text{SR}}_{\text{Pr(use m)},\theta}$ $m \in \mathcal{M}$. For the short run elasticity with respect to change in buyer adoption costs we allow only consumer side to adjust its adoption decisions and keep merchant acceptance choices unchanged. For example, short run elasticity of cash usage probability with respect to consumer fixed cost of cash and debit is a change in usage probability when only consumer side adjusts its decisions. From the merchant point of view, consumers will use cash less (more) frequently but the merchant don't have time to adjust their own acceptance decisions. The change in usage probability of cash multiplied by ratio of fixed cost and current usage probability would then determine the short-run elasticity measure, i.e.,

$$\mathcal{E}^{SR}_{\Pr(\text{use m}),\theta_i} = \mathbb{E}_{b,j}\left[\begin{array}{l}\dfrac{\partial \Pr(\text{use m}, \overline{PM}_b, \overline{PM}_s)}{\partial \theta_i} \\ + \displaystyle\sum_{x\in\mathcal{M}} \dfrac{\partial \Pr(\text{use m}, \overline{PM}_b, \overline{PM}_s)}{\partial PM_{i,x}} \dfrac{\partial PM_{i,x}}{\partial \theta_i}\end{array}\right] \times \frac{\theta_i}{\Pr(\text{use m})}, \tag{18}$$

$$\theta_i \in (F_{i,\{ca,de\}}, F_{i,\{ca,de,cr\}} C_{i,ca}, C_{i,de}, C_{i,cr}),\ i = s, b.$$

The measure of short-run elasticity illustrates response of one side of the market when both the usage and adoption/acceptance decisions can be adjusted (but only on the side which cost parameters were increased). This change in policy functions on one side of the market becomes a surprise to the other side of the market.

Figure 5: Response of consumer usage decisions to an increase in own usage cost of credit cards (left) and merchant usage cost of credit cards (right)



Our medium run measure of elasticity allows each side of the market to adjust their adoption/acceptance decisions only once. This elasticity is defined as

$$\mathcal{E}^{MR}_{\Pr(\text{use m}),\theta} = \mathbb{E}_{b,j}\left[\begin{array}{l}\dfrac{\partial \Pr(\text{use m}, \overline{PM}_b, \overline{PM}_s)}{\partial \theta} \\ + \displaystyle\sum_{x\in\mathcal{M}} \dfrac{\partial \Pr(\text{use m}, \overline{PM}_b, \overline{PM}_s)}{\partial PM_{b,x}} \dfrac{\partial PM_{b,x}}{\partial \theta} \\ + \displaystyle\sum_{x\in\mathcal{M}} \dfrac{\partial \Pr(\text{use m}, \overline{PM}_b, \overline{PM}_s)}{\partial PM_{s,x}} \dfrac{\partial PM_{s,x}}{\partial \theta}\end{array}\right] \times \frac{\theta}{\Pr(\text{use m})}, \tag{19}$$

$$\theta \in (F_{b,\{ca,de\}}, F_{b,\{ca,de,cr\}}, C_{b,ca}, C_{b,de}, C_{b,cr}, F_{s,\{ca,de\}}, F_{s,\{ca,de,cr\}}, C_{s,ca}, C_{s,de}, C_{s,cr}).$$

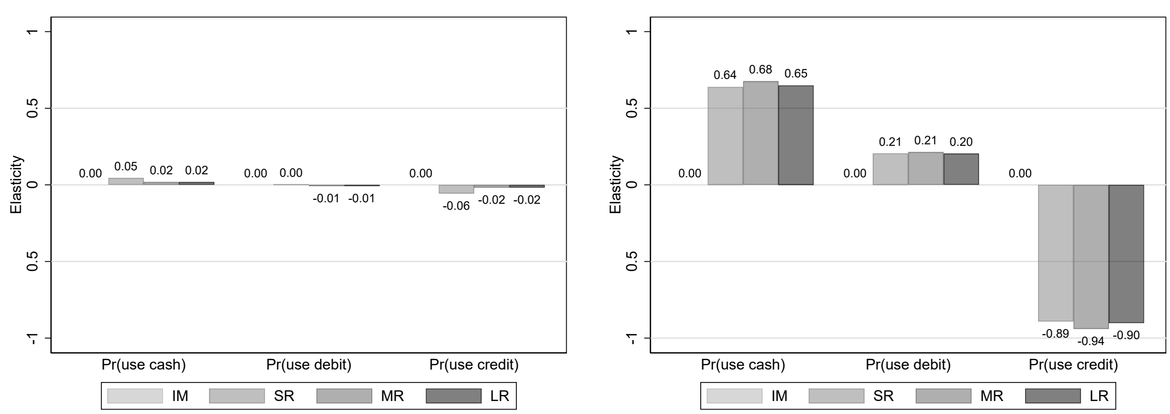
Intuition behind the medium run measure of responsiveness is in illustrating how long it may take to get to a new equilibrium. Under this scenario each side can adjust its decisions in both stages. However, since this is done only once, the resulting policy adjustment are unlikely to be optimal and would require further adjustments up until a new equilibrium is reached.

Finally, new equilibrium usage probabilities would determine our long run elasticity measure, which would fully account for the network effects on both sides of the market. Let θ^* be the original parameter value and $\theta^{**} = \theta^* + \epsilon$ for small enough ϵ. i.e.,

$$\mathcal{E}^{LR}_{\Pr(\text{use m}),\theta} = \mathbb{E}_{b,j}\left[\frac{\Pr(\text{use m}, \overline{PM}_b^{**}, \overline{PM}_s^{**}) - \Pr(\text{use m}, \overline{PM}_b^{*}, \overline{PM}_s^{*})}{\theta^{**}-\theta^{*}}\right] \times \frac{\theta^*}{\Pr(\text{use m})}. \qquad (20)$$

Note that the long-run response can be either larger or smaller depending on the sign of the network effects. By comparing short- and long-run response we can see the direction and magnitude of the network effects between two sides of the market. According to our estimation results, network effects can work in the same or in an opposite direction as the direct effects (immediate and short-run elasticity) and on average accounts for about 37% difference between the short-run and long-run elasticity (see Appendix A). There is a huge difference in magnitudes of the network effects. In particular, perturbations in consumer side parameters result in much larger network effect as measured by the difference in the short- and long-run elasticity of usage probability. Network effects coming from the merchant side of the market are usually small and range between 1 and 2 percent.

Figure 6: Response of consumer usage to an increase in own fixed cost of adopting all means of payment (left) and merchant fixed cost of adopting all means of payment (right)



As suggested by the results illustrated on Figures 5 and 6, immediate and short-run responses can be different from the long-run elasticities. This difference emphasizes the importance of having a structural model for making correct equilibrium predictions. Reduced form models or models using linear approximations to consumer and merchant policy functions (e.g., as a system of simultaneous equations) can be informative about the changes on the intensive margin or in the short-run on each side of the market. In order to accurately account for equilibrium effects, however, one needs to account for network externalities by modeling them explicitly.

By comparing the left and right panels in Figure 5 and Figure 6 we find that consumers respond more strongly to changes in merchant costs than their own. This is counterintuitive on the face of it, but is consistent with our knowledge of costs and the underlying model. With credit cards being significantly cheaper to use for consumers than cash and debit, they are very inelastic to credit card cost increases. Since their usage changes very little, their adoption and the resulting reaction from merchants changes little as well, leaving the entire system largely unchanged. On the other hand, credit cards are very expensive to merchants except for small transactions. Since usage is consumer-driven, merchants can react to an increase in usage cost only by reducing their acceptance of credit cards, and they do so significantly at the current level of costs (see Table 8). As a result, consumers have a significantly reduced chance of finding a merchant with credit card machines, and credit card usage is reduced. For a full summary of network effects in the short- and long-run, see Table 9 in Appendix A.

The analysis of local responses provided above should inform us about the likely short-run changes in the adoption/acceptance decisions by each side of the market and resulting equilibrium usage probabilities. To study the long-run response or response to a rather dramatic changes in the cost structure, we have to make out-of-sample predictions. This is done in the section that follows.

6 Counterfactual Simulations

6.1 Varying the usage cost of credit cards

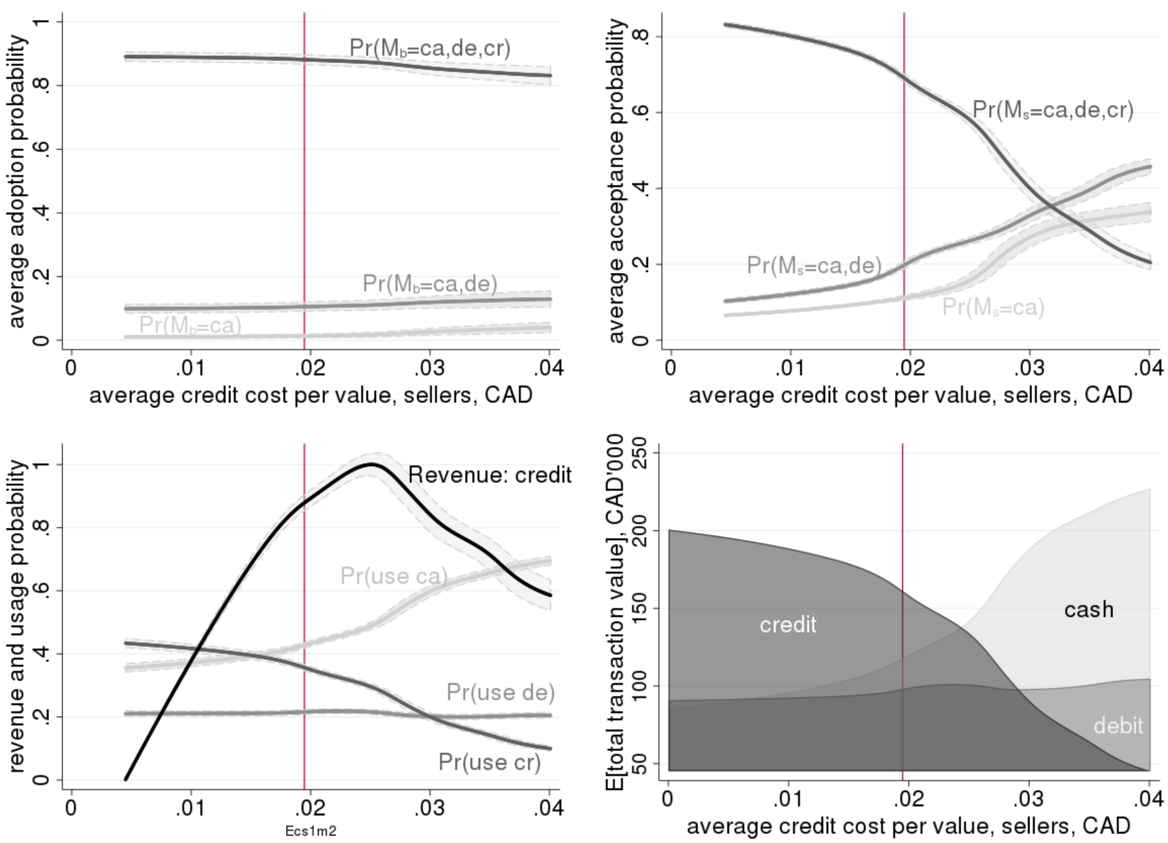
The counterfactual simulation in this section has been motivated in part by regulatory concerns. For example, the level of interchange fee for debit cards in the US or for credit cards in Canada remains a serious concern for the oversight institutions. The theory of Rochet and Tirole (2011) shows how merchants may accept the added cost of cards in order to avoid losing customers, allowing issuers to charge socially inefficient fees. The merchant indifference test (MIT) was designed based on this theoretical framework and was subsequently used in Europe (European Commission 2015) to provide guidance on the fee level that makes merchants indifferent between cards and other methods of payment. Unfortunately, due to its partial equilibrium nature, the MIT does not account for the feedback effects between merchant and consumer decisions that would occur as a result of changes in the costs of one (or more) side of the market. The same criticism can be applied to a reduced form analysis conducted in Rysman (2007) or a simultaneous equations estimation with instrumental variables performed by Carbó-Valverde et al. (2016). These studies do not model consumer and merchant decisions explicitly and can only be informative about local responses by each side of the market to small perturbations in the costs. When it comes to out-of-sample predictions induced by large changes in the cost structure, or long-run equilibrium effects, one would need to use a structural model analogous to the one presented in the earlier sections of this paper.

In addition to accounting for the equilibrium effects, our model allows us to disentangle direct and network effects of changes in the parameter values. We can apportion changes in the acceptance, adoption and usage probabilities into extensive, when adoption and acceptance decisions can be adjusted, and intensive margin, when only usage decision can be changed at a point of sale.

In our counterfactual analysis, we consider changing merchants' usage cost of credit cards. In particular, we vary the *per-value* cost of credit from 0.0001 to 0.04 (twice its true value) and compute market equilibrium for these alternative values of the merchant usage cost. Note that the change in the merchant usage costs makes credit more (less) attractive as the cost declines (increases).

Figure 7 illustrates sequence of equilibrium adoption/acceptance probabilities, usage probabilities, and expected total transaction values, which can occur for alternative values of per-value cost of credit.

Figure 7: Equilibrium response to change in merchants' per value cost of credit



Notes: Top left panel describes consumer long run response to changes in the per-value usage cost of credit for merchants. Top right panel illustrates changes in the equilibrium merchant acceptance probabilities. Bottom left panel describes usage probability and expected revenue from the interchange fee (assuming current value of the interchange fee is 1.5%). Bottom right panel compares expected total value of transactions for each mean of payment in our sample. Total expected value is a sum of all transaction prices weighted by the corresponding usage probabilities. Gray areas show 95 percent confidence intervals. Red line is at factual equilibrium.

According to the top-left panel of Figure 7, when the per-value merchant usage cost of credit increases, consumers do not respond much. This finding appears consistent with adoption cost estimates in Table 3. According to our estimates, cash and debit payment combination costs about \$33 per month, while adopting all three means of payment would bring benefit of about \$7 per month.[5] This, in turn, is consistent with the fact that only 10% of consumers choose cash and debit only, while all three means of payment are adopted by about 83% of consumers in our sample. To recapitulate: when the cost of payment methods is not too large, consumers may find it optimal to keep the same level of adoption even when significantly smaller fraction of merchants accept credit.

Since an increase in the per-value cost of credit directly affects merchants usage costs, it is not surprising to find that merchants respond to this innovation. The top right panel of Figure 7 illustrates the likely patterns of substitution in merchant acceptance decisions. In particular, the probability of accepting all means of payment declines from 0.7 (factual) to about 0.2 when the usage cost of credit doubles. Merchants substitute away from accepting all means of payment to accepting either cash only (more than threefold increase in acceptance probabilities) or cash and debit (acceptance probability more than doubles as compared to observed level).

Bottom-left panel of Figure 7 describes changes in the expected usage probabilities for each mean of payment. Not surprisingly, the probability of using credit declines 3 times from about 0.35 to 0.1. This reduction is almost entirely associated with the increased usage of cash, while there is very small increase in the usage of debit cards. This can be explained by the relatively high usage cost of debit for consumers.

Another interesting exercise can be done using bottom-left panel. If we assume that per-value cost of credit for merchants consists of the true costs of accepting credit plus interchange fee, i.e.,

$$c_{1,s,cr} = \bar{c}_{1,s,cr} + \text{if},$$

where $c_{1,s,cr}$ is the coefficient on transaction price in equation (6). Further, assuming that current level of the interchange fee is 1.5%, we can calculate expected total transaction value for credit card and apportion it into merchant cost and the revenue for credit card provider. Black line labeled "Revenue: credit" illustrates the levels of revenue collected by the credit card provider in each of the market equilibria. Interestingly, at observed equilibrium (red line) revenue is not maximized. Maximum revenue is attained for the level of interchange fee which is 35% higher than the observed one. Without knowing marginal costs of the credit card provider it is hard to tell whether profit is maximized at the current level of interchange fee. However, we can claim that if the true marginal cost of the credit card provider is sufficiently close to zero, then the profit is not maximized at the observed level of interchange fee. In other words, Visa and MasterCard may indeed voluntarily price below profit maximizing level.[6]

Last but not least, we show how the distribution of expected total transaction value across alternative payment methods evolves when we simulate counterfactual equilibria

[5] An important caveat is that our counterfactual simulation keeps the level of adoption costs (benefits) fixed at estimated value. It is conceivable that credit/debit card providers would change their loyalty programs and fees in response to changing equilibrium. As a result, our simulation is a partial equilibrium scenario, which provides an upper bound on the likely response by each side of the market.

[6] This statement should be treated with a fair amount of skepticism because our estimates are based on a small sub-sample of population.

by changing merchant usage cost of credit. This exercise is documented on the bottom-right panel of Figure 7. Relative to the observed equilibrium, a twofold increase in usage cost of credit for merchants would reduce total expected transaction value for credit by about 70%. Most of the substitution occurs with cash, increasing total expected transaction value of cash by 86%. Debit card usage also increases by about 12% relative to the observed outcome.

6.2 Increasing the usage cost of cash

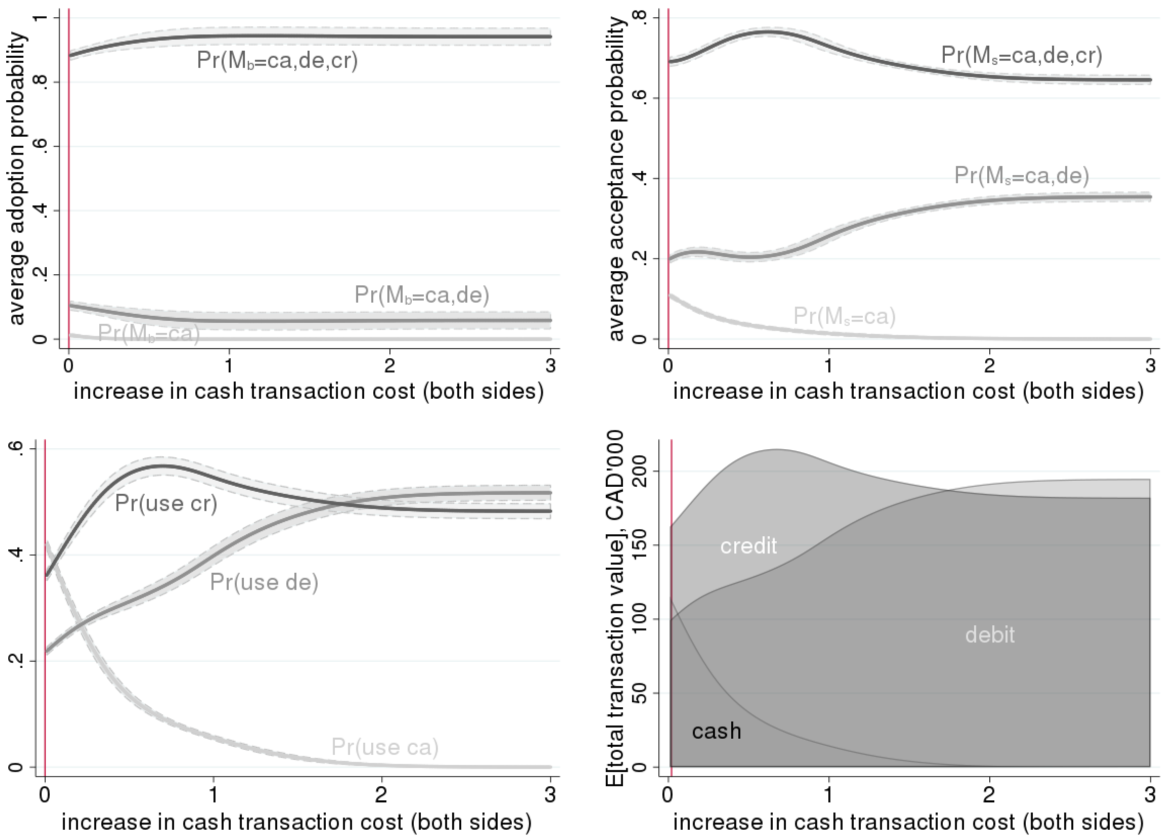
In this counterfactual we consider how consumers and merchants would behave when the usage cost of cash increases. Our model treats cash as a baseline method of payment that is always adopted by consumers and accepted by merchants. Thus, to conduct this counterfactual we increase the cost of cash so that it becomes costly relative to payment cards, dropping the usage of cash to essentially 0. Specifically, we increase the per-transaction cost of cash for both consumers and merchants and observe their substitution patterns in adoption, acceptance, and usage. This could represent, for example, a decrease in the number of ATMs in a person's neighbourhood, increasing the travel costs to obtain cash and so increasing the per-transaction cost to using cash. For merchants, significantly smaller volumes of cash transactions in the economy of scale is likely to result in higher per-transaction usage costs of cash. Equivalent counterfactuals could be produced by decreasing payment card costs rather than increasing cash costs – or some combination of the two.

In Figure 8 we start at the initial state on the left axis, where the per-transaction cost of cash on average is about 12 cents for consumers and 18 cents for merchants. Moving along the x-axis, we increase the per-transaction cost for both sides of the market at the same rate up to an increase of 3 dollars. We find that cash stops being used once costs have increased about 1.7 dollars.[7] Relatively speaking this is a large increase, corresponding to a point where consumer costs have increased by a factor of around 15 while merchant costs have increased by a factor of about 10.

At the point where consumers stop using cash, they compensate by adopting the remaining means of payment, resulting in almost uniform adoption of all methods of payment. On the merchant side, cash-only merchants tend to become cash-and-debit only. Interestingly, in equilibrium acceptance of all three means of payment is smaller than in a situation when cash would be used. Finally, as cash becomes very expensive, most cash transactions are substituted for debit card transactions and, to a lesser extent, credit card transactions. The fact that most of the substitution from cash occurs towards debit card transactions seems intuitive because a debit card is designed to convert debit balance into cash at an ATM.

[7] We define cash as no longer being used if its equilibrium usage probability falls below 0.01. Estimated usage probability falls below 1% at an increase of 1.7 dollars, while the lower bound of the confidence interval falls below 1% at 1.6 dollars.

Figure 8: Equilibrium response to change in merchants' per value cost of credit



Notes: Top left panel describes consumer long run response to an increase in per-transaction usage cost of cash for both sides. Top right panel illustrates the response in the equilibrium acceptance probabilities for merchants. Bottom panels describes resulting equilibrium usage probability and total expected value of transactions conducted by each mean of payment. Red line shows factual equilibrium.

These counterfactual simulations may seem esoteric for Canada. However, one sign that this evolution has started is the closure of about five percent of bank branches in the period 2012-2017.[8] The reduction in physical branches increases the cost of accessing cash especially in rural areas. The latest statistics from the 2017 Method-Of-Payments survey indicate that the volume of cash transactions at the POS has declined from 53% to 32% during the period from 2009 to 2017, see Henry et al. (ming). There has been substitution away from cash toward electronic method-of-payments such as debit and credit cards. However, there are some cases where these electronic methods of payment are not available due to lack of infrastructure, for example in remote and sparsely populated areas. As a result, Engert et al. (ming) discuss that if a public authority wanted to ensure 100% access to these digital payments there may be scope in issuing central bank digital currency.

[8]Statistics based on Canadian Banking Association aggregate banking statistics `https://www.cba.ca/bank-branches-in-canada`.

7 Conclusions

We developed and estimated a structural equilibrium model of interactions between consumers and merchants in two-sided market for payment methods. Our estimates suggest that consumers who adopt cash and debit incur a cost of $33 per month. While consumers having all three means of payment in their wallets would instead enjoy about $7/month in benefits. The difference in results could be due to the cost of withdrawing cash or debit card or account fees while most credit card may offer rewards. On the merchant side, accepting cash and debit only is associated with $90 cost per year for a merchant having sales of 375 thousand dollars and about $1800 for a merchant with annual sales of 7.5 million dollars. However, if a merchant decides to accept all means of payment which would attract more informed consumers this can generate additional benefit of about $12,100 for a merchant with 375 thousand dollars in annual sales and almost 160 thousand dollars for a merchant with 7.5 million of dollars in sales.

In terms of elasticities, consumers and merchants reduce their adoption and acceptance probabilities for the payment methods when usage costs increase. On the consumer side, the most elastic response is found for the usage cost of cash (-1.7) and the least elastic response is found for the usage cost of credit (-0.01). On the merchant side, cash has the largest elasticity with respect to own usage cost of cash (-1.15), followed by the cost-elasticity for credit (-0.80), and the smallest response found for the usage cost of debit (-0.52). Both merchant and consumer elasticities of acceptance/adoption probability with respect to increase in the usage cost on the other side of the market are lower than 1 in absolute value. Most of merchant response to increase in consumer usage costs appears larger than the one for consumers responding to an increase in the merchant usage costs.

In terms of the fixed cost of adoption, we find that the highest elasticity is related to the combination cash and debit (-1.49) while it is inelastic (-0.07) for the combination cash, debit and credit. On the merchant side, an increase in the fixed acceptance cost for cash and debit results in a very small decline in the acceptance probability (-0.06) for this combination. When acceptance cost of all three means of payment goes up, the merchant response is much bigger but is still in the inelastic range (-0.89). The merchant response to an exogenous shift in the distribution of adoption decisions induced by an increase in one of the fixed adoption costs is usually larger than for the consumer side.

An analysis of the equilibrium usage probabilities suggests that network effect originating on the consumer side of the market are stronger than those coming from the merchant side. In other words, the best way to affect equilibrium usage probabilities is to design policies directed towards the consumer side.

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A Elasticity of usage decisions with respect to structural parameters

Table 9: Elasticity of usage decisions with respect to structural parameters

measure	Fixed adoption/acceptance costs				Usage costs					
	buyers		sellers		buyers			sellers		
	$F_{b,\{ca,de\}}$	$F_{b,\{ca,de,cr\}}$	$F_{s,\{ca,de\}}$	$F_{s,\{ca,de,cr\}}$	$C_{b,ca}$	$C_{b,de}$	$C_{b,cr}$	$C_{s,ca}$	$C_{s,de}$	$C_{s,cr}$
$\mathcal{E}^{\text{IM}}_{\text{Pr(use ca)},\cdots}$					-0.46	0.25	0.06			
$\mathcal{E}^{\text{IM}}_{\text{Pr(use de)},\cdots}$					0.27	-1.04	0.06			
$\mathcal{E}^{\text{IM}}_{\text{Pr(use cr)},\cdots}$					0.39	0.33	-0.11			
$\mathcal{E}^{\text{SR}}_{\text{Pr(use ca)},\cdots}$	-0.09	-0.05	-0.00	-0.64	-0.50	0.25	0.07	-0.27	0.04	0.57
$\mathcal{E}^{\text{SR}}_{\text{Pr(use de)},\cdots}$	-0.08	-0.00	-0.01	-0.21	0.28	-1.06	0.06	0.08	-0.15	0.18
$\mathcal{E}^{\text{SR}}_{\text{Pr(use cr)},\cdots}$	0.16	0.06	0.01	0.89	0.44	0.34	-0.12	0.27	0.04	-0.80
$\mathcal{E}^{\text{MR}}_{\text{Pr(use ca)},\cdots}$	-0.01	-0.02	-0.00	-0.68	-0.36	0.43	0.02	-0.28	0.04	0.61
$\mathcal{E}^{\text{MR}}_{\text{Pr(use de)},\cdots}$	-0.05	0.01	-0.01	-0.21	0.34	-0.99	0.04	0.08	-0.15	0.19
$\mathcal{E}^{\text{MR}}_{\text{Pr(use cr)},\cdots}$	0.04	0.02	0.01	0.94	0.22	0.09	-0.05	0.29	0.04	-0.84
$\mathcal{E}^{\text{LR}}_{\text{Pr(use ca)},\cdots}$	-0.01	-0.02	-0.00	-0.65	-0.35	0.43	0.02	-0.27	0.04	0.58
$\mathcal{E}^{\text{LR}}_{\text{Pr(use de)},\cdots}$	-0.05	0.01	-0.01	-0.20	0.34	-0.99	0.04	0.08	-0.15	0.18
$\mathcal{E}^{\text{LR}}_{\text{Pr(use cr)},\cdots}$	0.04	0.02	0.01	0.90	0.22	0.08	-0.05	0.27	0.04	-0.81
	92%	61%	-1%	-2%	30%	73%	-69%	-2%	1%	2%
network effect	40%	350%	-1%	1%	22%	6%	-31%	2%	-1%	-1%
	-76%	-70%	1%	1%	-50%	-76%	58%	1%	0%	-1%

Notes: network effect is calculated as percentage difference between short-run elasticity measure and its long-run value, i.e., $(\mathcal{E}^{\text{LR}}_{\text{Pr(use m)},\cdots} - \mathcal{E}^{\text{SR}}_{\text{Pr(use m)},\cdots})/\mathcal{E}^{\text{SR}}_{\text{Pr(use m)},\cdots}$. Network effect may either amplify the direct effect or make it weaker depending on the signs of these effects.

B Alternative specifications

B.1 Logit with variance (LLV)

Because costs are assumed to be known, the LL model is restrictive in the sense that there are no free parameters in the usage stage. To improve model fit, we now allow the logit errors to have a scale parameter that captures variability in costs. We assume there is a single standard deviation σ_2^b for consumer usage costs, σ_1^b for consumer adoption costs, and σ_1^s for merchant acceptance costs. As discussed above, the latter is not identified, so we set $\sigma_1^s = 1$. We preserve the computational simplicity of the logit by simply dividing costs by the corresponding scale parameter. The resulting probability formulas are:

$$Pr(\text{use } m)_{ij} = \frac{\exp(E[C^b_{m,ij}]/\sigma_2^b)}{\sum\limits_{m \in \mathcal{M}_{bi} \cap \mathcal{M}_{sij}} \exp(E[C^b_{m,ij}]/\sigma_2^b)} \tag{21}$$

$$Pr(\text{adopt } \mathcal{M}_b)_i = \frac{\exp(E[TC_{\mathcal{M}_b,i}]/\sigma_1^b)}{\sum\limits_{\mathcal{M}_b} \exp(E[TC_{\mathcal{M}_b,i}]/\sigma_1^b)} \tag{22}$$

$$Pr(\text{accept } \mathcal{M}_s)_k = \frac{\exp(E[TC_{\mathcal{M}_s,k}]/\sigma_1^s)}{\sum\limits_{\mathcal{M}_s} \exp(E[TC_{\mathcal{M}_s,k}]/\sigma_1^s)} \tag{23}$$

The expected minimum usage cost for consumers changes similarly:

$$E\left[\min_{m \in \mathcal{M}_b \cap \mathcal{M}_s} \{C^b_{m,ij}\}\right] = \sigma_2^b \log\left(\sum_{m \in \mathcal{M}_b \cap \mathcal{M}_s} \exp(E[C^b_{m,ij}]/\sigma_2^b)\right) \tag{24}$$

C Alternative specifications

C.1 Normal errors for both sides in both stages: consumer usage costs

We begin by describing consumer usage costs in the second stage of the game. Notation:

- Consumer cost of transacting using cash, $C_0^b(p_{bj}) = c_{00}^b + c_{10}^b * p_{bj} + \varepsilon_0^b$,
- Consumer cost of transacting using debit, $C_1^b(p_{bj}) = c_{01}^b + c_{11}^b * p_{bj} + \varepsilon_1^b$,
- Consumer cost of transacting using credit, $C_2^b(p_{bj}) = c_{02}^b + c_{12}^b * p_{bj} + \varepsilon_2^b$.

Conditional on the first stage decision $\mathcal{M}_b$, the usage cost can be written as

$$UC_b(\mathcal{M}_b) = \mathbb{E}_{\mathcal{M}_s,\varepsilon}\left[\sum_{j\in\mathcal{J}_b} \min_{m'\in\mathcal{M}_s\cap\mathcal{M}_b} C_{m'}^b(p_{bj})\right] \tag{25}$$

Given consumer beliefs about $\mathcal{M}_s$, we can re-write (25) for each possible value of $\mathcal{M}_b$ as

- If a consumer chooses to adopt cash only ($\mathcal{M}_b = \{0\}$)

$$UC_b(\{0\}) = \mathbb{E}_\varepsilon\left[\sum_{j\in\mathcal{J}_b} C_0^b(p_{bj})\right]$$

- If a consumer chooses to adopt cash & debit ($\mathcal{M}_b = \{0,1\}$)

$$UC_b(\{0,1\}) = \sum_{j\in\mathcal{J}_b}\begin{pmatrix} \Pr(\mathcal{M}_s = \{0\}) \times \mathbb{E}_\varepsilon C_0^b(p_{bj}) \\ + (1 - \Pr(\mathcal{M}_s = \{0\})) \times \mathbb{E}_\varepsilon \min\left\{C_0^b(p_{bj}), C_1^b(p_{bj})\right\}\end{pmatrix}$$

- If a consumer chooses to adopt all three means of payment,

$$UC_b(\{0,1,2\}) = \sum_{j\in\mathcal{J}_b}\begin{pmatrix} \Pr(\mathcal{M}_s = \{0\}) \times \mathbb{E}_\varepsilon C_0^b(p_{bj}) \\ + \Pr(\mathcal{M}_s = \{0,1\}) \times \mathbb{E}_\varepsilon \min\left\{C_0^b(p_{bj}), C_1^b(p_{bj})\right\} \\ + \Pr(\mathcal{M}_s = \{0,1,2\}) \times \mathbb{E}_\varepsilon \min\left\{C_0^b(p_{bj}), C_1^b(p_{bj}), C_2^b(p_{bj})\right\}\end{pmatrix}$$

C.2 Normal errors for both sides in both stages: merchant usage costs

- Merchant cost of transacting using cash, $C_0^s(p_{bj}) = c_{00}^s + c_{10}^s * p_{bj} + \varepsilon_0^s$,
- Merchant cost of transacting using debit, $C_1^s(p_{bj}) = c_{01}^s + c_{11}^s * p_{bj} + \varepsilon_1^s$,
- Merchant cost of transacting using credit, $C_2^s(p_{bj}) = c_{02}^s + c_{12}^s * p_{bj} + \varepsilon_2^s$.

Conditional on the first stage decision $\mathcal{M}_s$, the usage cost of merchants is determined by the consumer preferences for payment methods,

$$UC_s(\mathcal{M}_s) = \frac{1}{N_s} \sum_b \sum_{j \in \mathcal{J}_b} \Pr\left(m = \underset{m' \in \mathcal{M}_s \cap \mathcal{M}_b}{\arg\min} \; C^b_{m'}(p_{bj}) \right) \mathbb{E}_\varepsilon C^s_m(p_{bj}) \tag{26}$$

Given merchant beliefs about $\mathcal{M}_b$, we can write (26) for each possible acceptance choice,

- If a merchant chooses to accept cash only,

$$UC_s(\mathcal{M}_s = \{0\}) = \frac{1}{N_s} \sum_b \sum_{j \in \mathcal{J}_b} \mathbb{E}_\varepsilon C^s_0(p_{bj})$$

- If a merchant chooses to accept cash & debit,

$$UC_s(\mathcal{M}_s = \{0,1\}) = \frac{1}{N_s} \sum_b \sum_{j \in \mathcal{J}_b} \begin{pmatrix} \Pr(\mathcal{M}_b = 0)\mathbb{E}_\varepsilon C^s_0(p_{bj}) \\ + (1 - \Pr(\mathcal{M}_b = 0) \times \Phi\left(d_{10}\right) \times \mathbb{E}_\varepsilon C^s_0(p_{bj}) \\ + (1 - \Pr(\mathcal{M}_b = 0) \times \Phi\left(d_{01}\right) \times \mathbb{E}_\varepsilon C^s_1(p_{bj}) \end{pmatrix}$$

where $d_{kl} = \frac{C^b_k(p_{bj}) - C^b_l(p_{bj})}{\sqrt{\sigma^2_{bk} + \sigma^2_{bl}}}$

- If a merchant chooses to accept all three means of payment,

$$UC_s(\mathcal{M}_s = \{0,1,2\}) = \frac{1}{N_s} \sum_b \sum_{j \in \mathcal{J}_b} \begin{pmatrix} \Pr(\mathcal{M}_b = \{0\}) \times \mathbb{E}_\varepsilon C^s_0(p_{bj}) \\ + \Pr(\mathcal{M}_b = \{0,1\}) \times \Phi\left(d_{10}\right) \times \mathbb{E}_\varepsilon C^s_0(p_{bj}) \\ + \Pr(\mathcal{M}_b = \{0,1\}) \times \Phi\left(d_{01}\right) \times \mathbb{E}_\varepsilon C^s_1(p_{bj}) \\ + \Pr(\mathcal{M}_b = \{0,1,2\}) \times \Phi_2\left(d_{10}, d_{20}, \sigma^2_{b0}\right) \times \mathbb{E}_\varepsilon C^s_0(p_{bj}) \\ + \Pr(\mathcal{M}_b = \{0,1,2\}) \times \Phi_2\left(d_{01}, d_{21}, \sigma^2_{b1}\right) \times \mathbb{E}_\varepsilon C^s_1(p_{bj}) \\ + \Pr(\mathcal{M}_b = \{0,1,2\}) \times \Phi_2\left(d_{02}, d_{12}, \sigma^2_{b2}\right) \times \mathbb{E}_\varepsilon C^s_2(p_{bj}) \end{pmatrix}$$

C.3 Consumer adoption probabilities

Consumer adoption probabilities are calculated as follows:

- Probability of adopting cash only,

$$\begin{aligned} \Pr(\mathcal{M}_b = \{0\}) &= \Pr\begin{pmatrix} UC_b(0) + \tilde{F}_{b0} < UC_b(\{0,1\}) + \bar{F}_{b01} + \tilde{F}_{b01}, \\ UC_b(0) + \tilde{F}_{b0} < UC_b(\{0,1,2\}) + \bar{F}_{b012} + \tilde{F}_{b012} \end{pmatrix} \\ &= \Pr\begin{pmatrix} \tilde{F}_{b0} - \tilde{F}_{b01} < UC_b(\{0,1\}) - UC_b(0) + \bar{F}_{b01}, \\ \tilde{F}_{b0} - \tilde{F}_{b012} < UC_b(\{0,1,2\}) - UC_b(0) + \bar{F}_{b012} \end{pmatrix} \\ &= \Phi_2\left(\frac{UC_b(\{0,1\}) - UC_b(0) + \bar{F}_{b01}}{\sqrt{\sigma^2_{b0} + \sigma^2_{b01}}}, \frac{UC_b(\{0,1,2\}) - UC_b(0) + \bar{F}_{b012}}{\sqrt{\sigma^2_{b0} + \sigma^2_{b012}}}, \sigma^2_{b0} \right) \end{aligned}$$

- Probability of adopting cash and debit,

$$\begin{aligned}
\Pr(\mathcal{M}_b = \{0,1\}) &= \Pr\begin{pmatrix} UC_b(\{0,1\}) + \bar{F}_{b01} + \tilde{F}_{b01} < UC_b(\{0\}) + \tilde{F}_{b0}, \\ UC_b(\{0,1\}) + \bar{F}_{b01} + \tilde{F}_{b01} < UC_b(\{0,1,2\}) + \bar{F}_{b012} + \tilde{F}_{b012} \end{pmatrix} \\
&= \Pr\begin{pmatrix} \tilde{F}_{b01} - \tilde{F}_{b0} < UC_b(\{0\}) - UC_b(\{0,1\}) - \bar{F}_{b01}, \\ \tilde{F}_{b01} - \tilde{F}_{b012} < UC_b(\{0,1,2\}) + \bar{F}_{b012} - UC_b(\{0,1\}) - \bar{F}_{b01} \end{pmatrix} \\
&= \Phi_2\left(\frac{UC_b(\{0\}) - UC_b(\{0,1\}) - \bar{F}_{b01}}{\sqrt{\sigma^2_{b01} + \sigma^2_{b0}}}, \frac{UC_b(\{0,1,2\}) + \bar{F}_{b012} - UC_b(\{0,1\}) - \bar{F}_{b01}}{\sqrt{\sigma^2_{b01} + \sigma^2_{b012}}}, \sigma^2_{b01} \right)
\end{aligned}$$

- Probability of adopting cash and debit,

$$\begin{aligned}
\Pr(\mathcal{M}_b = \{0,1,2\}) &= \Pr\begin{pmatrix} UC_b(\{0,1,2\}) + \bar{F}_{b012} + \tilde{F}_{b012} < UC_b(\{0\}) + \tilde{F}_{b0}, \\ UC_b(\{0,1,2\}) + \bar{F}_{b012} + \tilde{F}_{b012} < UC_b(\{0,1\}) + \bar{F}_{b01} + \tilde{F}_{b01} \end{pmatrix} \\
&= \Pr\begin{pmatrix} \tilde{F}_{b012} - \tilde{F}_{b0} < UC_b(\{0\}) - UC_b(\{0,1,2\}) - \bar{F}_{b012}, \\ \tilde{F}_{b012} - \tilde{F}_{b01} < UC_b(\{0,1\}) + \bar{F}_{b01} - UC_b(\{0,1,2\}) - \bar{F}_{b012} \end{pmatrix} \\
&= \Phi_2\left(\frac{UC_b(\{0\}) - UC_b(\{0,1,2\}) - \bar{F}_{b012}}{\sqrt{\sigma^2_{b012} + \sigma^2_{b0}}}, \frac{UC_b(\{0,1\}) + \bar{F}_{b01} - UC_b(\{0,1,2\}) - \bar{F}_{b012}}{\sqrt{\sigma^2_{b012} + \sigma^2_{b01}}}, \sigma^2_{012} \right)
\end{aligned}$$

C.4 Usage probabilities

Probability of using each of the payment methods is defined as follows

- Probability of using debit,

$$\begin{aligned}
\Pr(\text{use de}) =& \mathbb{E}\Pr(\mathcal{M}_s = \{0,1\}) \times \big((\mathbb{1}(\mathcal{M}_b = \{0,1\}) + \mathbb{1}(\mathcal{M}_b = \{0,1,2\})) \times \Pr(C_1^b(p_{bj}) < C_0^b(p_{bj}))\big) + \\
& \mathbb{E}\Pr(\mathcal{M}_s = \{0,1,2\}) \times \begin{pmatrix} \mathbb{1}(\mathcal{M}_b = \{0,1\}) \times \Pr(C_1^b(p_{bj}) < C_0^b(p_{bj})) \\ + \mathbb{1}(\mathcal{M}_b = \{0,1,2\}) \times \Pr(C_1(p_{bj}) < C_0(p_{bj}), C_1(p_{bj}) < C_2(p_{bj})) \end{pmatrix}
\end{aligned}$$

- Probability of using credit,

$$\Pr(\text{use cr}) = \Pr(\mathcal{M}_s = \{0,1,2\}) \times \mathbb{1}(\mathcal{M}_b = \{0,1,2\}) \times \Pr\left(C_2^b(p_{bj}) < C_0^b(p_{bj}), C_2^b(p_{bj}) < C_1^b(p_{bj})\right)$$

- Probability of using cash is given as a complementary probability:

$$\Pr(\text{use ca}) = 1 - \Pr(\text{use de}) - \Pr(\text{use cr})$$

Figure selection

C.5 Model fit with median model predictions

Figure 9: Model fit for three acceptence combinations, merchants

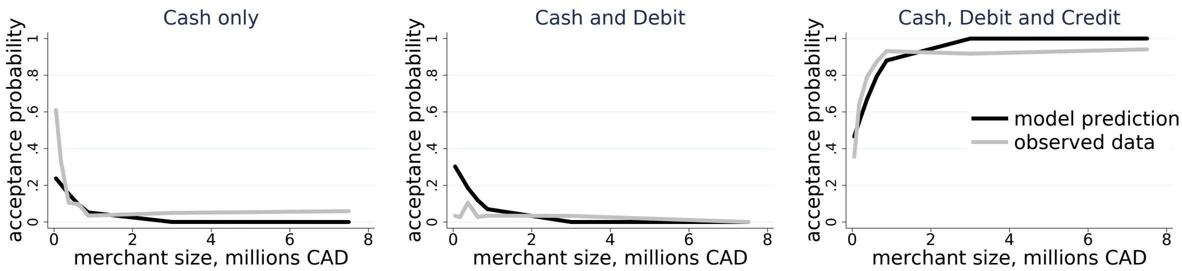
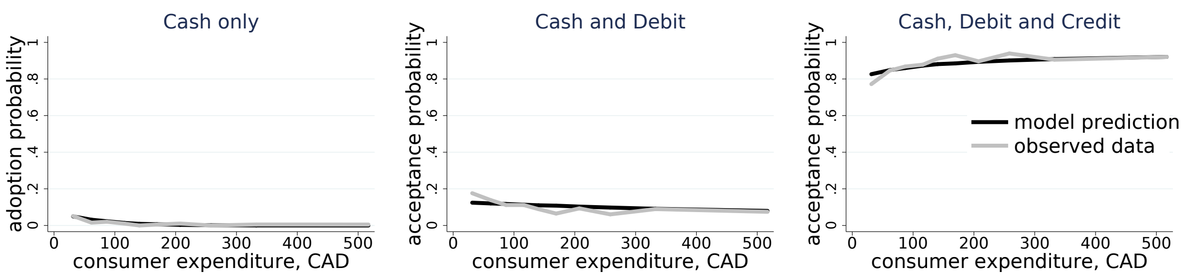


Figure 10: Model fit for three acceptence combinations, consumers



C.6 Model fit with average model predictions

Figure 11: Model fit for three acceptence combinations, merchants

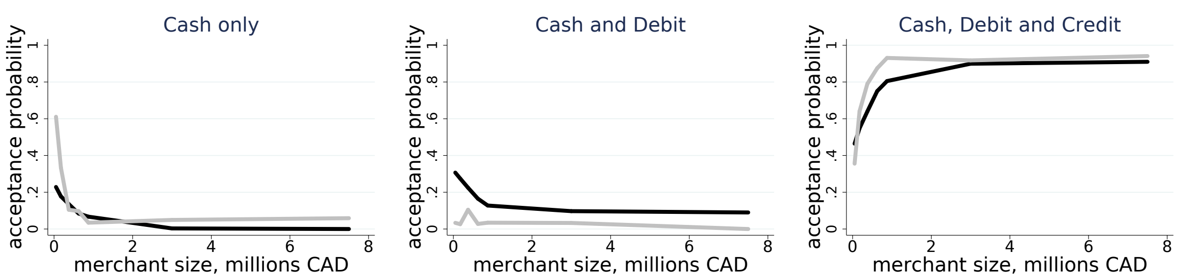


Figure 12: Model fit for three acceptence combinations, consumers