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Consumer Choice and Merchant Acceptance of Payment Media

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Abstract

We study the ability of banks and merchants to influence consumer payment instrument choice. With sufficiently low processing costs relative to theft and default risk, the social planner sets a zero merchant fee, completely internalizing the card acceptance externality. The bank may also set zero merchant fees if merchants are able to sufficiently pass on payment costs to their consumers or if payment costs are zero. If payment card costs are too high, the social planner sets a higher merchant fee than the bank. We find that bank profit increases when merchants are unable to pass on payment costs to consumers due to lower goods prices and greater ability to extract merchant surplus. The relative costs of providing debit and credit cards determine whether the bank will provide both or only one type of payment card. Our model further predicts that when merchants are restricted to setting a uniform price for goods, the bank benefits while consumers and merchants are worse off.

Key Words: Retail Financial Services, Network Effects, Social Welfare, Multihoming, Payment Card Networks

JEL Codes: L11, G21, D53

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1 Introduction

A new set of economic models studies the efficient pricing of services provided by a single platform to different types of end-users, such as payment networks, communication and media portals, or dating clubs. This growing literature blends together the multiproduct firm literature, which studies how firms set prices for more than one product, with the network economics literature, which studies how consumers benefit from increased participation in networks by other consumers. Models in this literature compare the social welfare maximizing and the platform's profit-maximizing fees under different market conditions. We contribute to this literature by constructing a model that incorporates various aspects of industrial organization and consumer theory with some elementary aspects of the medium of exchange literature. Our model serves as a useful benchmark for the policy debate regarding the pricing of payment services that has attracted antitrust scrutiny in various jurisdictions.

Over the last two decades, consumer usage and merchant acceptance of payment cards have increased in advanced economies while cash and check usage has declined. Many observers argue that movement away from paper-based payment instruments to electronic ones such as payment cards has increased overall payment system efficiency. However, policymakers in various jurisdictions have questioned the pricing of payment card services. The U.S. Congress is considering legislation that would grant antitrust immunity to merchants to collectively negotiate fees with payment providers. Recently, the European Commission came to an agreement with MasterCard to significantly reduce interchange fees—the fee that the merchant's bank pays the cardholder's bank—for cross-border European payment card transactions. In addition, some public authorities around the world have removed restrictions by payment networks that prevent merchants to set different prices for goods and services based on the payment instrument used.

Payment card networks consist of three types of participants—consumers, merchants, and financial institutions. Consumers establish relationships with financial institutions so that they can make payments that access funds from their accounts or utilize credit facilities. They may be charged fixed fees in addition to finance charges if they borrow for an extended period of time. For consumers to use payment cards, merchants must accept them. Merchants establish relationships with financial institutions to convert card payments into bank deposits and are generally charged per-transaction fees. The merchant's bank, the acquirer, generally pays an interchange fee to the cardholder's bank, the issuer. The underlying payment fee structure is determined by the interrelated bilateral relationships among the participants, their bargaining power, and the ability of the network to maximize profits for its members.

Our paper contributes to the growing theoretical payment card literature that started with Baxter (1983).[1] In his model, consumers are homogenous with merchants, issuers, and acquirers operating in perfectly competitive markets. He argued that the interchange fee balances the demands of consumers and merchants and improves consumer and merchant welfare. Rochet and Tirole (2002) find that business stealing may result in the profit-maximizing interchange fee being higher than the socially optimal one when there is consumer heterogeneity. Wright (2004) shows that introducing merchant heterogeneity results in the profit-maximizing interchange fee being potentially above or below the socially optimally one.

For the most part, these models ignore the ability of merchants to steer consumers by imposing instrument-contingent pricing. Carlton and Frankel (1995) argue that if merchants are able to set instrument-contingent pricing, the interchange fee would be neutral. The interchange fee is said to be neutral if a change in the fee does not change the quantity of consumer purchases and the level of merchant and bank profits. Gans and King (2003) find that if payment separation is achieved, the interchange fee is neutral. Payment separation occurs in competitive markets where merchants separate into cash and card stores or if monopolist merchants impose instrument-contingent pricing where merchant acceptance of payment cards is invariant to changes in the interchange fee, merchant profits and quantities that consumers consume.

The models discussed so far do not consider an increase in total consumption resulting from payment card adoption. Chakravorti and To (2007) focus on a key aspect of certain types of payment cards—the extension of credit. They construct a model focusing on the credit aspect of payment cards where consumption occurs prior to the arrival of income benefitting both consumers and merchants. Chakravorti and To demonstrate that merchants may be willing to absorb higher payment fees if their sales increase sufficiently. However, they do not endogenously solve for the optimal price structure between the two types of end-users.

[1] For a recent review of the literature, see Bolt and Chakravorti (2008b).

We construct a model in the spirit of Diamond and Dybvig (1983) that analyzes the pricing decision of banks in the provision of payment instruments to maximize profits in a two-sided market. In our model, some consumers want to consume before their income arrives. A market is said to be two-sided if two distinct sets of end-users are unable to negotiate prices and the prices charged to each end-user affects the allocation of goods or services (Armstrong, 2005, and Rochet and Tirole, 2006).

Our model differs from the existing literature in the following ways. First, for the most part, the payment card literature uses a reduced-form approach when considering the costs and benefits of payment cards.[2] In our model, consumers participate in non-cash payment networks to insure themselves from three types of shocks—income, theft, and the type of merchant that they are matched to. Second, consumers are willing to pay a fixed fee as long as their expected utility when they participate in a card network is at least as great as their expected utility if they only use cash. In other words, consumers must balance income spent on consumption goods and payment services. Third, acceptance of payment cards may increase merchant profits resulting from increased sales. Merchants trade off increased profits from additional sales against payment fees. Fourth, we are able to provide insights into how merchants' ability to pass through payment costs to consumers through higher retail prices affects merchant acceptance, optimal structure of payment prices, and bank profits. Our analysis suggests that merchant acceptance may not be complete even when surcharging is allowed. Merchants that are unable to pass along their fees completely to consumers because of market conditions such as competitive pressures may choose to decline payment cards. Furthermore, evidence from countries that allow surcharging suggests that merchant acceptance is not complete.

Our main results can be summarized as follows. First, we solve for the optimal bank profit-maximizing fee structure for consumer and merchant fees. Our model predicts that the bank will extract all consumer surplus and extract merchant surplus to balance the network externality that greater merchant acceptance increases the total number of transactions against greater profits.

Second, bank profit increases when merchants are unable to pass on payment costs to consumers because cost absorption by merchants leads to lower goods prices and greater

[2] Chakravorti and To (2007) and McAndrews and Wang (2006) are notable exceptions.

ability to extract merchant surplus. However, merchant acceptance may decrease as a result.

Third, if bank profits are restricted to be zero, different "Ramsey" price structures emerge where both consumers and merchants pay positive fees. Unlike the bank profit-maximization case, consumers are not fully extracted resulting in greater social welfare. Generally, extraction from consumers is preferred to merchant extraction given the network externality when costs are sufficiently low.

Fourth, whether the bank's profit-maximizing merchant fees is equal, higher, or lower than the Ramsey socially optimal fees for debit or credit cards crucially depends on the level of payment processing cost relative to the probability of getting mugged and the level of default risk. In particular, for low levels of processing cost, the Ramsey planner would want to fully exploit the positive externality of widespread merchant acceptance by setting zero merchant card fees, thereby avoiding aggregate theft and default risk. Yet, for low cost levels, the bank would have an incentive to extract merchant surplus by setting positive merchant fees reducing acceptance. In contrast, for high levels of processing cost, the Ramsey planner would stop issuing payment cards in favor of cash use, whereas the bank would still make a profit by providing card services.

Fifth, depending on card processing and default costs, banks may have an incentive to simultaneously supply debit and credit cards. For relatively low credit card costs, however, the bank would not supply debit cards and only offer credit card services. We also find that when merchants are restricted to setting a uniform price regardless of the type of payment instrument used, bank profits rise but consumers and merchants are worse off. This negative externality arises because consumers that are able to use debit cards do not have an incentive to use the less expensive payment instrument.

In the next section, we describe the environment, agents, and payment technologies. We consider economies with debit and credit cards in sections 3 and 4, respectively. In section 5, we discuss social welfare. We explore an economy where all three instruments exist in section 6 and conclude in section 7.

2 A Model of Payment Cards

2.1 Environment and Agents

There are three types of agents—consumers, merchants, and a monopolist bank. In our model, we have combined the issuer and acquirer into one entity so as to abstract from the interchange fee decision between issuers and acquirers.[3] All agents are risk neutral. A continuum of ex ante identical consumers reside on a line segment from 0 to 1. A continuum of monopolist merchants reside on a line segment from 0 to 1 differentiated by the type of good and the cost that they face to serve each customer. Individual consumers and merchants are atomistic and are unable to collude among themselves.

Consumers are subject to three shocks. First, each consumer either receives income, I, in the morning with exogenous probability, ϕ_1, or at night with exogenous probability, ϕ_2, or no income at all with probability, $1 - \phi_1 - \phi_2$, where $\phi_1 + \phi_2 \leq 1$.[4] Second, before leaving home, each consumer is randomly matched to a merchant selling a unique good. Third, a cash-carrying consumer may also be mugged in transit to the merchant with probability $1 - \rho$ resulting in complete loss of income (and consumption).[5]

Consumers maximize expected utility. For computational ease, we make the following assumptions about consumers. First, we assume a linear utility function $u(x) = x$. Second, consumers only have positive utility when consuming goods sold by the merchant they are matched to. Third, each consumer spends all of her income during the day because she receives no utility from unused income after that.

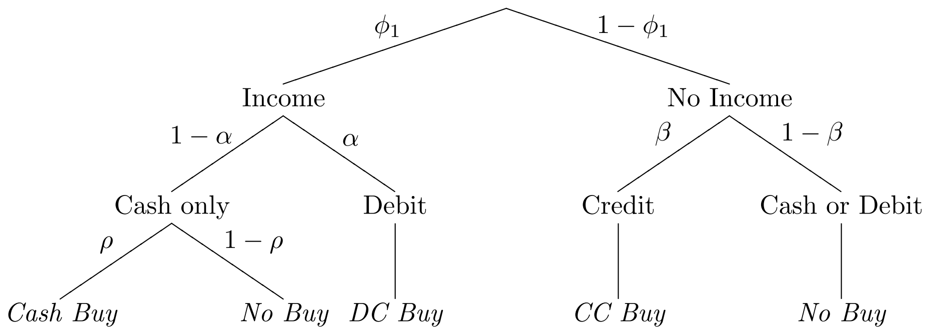
Merchant heterogeneity is based on the type of good that they sell and their cost. Each merchant faces a unique exogenously given cost, γ_i. Merchant costs are uniformly distributed on a line segment from 0 to 1. Although merchants face different costs, each merchant sells its good at p_m, the cash price for the consumption good. For convenience, p_m is normalized to 1. We make this assumption to capture merchant pricing power heterogeneity in a tractable

[3] A four-party network is mathematically equivalent to a three-party network when issuing or acquiring is perfectly competitive. Under these conditions, the optimal interchange fee is directly derived from the optimal consumer and merchant fee.

[4] The default rate can be significant. Scholtes (2009) reported that losses on U.S. credit cards hit a record of more than 10 percent in June 2009.

[5] Both theoretical and empirical models of money demand consider theft as a negative cost of carrying cash. He, Huang, and Wright (2005) construct a theoretical search model of money and banking that endogenizes the probability of theft. Alvarez and Lippi (2009) estimate the probability of cash theft around 2 percent in Italy in 2004.

Figure 1: Probability tree for payment card use



model. In other words, this assumption reflects that different merchants have different mark-ups across the economy. The per customer (expected) profit of merchant i when accepting cash, Π_m^i, is:

$$\Pi_m^i = \phi_1 \rho (1 - \gamma_i) I.$$

In a cash economy, merchants can only make sales to consumers that receive income in the morning and arrive at their stores without being mugged. The bank makes no profit in a cash-only economy, $\Pi_m^B = 0$.

2.2 Alternative Payment Technologies

The monopolist bank provides two types of payment instruments—debit cards and credit cards. Debit cards offer consumers protection from theft while credit cards also allow consumption before income arrives. The supply of debit and credit card services by the bank increases the states of the world where consumption occurs. In figure 1 we diagram the different consumption states of the world depending on when income arrives, the acceptance policies of merchants that consumers are matched to, and the loss associated with theft if carrying cash assuming that consumers face lower prices when using their debit cards than their credit cards. In this figure, α and β are the proportion of merchants accepting debit and credit cards, respectively. In our model, α and β are endogenous and we will solve for them later.

Consumers that choose to participate in a debit or credit card network sign fully enforceable contracts. Their incomes are directly deposited into their bank accounts when realized.

The bank provides access to cash for free, but charges consumers membership fees to use debit cards, $F_d \geq 0$, and credit cards, $F_c \geq 0$, that are deducted from their payroll deposits upon arrival. In most advanced economies, consumers rarely pay per-transaction fees but often pay fixed fees. The bank sets merchant per-transaction fees, $f_d \geq 0$ and $f_c \geq 0$, for debit and credit card transactions, respectively. In reality, the bulk of the cost to merchants of accepting payment cards is captured in the per-transaction fee.

To maintain tractability and still capture some key characteristics of payment cards, we make the following assumptions about merchant pricing. First, for time consistency, merchants cannot charge higher prices than those that they posted when consumers made their decision to join one or more payment networks. Second, we assume that all merchants will post the same price for their goods given the payment instrument used to make the purchase. Merchants set p_d for goods purchased with a debit card and set p_c for goods purchased with a credit card.[6] Third, as in the cash case, we distinguish merchants by the level of their profit margin.

To capture a continuum of pass-through from none to complete, we introduce an exogenous parameter, $\lambda_j \in [0, 1]$, $j = d, c$.[7] We define the good's price p_j as:

$$p_j(f_j) = \frac{1}{1 - \lambda_j f_j}, \qquad j = d, c. \tag{1}$$

Two polar cases are apparent. When $\lambda_j = 0$, merchants cannot pass on any payment processing costs in the form of higher prices to consumers, $p_d = p_c = p_m = 1$. When $\lambda_j = 1$, merchants are able to pass on all payment processing costs to consumers, $p_j = 1/(1 - f_j)$, $j = d, c$. Within this simple framework, our analysis allows to study intermediate cases where merchants cannot fully pass on their payment costs but have to absorb some of these costs.

A consistent finding in the payment card literature is that if there is pass-through of payment costs to consumers in the form of higher retail prices by merchants, the structure of fees does not matter (Gans and King, 2003). In our analysis, neutrality of the fee structure may occur under full pass-through, $\lambda_j = 1$. Instrument-contingent payment pricing under

[6]Note that in reality, many merchants do not set instrument-contingent pricing but may set one uniform price. We will consider such merchant pricing later in the paper.

[7]The parameter λ_j can also be interpreted as the bargaining power between consumers and merchants regarding the proportion that each pays of the merchant payment card fee.

Table 1: Variables in the Model

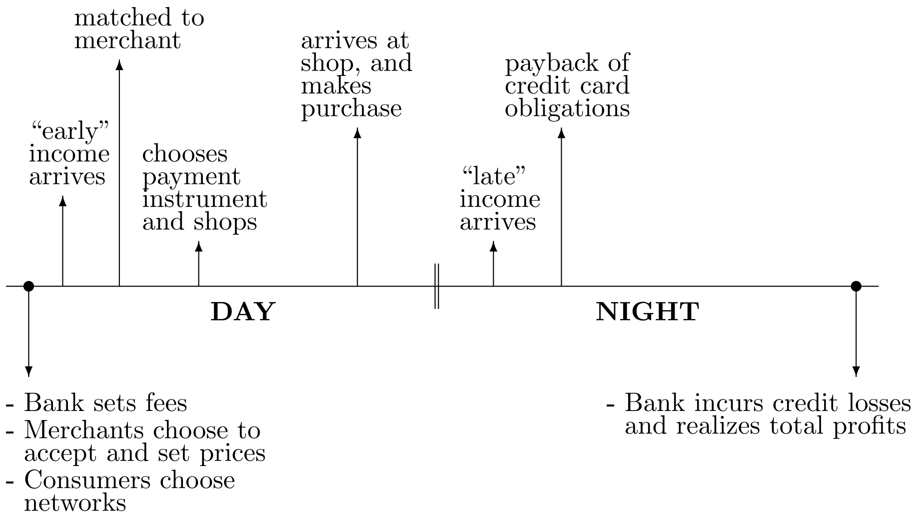
Exogenous variables:	
I	Income for consumer
ϕ_1	Probability of receiving income before shopping
ϕ_2	Probability of receiving income after shopping
ρ	Probability of not getting robbed when carrying cash
γ_i	Merchant-specific cost
p_m	Price for good if paying by cash
λ_d	Proportion of debit card merchant fee passed onto consumers
λ_c	Proportion of credit card merchant fee passed onto consumers
c_d	Bank's per-transaction cost to process debit card transaction
c_c	Bank's per-transaction cost to process debit card transaction
Endogenous variables:	
α	Proportion of merchants accepting debit cards
β	Proportion of merchants accepting credit cards
p_d	Price of good if paying with debit card
p_c	Price of good if paying with credit card
F_d	Fixed consumer fee for debit card
F_c	Fixed consumer fee for credit card
f_d	Per-transaction merchant fee for debit card
f_c	Per-transaction merchant fee for credit card

incomplete pass-through, $\lambda_j < 1$, always yields a (unique) optimal structure of fees, and possibly resulting in incomplete merchant acceptance. While our approach to merchant pricing is simplistic, we are able to consider a richer set of merchant decisions and outcomes than previously considered in the payment card literature. We consider this continuum of merchant pricing to capture that not all merchants will accept payment cards even if they can pass on some of their payment processing costs to consumers.[8] We observe that in countries that allow merchants to surcharge for payment cards, some merchants do not surcharge and others refuse to accept payment cards at all. In other words, there are other factors that prevent all merchants from fully recovering costs even when they are contractually allowed to do so.

The bank faces two types of costs. First, it faces a per-transaction, proportional cost, c_d and c_c, to process debit and credit cards, respectively. These costs can be interpreted as costs that include authorization, clearance, and settlement costs. For simplicity, fixed costs are assumed to be zero. Given the extra functionality of credit cards, we assume that $c_c \geq c_d$.

[8] For more discussion, see Katz (2005).

Figure 2: Timing of events



Second, the bank faces default losses when providing credit cards, because some consumers pay with credit cards and are unable to pay back. For reference, we list the exogenous and endogenous variables that appear in our model in table 1.

The timing of events is depicted in figure 2. In the early morning, the bank posts its prices for payment services, merchants announce their acceptance of payment products and their prices, and consumers choose which payment networks to participate in. Next, consumers realize whether they receive income before shopping and are matched with a specific merchant. Each consumer decides which payment instrument to use before leaving home based on her merchant's acceptance, its prices based on payment instrument used, and if she received income. During the day, consumers go shopping. At night, a proportion of consumers, ϕ_2, that did not receive income in the morning receive income and pay back their credit card obligations.

3 Debit Cards

In this section, we will limit our analysis to an economy with cash and debit cards. We endogenously determine the proportion of merchants that accepts debit cards and denote it as α. Consumers can consume in additional $\alpha(1-\rho)$ states of nature when debit cards exist. Merchants benefit from making sales to debit card consumers because they all arrive to their stores safely. Our model does not capture merchant incentives to accept cards to steal customers from other merchants. Since debit cards may not be accepted by all merchants, consumers must use cash for some purchases.

Consumers are willing to participate in a debit card network if the fixed fee, F_d, is less than or equal to the expected additional consumption. In other words, the following inequality must be satisfied:

$$\rho\phi_1 I \leq \phi_1 \left((1-\alpha)\rho + \frac{\alpha}{p_d} \right) (I - F_d).$$

This inequality yields the maximum debit card fee, F_d^{max}, that consumers are willing to pay as a function of exogenous parameters, ρ, ϕ_1, and I, and endogenous parameters, α and p_d. Given that consumers must commit to the membership fee before being matched to a merchant, all consumers purchasing from stores that accept debit cards will always use their debit cards and leave home without cash, because they face a positive probability of being mugged when carrying cash in transit.

In an economy where all consumers sign up for debit cards, Π_m^i changes from the cash-only case to:

$$\Pi_{m(d)}^i = \phi_1\rho(1-\gamma_i)(I - F_d).$$

All consumers have less disposable income to spend because of their participation in the debit card network. Merchants are unable to internalize the loss in disposable income from the consumer's fixed fee in an economy with debit cards because they are atomistic and cannot jointly bargain with the bank. If merchants could do so, their participation threshold would occur at a lower fee. Merchant i's (expected) profit from accepting debit cards, Π_d^i, is:

$$\Pi_d^i = \phi_1 \left((1 - f_d) - \frac{\gamma_i}{p_d} \right) (I - F_d).$$

Merchant i accepts debit cards only when $\Pi_{m(d)}^i \leq \Pi_d^i$. Note that by accepting debit cards merchants increase their sales because all consumers avoid being mugged. Moreover, we consider scenarios where merchants can increase their goods price from p_m to p_d to offset their cost of accepting debit cards. There exists a threshold cost γ_d, below which merchants accept debit cards for payment. Note that cash-only merchants are strictly worse off in a debit card economy because consumers that arrive at their stores have less disposable income.

Having substituted debit card pricing rule (1) in γ_d, the proportion of merchants willing to accept debit cards is:

$$\alpha(f_d) = Pr[\gamma_i \leq \gamma_d] = \gamma_d = \frac{1 - f_d - \rho}{1 - \lambda_d f_d - \rho}. \tag{2}$$

As the degree of pass-through increases, more and more merchants are able to accept debit cards. We observe that $\alpha(f_d) \in [0,1]$ if and only if $f_d \in [0, 1-\rho]$ and $\lambda_d < 1$. Note that if merchants are able to fully pass on costs to consumers ($\lambda_d = 1$), all merchants will accept debit cards ($\alpha = 1$), regardless of the fee.

Lemma 1 *The maximum debit card fixed fee, F_d^{max}, is:*[9]

$$F_d^{max}(f_d) = \left(1 - \frac{\rho}{1 - f_d}\right) I. \tag{3}$$

Equation (3) expresses the highest fixed fee, F_d^{max}, that consumers are willing to pay given the probability of not getting mugged, ρ, and the merchant fee, f_d. For the bank to set a positive consumer fee, the merchant fee must be smaller than the probability of getting mugged. For larger merchant fees, i.e. $f_d > 1 - \rho$, no merchant will accept and therefore no consumer is willing to pay, $F_d^{max} = 0$. On the other hand, when $f_d = 0$, all merchants accept and consumers pay the highest possible fixed fee, i.e. $F_d^{max} = (1-\rho)I$. The consumer fee captures the network effect that consumers are willing to pay higher fixed fees when more merchants accept the card. However, this effect is dampened by a decrease in purchasing power depending on the degree to which merchants increase their price for debit card purchases and from paying a fixed fee. Merchant acceptance of debit cards is higher when f_d is lower except when merchants fully pass on their payment costs to consumers.

For simplicity, we will assume that fixed fees are paid by consumers that receive income in the morning and use their debit cards. In other words, the fee is state contingent. In a previous version of the model, we consider the bank's ability to capture fees from those consumers that received income at night and were unable to use their debit cards.[10]

The bank maximizes its expected per-consumer profit, given the consumer participation

[9] Proofs of lemmas and propositions are in the appendix.

[10] In Bolt and Chakravorti (2008a), we show that the ability of the bank to extract fees from consumers that receive their income in the night widens the range of cost levels for which the bank sets a zero merchant fee.

constraint and the merchant acceptance condition:

$$\Pi_d^B(f_d) = \phi_1 \left(\alpha(f_d - c_d)(I - F_d)\right) + \phi_1 F_d, \tag{4}$$
$$\text{subject to:} \quad i)\ F_d = F_d^{max}(f_d), \quad ii)\ \alpha = \alpha(f_d).$$

Note that the bank's profit is positive when debit cards are accepted and used, i.e. $\alpha > 0$, and bank cost, c_d, is sufficiently small. The bank is able to capture fees from consumers receiving income at night even though these consumers are unable to consume. Notice that bank profits are zero for merchant fees above a threshold where no merchant accepts them. Let us denote $f_d^*(c_d, \rho, \lambda_d) \in [0, 1-\rho]$ as the merchant fee such that $d\Pi_d^B(f_d)/df_d = 0$. Also denote $\overline{\lambda}_d = \rho < 1$ as an upper bound on pass-through.[11] The following proposition characterizes the profit-maximizing fee.

Proposition 1 *For $\lambda_d \leq \overline{\lambda}_d$, the debit card merchant fee f_d^* that maximizes $\Pi_d^B(f_d)$ is given by:*

$$f_d^* = \begin{cases} f_d^*(c_d, \rho, \lambda_d) & \text{if } \ 0 < c_d \leq \bar{c}_d, \\ 0 & \text{if } \ c_d = 0, \end{cases}$$

where

$$\bar{c}_d = \frac{(1-\rho)(1+\rho)(1-\lambda_d)}{\rho}.$$

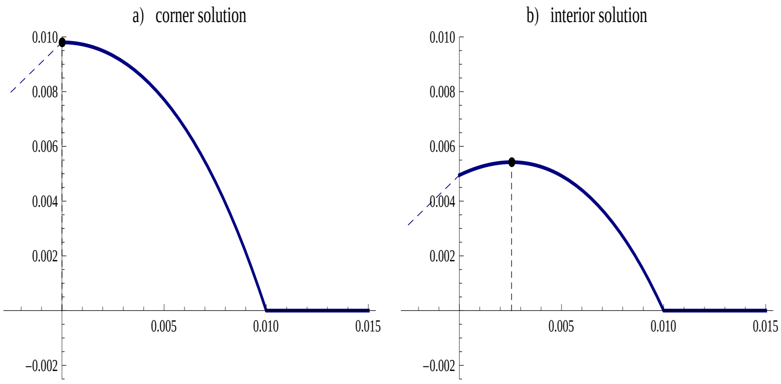
Consumers pay a fixed fee $F_d^* = F_d^{max}(f_d^*)$.

Our model identifies two cases. If bank costs are zero, merchants pay no fee and acceptance is complete. Consumers bear all the payment cost through fixed fees. However, if the bank cost is positive, the bank also extracts surplus from merchants and sets a positive merchant fee. Now, merchant acceptance is incomplete, and accepting merchants will surcharge card payments if they can to partially offset their payment processing cost. Figure 3 depicts these two different cases. Finally, if the bank cost is too high, neither consumers nor merchants are willing to pay for debit cards, and they only use cash.

Our model also allows us to study how the ability of merchants to pass on payment costs to consumers affects bank profits. As merchants absorb more costs, i.e. as λ_d approaches 0,

[11] When pass-through is "too" high, the bank cannot extract sufficient surplus from merchants and is forced to set a zero merchant fee to preserve consumer's purchasing power while generating complete merchant acceptance and increasing consumers' willigness to pay. This pricing strategy corresponds to a corner solution.

Figure 3: Bank debit card profits



Note: In left panel, $c_d = 0$ and $f_d^* = 0$; in right panel, $0 < c_d = 0.005 \leq \bar{c}_d$ and $f_d^* \in (0, 1-\rho]$. Other parameter values: $\rho = 0.99$, $\phi_1 = 0.98$, $\phi_2 = 0$, $\lambda_d = 0.25$, and $I = 1$. These values yield: $\underline{c}_d = 0$, $\bar{c}_d = 0.018$ and $f_d^* = 0.003$ (in panel b).

the bank is able to set a higher F_d because of an increase in the consumer's purchasing power resulting from a lower p_d. However, to compensate for the potential decrease in acceptance, the bank reduces f_d to almost maintain a similar acceptance level. In other words, the merchant's absorption of f_d rises faster than the reduction in f_d. Yet, the fixed fee effect dominates the acceptance effect, and hence the bank's profit increases. In addition, the bank faces a lower real resource cost when retail prices are lower. This effect results from a proportional processing cost.

Proposition 2 *As the ability of merchants to pass on costs to consumers decreases, the bank's maximum profits increase. That is,*

$$\frac{\partial \Pi_d^B(f_d^*)}{\partial \lambda_d} < 0.$$

Observe from proposition 1 that high pass-through rates of merchant payment costs (λ_d close to 1) can only be sustained when ρ is close to 1. However, when $\lambda_d > \overline{\lambda}_d$ the structure of the maximization problem changes. For $\lambda_d > \overline{\lambda}_d$, and for small enough processing cost, the optimal merchant fee is always zero. As pass-through increases, the purchasing power of consumers decreases. The bank sets the merchant fee as low as possible, $f_d^* = 0$, thus lowering goods prices while generating a strong network effect, so that consumers are willing to join the debit card network by paying $F_d^{max} = (1-\rho)I$. Lower goods prices result in lower real resource costs for the bank. Thus, if the bank is unable to extract sufficient surplus from merchants, it prefers to fully extract from consumers by setting merchant fees as low as possible to achieve the greatest merchant acceptance.

Finally, let us consider the special case of full pass-through, $\lambda_d = 1$. Given our pricing rule (1), full pass-through induces $\alpha = 1$. In other words, the bank is unable to extract any surplus from merchants. Consumers bear the full cost of the debit card network. When $\lambda_d = 1$, only $c_d = 0$ yields constant bank profits $\Pi_d^B = (1-\rho)\phi_1 I$, leaving the price structure fully neutral.[12]

4 Credit Cards

In addition to being as secure as debit cards, credit cards allow consumption when consumers have not received income before they go shopping if merchants accept them. Merchants benefit from making sales to consumers without funds. An endogenously-determined proportion of β merchants accepts credit cards. Consumers are able to consume in $\beta(2-\rho-\phi_1)$ additional states of nature when participating in a credit card network than when only making cash purchases. The bank faces potential default losses when income does not arrive at all.

Consumers are willing to hold a credit card if their expected consumption from participating in a credit card network is greater than not participating. Their credit card participation constraint is:

$$\rho\phi_1 I \leq \left(\phi_1(1-\beta)\rho + \frac{\beta}{p_c}\right)(I - F_c).$$

This inequality yields the maximum credit card fee F_c^{max} that consumers are willing to pay.

Merchant i's (expected) profit from accepting credit cards, Π_c^i, is:

$$\Pi_c^i = \left((1-f_c) - \frac{\gamma_i}{p_c}\right)(I - F_c).$$

To participate in a credit card network, merchants must make at least as much profit from accepting credit cards as accepting only cash in an economy with credit cards. As in the debit card case, consumers have less disposable income to spend at merchants than in the cash-only

[12] Our model replicates the interchange fee neutrality result of Gans and King (2003) for certain parameter values that have not been considered before, namely cost based on purchase amount and default risk. If we would allow for negative merchant fees, "asymptotic" neutrality can be achieved even for $c_d > 0$. For $c_d > 0$, bank profit approaches $(1-\rho)\phi_1 I$ when $f_d \longrightarrow -\infty$.

economy. In other words, when all consumers hold credit cards, a cash-only merchant would have the following profit function.

$$\Pi^i_{m(c)} = \phi_1 \rho (1 - \gamma_i)(I - F_c).$$

Merchant i will accept credit cards when $\Pi^i_c \geq \Pi^i_{m(c)}$.

Furthermore, as in the debit card case, all consumers purchasing from stores that accept credit cards will always use their credit cards because they face no per-transaction cost and have considered the tradeoff between higher prices and the probability of being mugged. Clearly, those with no income in the morning can only consume with their credit cards at merchants that accept them. These conditions imply a threshold value of merchant cost, γ_c, below which merchants will accept credit cards. This threshold value γ_c determines merchant acceptance of credit cards. Substituting the pricing rule, $p_c(f_c)$, yields:

$$\beta(f_c) = Pr[\gamma_i \leq \gamma_c] = \gamma_c = \frac{1 - f_c - \rho\phi_1}{1 - \lambda_c f_c - \rho\phi_1}. \tag{5}$$

When $\lambda_c < 1$,we observe that $\beta(f_c) \in [0, 1]$ if and only if $f_c \in [0, 1 - \rho\phi_1]$. With full pass-through, $\lambda_c = 1$, merchant acceptance is complete, $\beta(f_c) = 1$ for all f_c.

Lemma 2 *The maximum credit card fixed fee, F^{max}_c, is:*

$$F^{max}_c(f_c) = \left(1 - \frac{\rho\phi_1}{1 - f_c}\right) I. \tag{6}$$

Note that $F^{max}_c(f_c) = 0$ when $f_c = 1 - \rho\phi_1$, so that zero merchant acceptance induces zero fixed fees. Furthermore, a consumer is willing to pay more for a credit card than a debit card, all else equal, because credit cards offer more benefits especially when matched with a credit card accepting merchant and the consumer has yet to receive her income.

When issuing credit cards, the bank faces a certain aggregate loss from consumers that never receive income. For a given $\phi_1 < 1$, there is no credit loss if income always arrives, i.e. $\phi_2 = 1 - \phi_1$. Maximum credit loss occurs when $\phi_2 = 0$. In contrast to debit cards, income uncertainty, $\phi_1 \leq 1$, and default risk, $1 - \phi_1 - \phi_2 > 0$, do play an important role for credit card pricing. Taking into account the consumer and merchant participation constraints, the bank maximizes its profits:

$$\Pi_c^B(f_c) = \beta(f_c - c_c)(I - F_c) + (\phi_1 + \phi_2)F - \beta(1 - \phi_1 - \phi_2)(I - F_c), \tag{7}$$

$$\text{subject to:} \quad i)\ F_c = F_c^{max}(f_c), \quad ii)\ \beta = \beta(f_c).$$

Similar to debit cards, observe that bank profits are zero when $f_c \geq 1 - \rho\phi_1$, and that the profit maximizing credit card fee, f_c^*, lies between 0 and $1 - \rho\phi_1$ for sufficiently small processing costs. Denote $f_c^*(c_c, \rho, \phi_1, \phi_2, \lambda_c) \in [0, 1 - \rho]$ which yields $d\Pi_c^B/df_c = 0$, and denote upper bound $\overline{\lambda}_c = \rho\phi_1 < 1$. Observe that $\overline{\lambda}_c$ approaches 1 when ρ and ϕ_1 go to 1. The following proposition characterizes the profit-maximizing credit card fee.

Proposition 3 *For $\lambda_c \leq \overline{\lambda}_c$, the credit card merchant fee f_c^* that maximizes $\Pi_c^B(f_c)$ is given by:*

$$f_c^* = f_c^*(c_c, \rho, \phi_1, \phi_2, \lambda_c) \quad \text{if} \ \ 0 \leq c_c \leq \bar{c}_c,$$

where

$$\bar{c}_c = \frac{(1-\rho)(1-\lambda_c)(\phi_1 + \phi_2) + \rho\phi_1((1-\rho)\phi_1 + \phi_2)}{\rho\phi_1}.$$

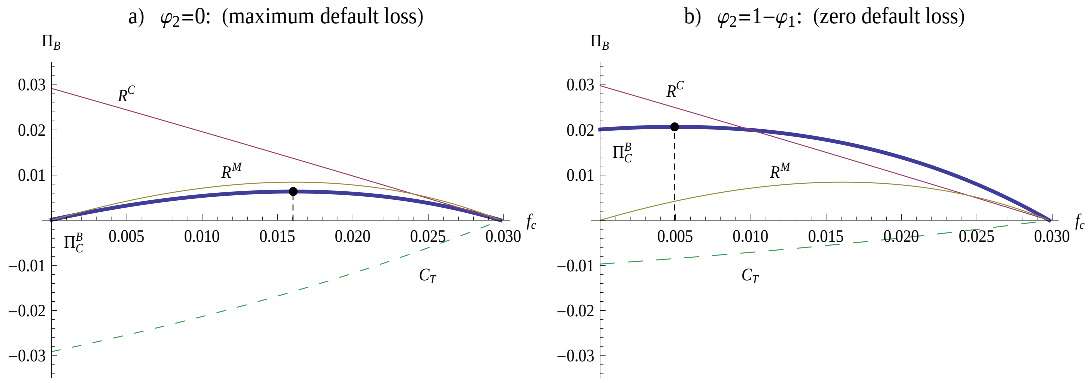
Consumers pay a fixed fee $F_c^* = F_c^{max}(f_c^*)$.

Unlike the debit card case, the bank has two types of costs—per-transaction cost to operate the system and credit losses from consumers who made credit card purchases but did not receive income in the night. Due to higher bank cost and the inability of merchant to sufficiently pass on credit card fees onto consumers, the bank will always fully extract surplus from consumers and capture some surplus from merchants to fund potential default losses. As a consequence, profit-maximizing merchant credit card fees will never be set at zero for any level of processing costs.

Three components contribute to bank credit card profits—merchant revenue (R_c^M), consumer revenue (R_c^C), and total costs (C_c^T) which is the sum of total processing costs and default losses. The bank's profit function can be rewritten as:

$$\Pi_c^B = R_c^C + R_c^M - C_c^T,$$

Figure 4: Bank credit card profits and default probability



Note: Given parameter values $\rho = 0.99$, $\phi_1 = 0.98$, $c_c = 0.01$, $\lambda_c = 0.25$, and $I = 1$, in panel a) we calculate $f_c^* = 0.016$ for $\phi_2 = 0$, and in panel b) $f_c^* = 0.005$ for $\phi_2 = 0.02$. The cut off value that yields $f_c^* = c_c$ is $\bar{\phi}_2 = 0.011$.

where

$$R_c^M = \beta f_c(I - F_c^{max}),$$
$$R_c^C = (\phi_1 + \phi_2)F_c^{max},$$
$$C_c^T = \beta(c_c + (1 - \phi_1 - \phi_2))(I - F_c^{max}).$$

Figure 4 shows the bank profit and its components for the two polar cases: $\phi_2 = 0$ and $\phi_2 = 1 - \phi_1$. Given a sufficiently large c_c, merchant share of payment costs increases as credit risk goes up. Merchants pay a higher fee when default losses can no longer be extracted from consumers. In other words, as additional benefits to merchants increase and the ability of consumers to pay decreases, merchants pay a higher fee. In effect, merchants start subsidizing credit card default losses.

Proposition 4 *For sufficiently small c_c, there exists $\bar{\phi}_2 \in [0, 1 - \phi_1]$ such that $f_c^* = c_c$ for $\phi_2 = \bar{\phi}_2$.*

Regarding comparative statics, if $\phi_2 < \bar{\phi}_2$ then lowering fees to the cost level, $f_c = c_c$, increases merchant acceptance and reduces goods prices p_c. This allows a higher fixed credit card fee for consumers. But the bank loses on the merchant side by lowering merchant fees, and suffers more default losses as credit card acceptance gets more widespread. These latter effects dominate resulting in lower bank profit. For the opposite case, when $\phi_2 > \bar{\phi}_2$, raising fees to $f_c = c_c$ induces lower merchant acceptance and higher goods prices. This leads to lower fixed fees, but also to lower default losses. On net, the bank's profit decreases. For larger c_c, the threshold $\bar{\phi}_2$ is bounded at zero, meaning that for any amount of default risk $(1 - \phi_1 - \phi_2 \geq 0)$, the processing cost exceeds the merchant fee.

Similar to the debit card case, when $\lambda_c = 0$ ($p_c = p_m = 1$) bank profit is higher. The inability of merchants to pass any processing costs to consumers results in lower merchant acceptance and lower goods prices. This induces higher fixed fees and lower default losses, yielding higher bank profits. In other words, the bank extracts surplus from both consumers and merchants. Full pass-through, i.e. $\lambda_c = 1$ and $p_c = 1/(1 - f_c)$, corresponds to neutrality of the price structure when $c_c = 0$. In this case, bank profits are constant, $\Pi_c^B = ((1-\rho)\phi_1 + \phi_2)I$, regardless of the choice of merchant fee and the corresponding consumer fee.

5 Welfare

In this section, we compare the social planner's welfare-maximizing to the bank profit-maximizing consumer and merchant fees for debit and credit cards. In our model, if the social planner wants to achieve the first-best solution, it must be able to decide which merchants should accept payment cards and which not, depending on merchant cost type. Because such a strategy would require the planner to know ex ante the merchants' cost functions, the first-best outcome can generally not be attained nor implemented. A more realistic welfare standard is second-best, or "information-constrained," efficiency where social expected value needs to exceed costs. We define total welfare as the sum of expected utility or profits of the three types of agents—the consumer, the merchant, and the bank—for cash, debit and credit cards, respectively, as:

$$
\begin{aligned}
&\text{(cash)} & W_m &= \bar{u}_m^C + \bar{\Pi}_m^M + \bar{\Pi}_m^B, \\
&\text{(debit)} & W_d(F_d, f_d, \alpha, p_d) &= \bar{u}_d^C + \bar{\Pi}_d^M + \bar{\Pi}_d^B, \\
&\text{(credit)} & W_c(F_c, f_c, \beta, p_c) &= \bar{u}_c^C + \bar{\Pi}_c^M + \bar{\Pi}_c^B.
\end{aligned}
$$

In a market with (two-sided) network effects, second-best socially optimal prices will usually lead to negative profits for network providers (see e.g. Hermalin and Katz, 2004; Bolt and

Tieman, 2006). Henceforth, to avoid potential distortionary effects of raising funds, our main interest is in characterizing second-best socially optimal pricing under a zero-profit constraint for the bank—also known as Ramsey pricing.

5.1 Benchmark: Cash Welfare

As a benchmark, in a cash-only environment, the expected consumption of a consumer is:

$$\bar{u}_m^C = \mathbb{E}[u(I)] = \phi_1 \rho I,$$

and the average merchant profit is:

$$\bar{\Pi}_m^M = \mathbb{E}[\Pi_m^i] = \frac{\phi_1 \rho I}{2}.$$

The bank makes no profit in a cash-only economy, $\bar{\Pi}_m^B = 0$. Hence, in a cash-only environment, total expected welfare per consumer is given by:

$$W_m = \frac{3\phi_1 \rho I}{2}.$$

Note that in a frictionless world without theft ($\rho = 1$) and income uncertainty ($\phi_1 = 1$) maximum total welfare amounts to $W = 3I/2$. Of course, in a frictionless world, there is no need for payment cards. However, the difference in surplus, $W - W_m$, creates the incentive for the bank to supply payment cards and extract surplus from consumers and merchants.

5.2 Debit Card Welfare

Society is better off adopting debit cards if:

$$W_m \leq W_d.$$

Expected consumer utility when using debit cards is:

$$\bar{u}_d^C = \phi_1 \left((1-\alpha)\rho + \frac{\alpha}{p_d} \right) (I - F_d).$$

The average expected merchant profit is:

$$\bar{\Pi}_d^M = \left(\phi_1\alpha\left(1 - f_d - \frac{\alpha}{2p_d}\right) + \phi_1\rho(1-\alpha)\frac{(1-\alpha)}{2}\right)(I - F_d).$$

The bank zero-profit condition stipulates:

$$\bar{\Pi}_d^B = \phi_1\alpha(f_d - c_d)(I - F_d) + \phi_1 F_d = 0.$$

Solving for F_d, this constraint yields:

$$F_d(\alpha, f_d) = \frac{\alpha(c_d - f_d)}{\alpha(c_d - f_d) + 1} I.$$

Under second-best welfare maximization, if the social planner does not know the merchant cost γ_d and is able to only set payment fees, it should maximize total welfare W_d under the merchant's participation constraint:

$$\alpha(f_d) = \gamma_d = \frac{1 - f_d - \rho}{1 - \lambda_d f_d - \rho}.$$

After substituting acceptance rule $\alpha(f_d)$, pricing rule $p_d(f_d)$ and zero-profit condition $F_d(\alpha, f_d)$ in the welfare function, $W_d^R(f_d) = W_d(F_d(\alpha(f_d), f_d), f_d, \alpha(f_d), p_d(f_d))$, the social planner maximizes:

$$\max_{f_d} \quad W_d^R(f_d).$$

Let us denote $f_d^R(c_d, \rho, \lambda_d) \in [0, 1-\rho]$ the fee such that $dW_d/df_d = 0$. Also denote upper bound on pass-through $\overline{\lambda}_d^R = (3\rho - 1)/2 < 1$, which approaches 1 when ρ goes to 1.

Proposition 5 *For $\lambda_d \leq \overline{\lambda}_d^R$, maximum Ramsey welfare $W_d^R(f_d)$ in a debit card system is characterized by:*

$$f_d^R = \begin{cases} f_d^R(c_d, \rho, \lambda_d) & \text{if } \underline{c}_d^R \leq c_d \leq \overline{c}_d^R \\ 0 & \text{if } c_d < \underline{c}_d^R \end{cases}, \quad F_d^R = F_d(\alpha(f_d^R), f_d^R) \leq F_d^{\max}(f_d^R),$$

where

$$\underline{c}_d^R = \frac{(1-\rho)(1-\lambda_d)}{(1-\lambda_d)(2+\rho) - 3(1-\rho)} \quad \text{and} \quad \overline{c}_d^R = \frac{(1-\rho)(3\rho + 2(1-\lambda_d))}{3\rho}.$$

First, observe that for $\lambda_d \leq \overline{\lambda}_d^R$, the profit-maximizing merchant fee f_d^R lies between 0 and $1-\rho$ when $0 \leq c_d \leq \overline{c}_d^R$. Hence, $W_d^R(f_d^R) \geq W_m$ because the social planner can always guarantee $W_d^R = W_m$ by setting $f_d^R = 1-\rho$ and $F_d^R = 0$.

Second, for low enough processing costs, merchant fees are set to zero and merchant acceptance is complete, $\alpha^R = 1$. With zero merchant fees and full acceptance, maximum Ramsey welfare amounts to $W_d^R = 3\phi_1 I/2(1+c_d)$, which illustrates the tradeoff between processing cost and income uncertainty compared to the frictionless world with welfare $W = 3I/2$. Even when the costs of running the debit card network are zero, so that $W_d^R = 3\phi_1 I/2$, the frictionless world cannot be reached when income uncertainty is positive (i.e. $\phi_1 < 1$). When costs become larger, merchants start to support the debit card network and acceptance decreases, $\alpha^R < 1$. For "extremely" high processing costs, merchant fees become too large to sustain any card acceptance, $\alpha^R = 0$, and only cash is used.

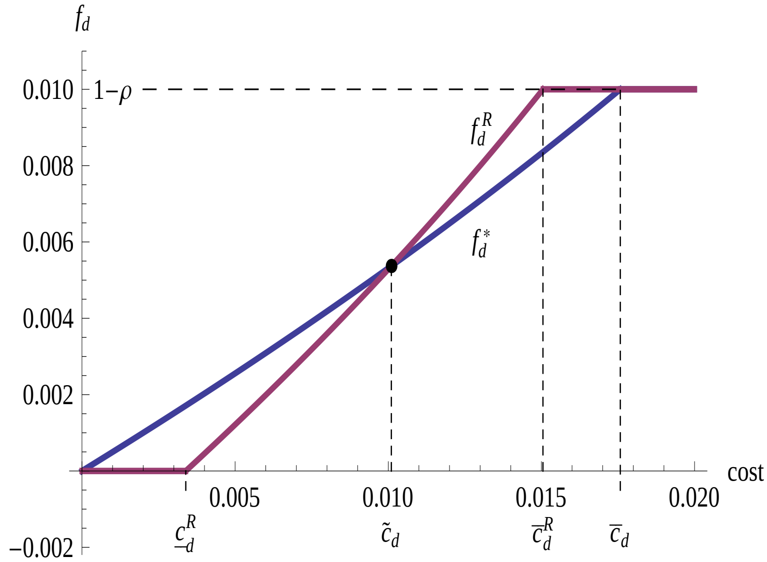
Third, the Ramsey planner pushes full merchant acceptance further than the profit-maximizing bank would. For a range of low processing cost levels, $0 < c_d \leq \underline{c}_d^R$, the planner would still implement a zero merchant fee, while the bank already charges the merchant (since $0 < \underline{c}_d^R$ for all $\lambda_d < \overline{\lambda}_d^R$). On the other hand, the Ramsey planner chooses not to offer debit cards for some high cost levels, $\overline{c}_d^R < c_d \leq \overline{c}_d$, whereas the bank would still choose to do so (since $\overline{c}_d^R < \overline{c}_d$ for all $\lambda_d < \overline{\lambda}_d^R$).

Lemma 3 *In contrast to the bank, Ramsey supports full debit card use for low cost and support full cash use for a high cost threshold. That is,*

$$\begin{array}{llll} i) & f_d^R = 0 < f_d^*, & \alpha^R = 1 > \alpha^*, & \text{if } 0 < c_d \leq \underline{c}_d^R, \\ ii) & f_d^R = 1-\rho > f_d^*, & \alpha^R = 0 < \alpha^*, & \text{if } \overline{c}_d^R \leq c_d < \overline{c}_d. \end{array}$$

This lemma implies that for some intermediate level of processing cost the Ramsey optimal merchant fee is equal to the profit-maximizing one. This cost level represents the cut-off that separates too little merchant acceptance from too much merchant acceptance of debit cards. Let us denote cut-off level $\widetilde{c}_d = (1-\rho)/\rho$. It is straightforward to verify that $f_d^R = f_d^*$ for $c_d = \widetilde{c}_d$. For lower cost levels, it is beneficial for welfare to set lower merchant fees to increase merchant acceptance reducing aggregate theft. In this case, the bank would rather dampen acceptance by setting higher fees than Ramsey so as to increase profit margins, leading to

Figure 5: Optimal debit card merchant fees: Bank vs Ramsey



Note: Given parameter values $\rho = 0.99$, $\phi_1 = 0.98$, $\phi_2 = 0$, $\lambda_d = 0.25$, and $I = 1$, the cut off value that yields $f_d^* = f_d^R$ is $\tilde{c}_d = 0.010$.

too little merchant acceptance and usage. The reverse is true for higher cost levels causing too much merchant acceptance and usage of debit cards. Note that safer travel—making cash more attractive—increases the likelihood that socially optimal merchant fees exceed profit-maximizing ones. When processing costs are high relative to safe travel, the planner wants to contract merchant acceptance of debit cards in favor of cash. Figure 5 depicts these findings.

Proposition 6 *Ramsey optimal debit card merchant fees are lower (higher) than profit maximizing merchant fees when processing costs are lower (higher) than $\widetilde{c}_d$. That is,*

$$i) \quad f_d^R < f_d^*, \quad \text{if } \underline{c}_d^R < c_d < \widetilde{c}_d,$$
$$ii) \quad f_d^R > f_d^*, \quad \text{if } \widetilde{c}_d < c_d < \overline{c}_d^R.$$

The following table illustrates our results. We observe that for high processing costs the cash-only economy dominates the debit card economy when the bank maximizes its profit. In the table, we also calculated the social optimum without concern as to whether the bank earns non-negative profits (see columns "Social Opt" in Table 2). Under this scenario, the social planner always sets the fixed consumer fee to zero so as to ensure that all income is used to generate profits for merchants and consumption for consumers. Indeed, we observe that socially optimal pricing without a zero-profit condition may lead to negative profits for the bank. In this case, the social value of debit card acceptance outweighs negative bank profit.

Under Ramsey pricing, different socially optimal price structures may arise. One set of prices that generates zero profit is a fixed consumer fee of zero and a merchant per-transaction fee equal to processing costs (i.e. $F_d = 0$, $f_d = c_d$). Another option is to set the fixed fee to its maximum F_d^{max} and to solve for the corresponding merchant fee that yields zero profits. In welfare terms, these different (F_d, f_d) combinations with zero profits trigger a tradeoff between merchant acceptance, processing cost, and the level of the fixed fee. A lower fixed fee gives more expected consumer utility, but induces also a higher merchant fee with lower acceptance, decreasing expected merchant's benefits. This tradeoff is influenced by the real resource cost of processing cards as is shown in Table 2. With low processing cost, Ramsey price structure pushes for high acceptance, requiring a relatively high fixed fee in a balanced budget situation (see "Ramsey Opt" column in Table 2 with low cost). For high processing cost, more weight is given to a low fixed fee and acceptance is kept minimal as to avoid the real resource cost of processing (see "Ramsey Opt" column in Table 2 with high cost). Observe that, in case of high costs, in the absence of a breakeven constraint, the social planner still wants to support merchant acceptance by setting low merchant fees, but—given zero consumer fixed fees as well—this happens at the expense of bank profit. The example of Table 2 shows that the three percent social loss that cash use levies on society, is reduced by a half a percent when debit cards are optimally issued under Ramsey (with low cost)—almost a twenty percent decrease.

5.3 Credit Card Welfare

Credit cards may improve on debit cards because they allow consumption when income has not arrived yet. Society is better off adopting credit cards if:

$$W_m \leq W_c.$$

Table 2: Welfare comparison of debit card outcomes

	Frictionless	Cash	low cost: $c_d = 0.005$ Social Opt	Ramsey Opt	Profit Max	high cost: $c_d = 0.015$ Social Opt	Ramsey Opt	Profit Max
f_d	-	-	0.000	0.001	0.003	0.005	0.010	0.008
F_d	-	-	0.000	0.003	0.007	0.000	0.000	0.002
α	-	-	1.000	0.906	0.795	0.536	0.007	0.211
p_d	-	-	1.000	1.000	1.001	1.001	1.002	1.002
$\bar{u}^C$	1.000	0.970	0.980	0.975	0.970	0.975	0.970	0.970
$\bar{\Pi}^M$	0.500	0.485	0.490	0.487	0.484	0.486	0.485	0.484
$\bar{\Pi}^B$	0.000	0.000	-0.005	0.000	0.005	-0.005	0.000	0.000
W	1.500	1.455	1.465	1.463	1.460	1.456	1.455	1.454

Note: Parameter values set to $\rho = 0.99$, $\phi_1 = 0.98$, $\phi_2 = 0$, $\lambda_d = 0.25$, and $I = 1$.

A social planner must trade off increased benefits against increased costs of all parties involved. Consumers expected utility is given by:

$$\bar{u}_c^C = \left(\phi_1 \rho (1-\beta) + \frac{\beta}{p_c}\right)(I - F_c).$$

Total average merchant profits are given by:

$$\bar{\Pi}_c^M = \left(\beta\left(1 - f_c - \frac{\beta}{2p_c}\right) + \phi_1 \rho (1-\beta)\frac{(1-\beta)}{2}\right)(I - F_c).$$

The zero-profit condition of the bank yields:

$$F_c(\beta, f_c) = \frac{\beta(c_c - f_c + 1 - \phi_1 - \phi_2)}{\beta(c_c - f_c + 1 - \phi_1 - \phi_2) + \phi_1 + \phi_2} I.$$

Under second-best welfare maximization, the Ramsey planner should maximize total welfare W_c under the merchant's participation constraint:

$$\beta(f_c) = \gamma_c = \frac{1 - f_c - \rho\phi_1}{1 - \lambda_c f_c - \rho\phi_1}.$$

After substituting acceptance rule $\beta(f_c)$, pricing rule $p_c(f_c)$ and zero-profit condition $F_c(\beta, f_c)$ in the welfare function, $W_c^R(f_c) = W_c(F_c(\beta(f_c), f_c), f_c, \beta(f_c), p_c(f_c))$, the social planner maximizes:

$$\max_{f_c} \quad W_c^R(f_c).$$

Let us denote $f_c^R(c_c, \rho, \phi_1, \phi_2, \lambda_c) \in [0, 1 - \rho\phi_1]$ the fee such that $dW_c/df_c = 0$. Also denote upper bound on pass-through $\overline{\lambda}_c^R = (3\rho\phi_1/(\phi_1 + \phi_2) - 1)/2 < 1$, which will approach 1 when ρ and ϕ_1 go to 1. Define $\overline{\phi}_2 = 2/3(1 - \phi_1)$.

Proposition 7 *For $\lambda_c \leq \overline{\lambda}_c^R(\rho, \phi_1, \phi_2)$ and $\phi_2 > \overline{\phi}_2$, maximum Ramsey welfare $W_c^R(f_c)$ in a credit card system is characterized by:*

$$f_c^R = \begin{cases} f_c^R(c_c, \rho, \phi_1, \phi_2, \lambda_c), & \text{if } \underline{c}_c^R < c_c \leq \overline{c}_c^R, \\ 0, & \text{if } c_c \leq \underline{c}_c^R, \end{cases} \qquad F_c^R = F_c(\alpha(f_c^R), f_c^R) \leq F_c^{\max}(f_c^R),$$

where

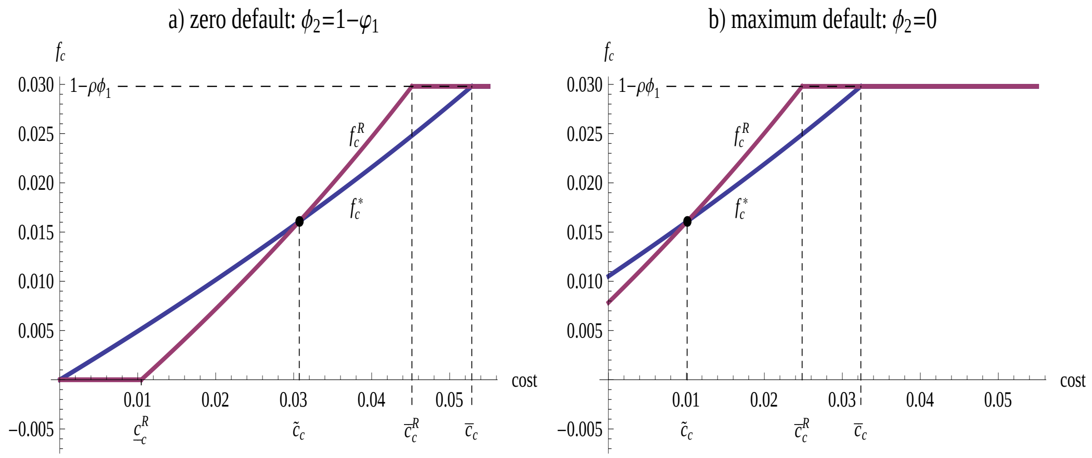
$$\begin{aligned} \underline{c}_c^R &= \frac{(1 - \lambda_c)(2 + \rho\phi_1 - 3(\phi_1 + \phi_2))}{(4 - \lambda_c)\rho\phi_1 - (1 + 2\lambda_c)} \quad \textit{and} \\ \overline{c}_c^R &= \frac{2(1 - \rho\phi_1)(1 - \lambda_c)(\phi_1 + \phi_2)}{3\rho\phi_1} + (1 - \rho)\phi_1 + \phi_2. \end{aligned}$$

The proposition states that when default losses are sufficiently low, $\phi_2 > \overline{\phi}_2$, income received in the night is sufficient compensation for the Ramsey planner to push for complete merchant acceptance of credit cards, $f_c^R = 0$, if resource costs are not too high, $0 \leq c_c \leq \underline{c}_c^R$. Otherwise, for $\underline{c}_c^R < c_c \leq \overline{c}_c^R$, the planner starts charging the merchant too.

The cost level that equates the Ramsey optimal merchant fee to the profit-maximizing one is given by $\widetilde{c}_c = ((1-\rho)\phi_1 + \phi_2)/(\rho\phi_1)$. Figure 6 shows how Ramsey merchant fees relate to profit-maximizing ones depending on the level of default risk. In panel a) zero default risk, $\phi_2 = 1 - \phi_1 > \overline{\phi}_2$, leaves a range of low cost levels for which the planner would set a zero merchant fee with full acceptance. With zero credit card merchant fees, total Ramsey welfare is given by $W_c^R = 3(\phi_1 + \phi_2)I/(2 + 2c_c)$. When default losses and processing costs are small, i.e. $\phi_1 + \phi_2$ close to 1 and c_c close to 0, the frictionless welfare $W = 3I/2$ is within reach.

When default losses are sufficiently high, $0 \leq \phi_2 \leq \overline{\phi}_2$, the Ramsey planner is generally forced to extract surplus from the merchant by setting positive merchant credit card fees for

Figure 6: Optimal credit card merchant fees: Bank vs Ramsey



Note: Parameter values set equal to $\rho = 0.99$, $\phi_1 = 0.98$, $\lambda_c = 0.25$, and $I = 1$. In panel a) we calculate $\tilde{c}_c = 0.03$ and $\bar{\rho} = 1.02$; in panel b) $\tilde{c}_c = 0.01$, and $\bar{\rho} = 0.96$.

all cost levels. Only when travel between home and the store is really unsafe, making cash use relatively undesirable, the Ramsey planner pushes again for complete acceptance when resource costs are low enough. In panel b) of figure 6, maximum default risk, $\phi_2 = 0$, and a sufficiently large ρ induce positive Ramsey merchant fees with incomplete acceptance for all cost levels.[13]

Since credit cards increase consumption possibilities, welfare is higher than in the debit card case, all else being equal, which can be seen from table 3. Observe that without income uncertainty (and default loss) credit cards completely mimic debit cards. The table illustrates that socially optimal payment fees without a zero-profit condition leaves the bank with negative profit. Ramsey pricing prevents negative profit but aggregate social welfare is lower. In other words, society might be better off with an ex post redistribution of surplus. The example shows that credit cards improve upon debit cards and cash. In the low cost case, credit cards reduce the welfare gap from 3 percent to 2.2 percent, an improvement of 25 percent compared to only cash. Ultimately, possible cost differentials (c_c vs. c_d) and/or cost absorption differentials (λ_c vs. λ_d) will determine whether the bank prefers to supply credit cards or debit cards.

[13] More precisely, for $\phi_2 < 2/3(1 - \phi_1)$, we can derive $\overline{\rho}_c = 3((\phi_1 + \phi_2) - 2)/\phi_1 < 1$, so that for $\rho < \overline{\rho}_c$ we calculate $\underline{c}_c^R > 0$, and $\underline{c}_c^R < 0$ otherwise.

Table 3: Welfare comparison of credit card outcomes

	Frictionless	Cash	low cost: $c_c = 0.005$ Social Opt	Ramsey Opt	Profit Max	high cost: $c_c = 0.015$ Social Opt	Ramsey Opt	Profit Max
f_c	-	-	0.000	0.012	0.013	0.000	0.020	0.019
F_c	-	-	0.000	0.009	0.017	0.000	0.006	0.011
β	-	-	1.000	0.700	0.626	0.991	0.381	0.434
p_c	-	-	1.000	1.003	1.003	1.000	1.005	1.005
$\bar{u}^C$	1.000	0.970	1.000	0.079	0.970	1.000	0.974	0.970
$\bar{\Pi}^M$	0.500	0.485	0.500	0.487	0.482	0.500	0.484	0.482
$\bar{\Pi}^B$	0.000	0.000	-0.025	0.000	0.009	-0.035	0.000	0.004
W	1.500	1.455	1.475	1.466	1.461	1.465	1.458	1.456

Note: Parameter values set to $\rho = 0.99$, $\phi_1 = 0.98$, $\phi_2 = 0$, $\lambda_c = 0.25$, and $I = 1$.

6 Full Multihoming

In this section, we will consider the case when the bank provides both debit and credit cards simultaneously. Unlike the previous two cases, when each card always dominated cash, consumers may not choose the same payment instrument in all income states when all payment instruments are accepted. If consumers are multihoming, they consider the benefits of each card before going to the store including any price differences based on the payment instrument used.[14] By differentiating debit card and credit card purchase prices, merchants may be able to steer some consumers to the low-cost payment instrument. However, when merchants are unable to price differentiate and post one price, consumers do not face any price incentives in the store, and opt for the instrument with the greatest functionality, regardless of whether they have income or not.[15]

6.1 Instrument-Contingent Pricing

Let us now consider the case when consumers hold both debit and credit cards, and merchants are able to price differentiate between cash, debit and credit cards. As before, all merchants post the same prices based on the payment instrument used. For mathematical convenience, in this section, we assume equal pass-through rates for debit and credit cards, $\lambda_d = \lambda_c = \lambda$.

[14]Recently, some U.S. consumers are preferring to use their debit cards instead of their credit cards to reduce their potential future debt burden. We do not consider such consumer preferences in our model.

[15]In reality, consumers may be given rewards to use more costly payment instruments. We do not consider these inducements.

We analyze the case when $p_d < p_c$. Under this condition (and $\lambda_d = \lambda_c$), credit acceptance is smaller than debit card acceptance ($\alpha \geq \beta$). The following inequality must be satisfied for consumers already holding debit cards, to hold credit cards:

$$\begin{aligned}
&\phi_1 \left[(1-\alpha)\rho(I - F_d) \ + \ \alpha(I - F_d)/p_d\right] \ \leq \\
&\phi_1 \left[(1-\alpha)\rho(I - F_d - F_c) + \alpha(I - F_d - F_c)/p_d\right] + \\
&(1-\phi_1)\beta(I - F_d - F_c)/p_c.
\end{aligned}$$

Because consumers pay a lower price when using their debit cards ($p_d < p_c$), they will use credit cards only when they have not yet received their income. The inequality yields the maximum credit card fee $F_c^{max}(F_d)$ that consumers are willing to pay, given that they have already joined the debit card network.

Consumers will multihome when each payment instrument yields benefits greater than the cost to participate. The maximum total card fee F_T^{max} under full multihoming is given by:

$$F_T^{max} = \frac{\beta(1-\phi_1)p_d + (p_c/p_d)\phi_1\alpha(1-p_d\rho)}{\beta(1-\phi_1)p_d + (p_c/p_d)\phi_1(\alpha(1-p_d\rho) + p_d\rho)} I. \tag{8}$$

When consumers multihome, only the total fixed fee matters and not the fee attributed to each card. Consumers are willing to spend up to F_T^{max} in return for participating in both the debit and credit card networks.

Merchant acceptance of cards is determined by threshold costs γ_d and γ_c for debit and credit cards, respectively. At the margin, the merchant has to trade off the costs and benefits of accepting debit and credit cards versus accepting cash only. As shown in sections 3 and 4, the proportion of merchants willing to accept debit cards is:

$$\alpha(f_d) = \frac{1 - f_d - \rho}{1 - \lambda f_d - \rho}, \tag{9}$$

and to accept credit cards is:

$$\beta(f_c) = \frac{1 - f_c - \rho\phi_1}{1 - \lambda f_c - \rho\phi_1}. \tag{10}$$

Substituting price rules (1), and acceptance rules (9) and (10) in fixed total fee (8) yields the maximum total card fee $F_T^{max}(f_d, f_c)$ as a function of only the merchant card fees and other exogenous variables (see appendix for an analytical expression).

Table 4: Comparison of profit-maximizing outcomes

		high cost: $c_c = 0.015 > c_c'$			low cost: $c_c = 0.010 < c_c'$		
		Debit only	Credit only	Multi-homing	Debit only	Credit only	Multi-homing
f_d^*		0.003		0.003	0.003		0.003
f_c^*			0.019	0.022		0.016	0.020
α^*		0.795		0.795	0.795		0.795
β^*			0.434	0.312		0.534	0.383
p_d^*		1.001		1.001	1.001		1.001
p_c^*			1.005	1.006		1.004	1.005
Bank profit	Π^B	0.005	0.004	0.005	0.005	0.006	0.005
breakout:							
Consumer revenue	R^C	0.007	0.011	0.013	0.007	0.014	0.015
Merchant revenue	R^M	0.002	0.008	0.002	0.002	0.008	0.002
Default loss	C^{def}	0.000	-0.004	-0.006	0.000	-0.010	-0.008
Processing cost	C^{proc}	-0.004	-0.006	-0.004	-0.004	-0.005	-0.004

Note: Parameter values set to $c_d = 0.005$, $\rho = 0.99$, $\phi_1 = 0.98$, $\phi_2 = 0$, $\lambda_c = \lambda_d = 0.25$, and $I = 1$. We (numerically) verify: $c_c' = 0.012$.

When merchants charge more for goods that are purchased by credit cards than debit cards, the bank maximizes:

$$\begin{aligned} \Pi^B_{mh}(F_T, f_d, f_c, \alpha, \beta) &= (\phi_1\alpha(f_d - c_d) + (1-\phi_1)\beta(f_c - c_c))(I - F_T) + \\ &\quad (\phi_1 + \phi_2)\, F_T - (1 - \phi_1 - \phi_2)\beta(I - F_T). \\ \text{subject to} &: \; i)\; F_T = F_T^{max}(f_d, f_c), \;\; ii)\; \alpha = \alpha(f_d) \text{ and } \beta = \beta(f_c). \end{aligned} \tag{11}$$

Under multihoming, the bank can always replicate the debit card equilibrium by setting high credit card fees to force zero adoption by consumers and merchants. In particular, setting $f_c = 1 - \rho\phi_1$, $f_d = f_d^*$, $F_T = F_d^{max}(f_d^*)$, yields $\Pi^B_{mh} = \Pi^B_d(f_d^*)$. Hence, given the exogenous parameters, in a multihoming equilibrium, the bank can never be worse off than in a debit card equilibrium. Let us denote f_d^{**} and f_c^{**} the profit-maximizing fees of $\Pi^B_{mh}(f_d, f_c)$ in the multihoming case.[16]

Lemma 4 *All else being equal, optimal multihoming bank profit dominate optimal bank profit*

[16]The model is too complex to analytically solve for f_{dc}^{**} and f_{cc}^{**}. Numerical approximations are reported in table 4 which are based on analytical expressions for the two Euler "reaction functions" $f_{dc}^R(f_{cc})$ and $f_{cc}^R(f_{dc})$.

in the debit card equilibrium. That is,

$$\Pi_{mh}^{B}(f_d^{**}, f_c^{**}) \geq \Pi_d^{B}(f_d^{*}).$$

For a given cost level c_d, there exists a $c_c'' > c_d$ such that optimal bank profits across debit cards and credit cards are the same, that is $\Pi_c^B(f_c^*) = \Pi_d^B(f_d^*)$ for $c_c = c_c''$. This must be the case, since—all else being equal—credit cards widen consumption possibilities from which the bank can extract some surplus. For $c_c \geq c_c''$, the debit card equilibrium yields higher bank profits. Since optimal multihoming profits are higher than optimal debit card profits, there must exist a $c_d \leq c_c' \leq c_c''$ such that optimal multihoming bank profits (just) dominate both debit card only and credit card only profits. Hence, for $c_c \geq c_c'$, the bank maximizes profits by issuing credit cards in addition to debit cards. On the other hand, for credit card processing cost $c_c < c_c'$, a credit card only environment would be preferred by the bank, because the relatively high markup on credit cards would be profitable in all income states. The next proposition summarizes these findings. Table 4 illustrates both situations.

Proposition 8 *All else being equal, given c_d, there exists a $c_c' > c_d$ such that for $c_c > c_c'$ optimal multihoming profits dominate optimal debit card and credit card profits when only one type of card exists. That is, given c_d,*

$$\Pi_{mh}^{B}(f_d^{**}, f_c^{**}) \geq \max\left\{\Pi_d^{B}(f_d^{*}),\ \Pi_c^{B}(f_c^{*})\right\} \quad if\ c_c > c_c'.$$

6.2 Uniform Pricing

Now, let us consider merchants that are only able to post one price, because of regulatory, contractual, and other reasons.[17] Unlike before, prices for goods were uniform across merchants for a given payment instrument. When merchants post one price, we assume that their new one price is the average of the prices weighted by the probability that consumers would use each instrument that they accept. Assume that there is a probability, μ, of a consumer using a debit card and a probability, $(1-\mu)$, of using a credit card, the uniform

[17] See e.g. Barron, Staten, and Umbeck (1992), IMA Market Development (2000) and Bolt, Jonker, and Van Renselaar (2009) for more discussion about merchant pricing based on payment instrument.

price would be:

$$p_u = \mu p_d + (1-\mu)p_c$$

In this economy, all credit card accepting merchants post the same price, p_u, which is different from the uniform price of debit card accepting merchants. Cash-only merchants post price, p_m.

Suppose each consumer receives additional benefit, ϵ, when using credit cards instead of debit cards at merchants that accept both when there is a uniform price.[18] In this case, $p_u = p_c$ for merchants that accept credit cards since all consumers would use their credit cards even though all consumers would be better off if consumers receiving income in the morning used their debit cards because p_u would be lower. The consumer's participation constraint becomes:

$$\begin{aligned}
&\phi_1\left[(1-\alpha)\rho(I-F_d) \;+\; \alpha(I-F_d)/p_d\right] \;\leq \\
&\phi_1\left[(1-\alpha)\rho(I-F_d-F_c)+(\alpha-\beta)(I-F_d-F_c)/p_d + \right.\\
&\left.\beta(I-F_d-F_c)/p_c\right]+(1-\phi_1)\beta(I-F_d-F_c)/p_c.
\end{aligned}$$

If $p_d = p_c$ and all merchants accepting debit cards also accept credit cards, consumers would never choose to participate in both networks and not multihome. If there is a sufficient mass of merchants that do not accept credit cards, there may be an incentive to hold debit cards.

The maximum total fee $F_{T_u}^{max}$ under full multihoming and uniform prices $p_d = p_c$ at merchants that accept debit and credit cards is given by:

$$F_{T_u}^{max} = \frac{\beta(1-\phi_1)+\phi_1\alpha(1-p_d\rho)}{\beta(1-\phi_1)+\phi_1(\alpha(1-p_c\rho)+p_c\rho)}I. \tag{12}$$

Similar to the cases when the bank issued only one card, merchants choose to accept payment cards if by doing so their profits increase. If merchants charge the same price regardless of the type of payment instrument used, bank profits become:

$$\begin{aligned}
\Pi_{mh_u}^B = (\phi_1(\alpha-\beta)(f_d-c_d)+\beta(f_c-c_c))(I-F_T)+ \\
(\phi_1+\phi_2)\,F_T-(1-\phi_1-\phi_2)\beta(I-F_T).
\end{aligned} \tag{13}$$

[18] We rule out the possibility that $p_d > p_c$.

The bank prefers uniform pricing to merchant steering of consumers by applying differential pricing assuming that consumers cannot collude. Because each consumer selects the card that offers them the greatest benefits, they all face the higher uniform price where no debit card transactions occur. In other words, consumers are in a prisoner's dilemma where the sum of their individual actions result in a worse allocation for all of them. The increase in the uniform price when one consumer defects is marginal. Merchants are also worse off because they must pay higher processing costs when some consumers could have used less expensive payment instruments if offered the right price incentives.

Proposition 9 *If revenue from credit cards are higher than debit cards in a multihoming equilibrium and the default risk is sufficiently low, by restricting merchants to set one price regardless of the type of instrument used, the bank earns greater profits than when merchants are able to steer consumers through price incentives.*

The main intuition here is that merchants prefer to separate consumers by those that have funds and those that do not whereas the bank prefers to entice consumers to the more profitable payment instrument. Some cost studies find that credit card transactions require more real resources suggesting that there is a potential welfare gain from encouraging less costly payment instruments assuming that consumer utility is unchanged. However, lack of incentives such as lower prices charged by merchants to use certain payment instruments over others may encourage use of more costly payment instruments by those that do not require the additional functionality.

7 Conclusion

We construct a model of consumer choice and merchant acceptance of payment instruments. Insurance and liquidity motives are incorporated into the payments context that are well established in the banking literature as justification for why banks exist. Our model is among the first to consider different levels of merchant pass-through of payment fees when merchants set instrument-contingent prices. The bank sets consumer and merchant fees to maximize its profit taking into consideration the adoption and usage externality present in two-sided markets. In equilibrium, the bank will extract all consumer surplus, but the level of surplus extracted from merchants depends on model parameters. If the cost to operate a card system is positive or the degree to which merchants are able to pass on costs to consumers is sufficiently low, the bank sets positive merchant payment card fees. Furthermore, as the default risk increases, the bank extracts greater surplus from merchants for credit card transactions.

We find that the Ramsey welfare-maximizing fee structure generally differs from the bank profit-maximizing. Depending on real resource costs, the social planner either stimulates or contracts payment card use relative to cash use by optimally setting merchant fees. In particular, when costs are low, the social planner is more likely to set a zero merchant fee to maximize the merchant adoption externality than the bank. However, when costs are high, the social planner sets a higher merchant fee resulting in lower merchant acceptance than the optimal bank merchant fee because the marginal cost of providing card services is higher relative to the marginal benefit of card services. Moreover, unlike the profit-maximizing bank, the social planner does not fully extract consumers because additional disposable income by consumers increases the welfare of consumers and merchants. Given that optimal bank fees may be lesser or greater than the planner's optimal fees, our model recommends policymakers to carefully estimate their specific parameter values prior to implementing fee ceilings.

Furthermore, we study consumer and merchant multihoming where consumers and merchants participate in multiple payment networks. When both types of payment instruments are available, merchants would prefer the ability to separate liquid consumers from illiquid ones whereas the bank may have incentives to entice consumers to always use their credit cards when possible. In other words, the inability of merchants to price differentiate based on payment instrument used reduces the welfare of consumers and merchants when all consumers multihome. However, our model does not consider merchants recovering more than their payment costs.

Given the current complexity of the model, we have left out key features of the payment card market. First, we have not considered long-term credit. Such an extension would require a model that considers credit cycles. Second, we ignore competition among banks in the provision of services that could put downward pressure on payment fees. Others have found that competition would occur on the consumer side and put upward pressure on merchant fees. Third, we assume that all consumers multihome, that is, they hold all payment instruments. In reality, not all consumers multihome and the uniform price may not be equal to the price of the most expensive instrument for the merchant to accept. Fourth, our model does not capture social benefits of positive bank profit in the long run. For example, if banks use these profits to improve their retail payment systems, social welfare may increase in the future offsetting any reduction in the current period. Fifth, we do not consider the bank setting merchant fees based on each merchant's willingness to pay. Such a pricing strategy may induce complete merchant acceptance but eliminate any merchant surplus. We leave these extensions for future research.

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Appendix

Note: All algebraic expressions and numerical results in our paper are derived using Mathematica, version 7, and program files are available upon request.

Proof of Lemma 1:
Solving the debit card consumer participation constraint (with an equality sign) for $F_d^{\max}$ yields $F_d^{\max}(f_d, \alpha, p_d)$, and substitution of the merchant acceptance condition $\alpha(f_d)$ and pricing rule $p_d(f_d)$ gives $F_d^{\max}(f_d) = (1 - \rho/(1 - f_d))I$.

Proof of Proposition 1:
First, when extending the domain of $\Pi_d^B(f_d)$ to allow for negative merchant fees $f_d < 0$ (so that by definition acceptance $\alpha = 1$), it easy to verify that the profit function $\Pi_d^B(f_d)$ is continuous in f_d. Given $\lambda_d < 1$, for small enough $c_d \geq 0$ we calculate that $d\Pi_d^B(f_d)/df_d > 0$ when $f_d < 0$. Hence, the maximum can never occur at $f_d < 0$. Second, non-negative profit exists for small enough processing cost. For example, for $c_d = 0$, $\Pi_d^B(0) = (1-\rho)\phi_1 I > 0$. Note that there is no card usage for $f_d \geq 1-\rho$ since acceptance is zero. Third, for small enough c_d, the optimal fee that maximizes bank profit lies between 0 and $1-\rho$. Solving $d\Pi_d^B(f_d)/df_d = 0$ yields two possible outcomes corresponding to a minimum and a maximum. Verifying the second-order conditions (and numerical verification) yields the profit-maximizing merchant fee:

$$f_d^*(c_d, \rho, \lambda_d) = \frac{(1-\rho)\lambda_d(c_d - (1-\lambda_d))}{(\lambda_d c_d - (1-\lambda_d)(1-\rho+\lambda_d))} + \frac{\sqrt{(1-\rho)(1-\lambda_d)(1-c_d\lambda_d-\rho)\rho(c_d-(1-\lambda_d))}}{(\lambda_d c_d - (1-\lambda_d)(1-\rho+\lambda_d))}.$$

Solving $f_d^*(c_d, \rho, \lambda_d) = 0$ for c_d yields $\underline{c}_d = 0$, and solving $f_d^*(c_d, \rho, \lambda_d) = 1-\rho$ gives $\bar{c}_d$. Fourth, for $\lambda_d \leq \overline{\lambda}_d = \rho$, it holds that $0 \leq \bar{c}_d$. Hence, if $c_d = 0$ then $f_d^* = 0$, else if $0 < c_d \leq \bar{c}_d$ then $0 < f_d^* \leq 1-\rho$. Fifth, if $\overline{\lambda}_d < \lambda_d < 1$, then only for $c_d < 1/\lambda_d - 1 < \bar{c}_d$, a global maximum exists for $f_d^* = 0$. Sixth, if $\lambda_d = 1$ then only $c_d = 0$ is consistent with constant profits $\Pi_d^B = (1-\rho)\phi_1 I$, independent of f_d (i.e. neutrality of the fee structure). Otherwise, for $\lambda_d = 1$, if $c_d > 0$, then profits are decreasing in f_d and approach $(1-\rho)\phi_1 I > \Pi_d^B(0)$ for $f_d \to -\infty$.

Proof of Proposition 2:
Applying the envelope theorem $d\Pi_d^B(f_d^*(c_d,\rho,\lambda_d),\lambda_d)/d\lambda_d = \partial\Pi_d^B(f_d,\lambda_d)/\partial\lambda_d$ yields:

$$\partial\Pi_d^B(f_d,\lambda_d)/\partial\lambda_d = \frac{f_d(c_d-f_d)(1-f_d-\rho)\rho\phi_1}{(1-f_d)(1-\lambda_d f_d-\rho)^2} I \geq 0,$$

since we can verify that $f_d^*(c_d,\rho,\lambda_d) \leq c_d$ for $c_d \leq \bar{c}_d$ and every $\lambda_d \in [0,1]$.

Proof of Lemma 2:
Solving the credit card consumer participation constraint (with an equality sign) for $F_c^{\max}$ yields $F_c^{\max}(f_c,\beta,p_c)$, and substitution of the merchant acceptance condition $\beta(f_c)$ and pricing rule $p_c(f_c)$ gives $F_c^{\max}(f_c) = (1-\rho\phi_1/(1-f_c))I$.

Proof of Proposition 3:
First, when extending $\Pi_c^B(f_c)$ to allow for negative merchant fees $f_c < 0$ (so that by definition acceptance $\beta = 1$), it easy to verify that the profit function $\Pi_c^B(f_c)$ is continuous in f_c. Given $\lambda_c < 1$, for small enough $c_c \geq 0$ we verify that $d\Pi_c^B(f_c)/df_c > 0$ when $f_c < 0$. Second, non-negative profit exists for small enough processing cost. For example, for $c_c = 0$, $\Pi_c^B(0) = ((1-\rho)\phi_1+\phi_2)I > 0$. Third, for small enough $c_c = 0$, the optimal fee that maximizes profits lies between 0 and $1-\rho\phi_1$. Solving $d\Pi_c^B(f_c)/df_c = 0$ yields two possible outcomes corresponding to a minimum and a maximum. Verifying the second-order conditions yields the profit-maximizing merchant fee:

$$f_c^*(c_c,\rho,\phi_1,\phi_2,\lambda_c) = \frac{(1-\rho\phi_1)((1-\lambda_c)-\lambda_c c_c)}{(1-\lambda_c)(1-\rho\phi_1+\lambda_c(\phi_2+\phi_1))-\lambda_c c_c} -$$

$$\frac{\sqrt{(1-\lambda_c)(1-\rho\phi_1)(\lambda_c(c_c+(1-\phi_1-\phi_2))-(1-\rho\phi_1))(\rho\phi_1 c_c-(1-\lambda_c)(\phi_1+\phi_2)))}}{(1-\lambda_c)(1-\rho\phi_1+\lambda_c(\phi_2+\phi_1))-\lambda_c c_c}.$$

Solving $f_c^*(c_c,\rho,\phi_1,\phi_2,\lambda_c) = 0$ for c_c yields $\underline{c}_c$, and solving $f_c^*(c_c,\rho,\phi_1,\phi_2,\lambda_c) = 1-\rho\phi_1$ gives $\bar{c}_c$. Fourth, $\underline{c}_c$ has an asymptote for $\lambda_c = \overline{\lambda}_c = \rho\phi_1$. Equating $\underline{c}_c = \bar{c}_c$ and solving for λ_c yields $\widetilde{\lambda}_c = \frac{\rho\phi_1}{\phi_1+\phi_2} \geq \overline{\lambda}_c$. Hence, as long as $\lambda_c \leq \overline{\lambda}_c$, it holds that $\underline{c}_c < 0 < \bar{c}_c$ and thus $0 < f_c^* \leq 1-\rho\phi_1$ for $0 \leq c_c \leq \bar{c}_c$. Fifth, if $\overline{\lambda}_c < \lambda_c < 1$ then only for $c_c < 1/\lambda_c - 1 < \bar{c}_c$ a global maximum exists for $f_c^* = 0$. Sixth, if $\lambda_c = 1$ then only $c_c = 0$ is consistent with constant profits $\Pi_c^B = (\phi_2+(1-\rho)\phi_1)I$, independent of f_c. Otherwise, for $c_c > 0$ and $\lambda_c = 1$, profits are decreasing in f_c and approach $(\phi_2+(1-\rho)\phi_1)\,I$ for $f_c \to -\infty$.

Proof of Proposition 4:
Solving $f_c^* = c_c$ for ϕ_2 yields:

$$\begin{aligned}\overline{\phi}_2 \;=\; & \frac{(1-\lambda_c)(1-\rho\phi_1)(1-\phi_1)-c_c(2-\rho\phi_1-\lambda_c)(1-\rho\phi_1)}{(1-\lambda_c)(1-\rho\phi_1-\lambda_c c_c^2)} + \\ & \frac{c_c^2((1-\rho\phi_1)(1+\lambda_c)+\phi_1\lambda_c(1-\phi_1))-\lambda_c c_c^3}{(1-\lambda_c)(1-\rho\phi_1-\lambda_c c_c^2)}.\end{aligned}$$

We can show that $\overline{\phi}_2 = 1-\phi_1$ when $c_c = 0$ and $d\overline{\phi}_2/dc_c < 0$ for small enough c_c and sufficiently large $\rho\phi_1$. Then there exists $\widetilde{c}_c > 0$ such that $\overline{\phi}_2 = 0$. Thus, for $0 \leq c_c \leq \widetilde{c}_c$ we have $0 \leq \overline{\phi}_2 \leq 1-\phi_1$.

Proof of Proposition 5:
First note that there is no card usage for $f_d \geq 1-\rho$, and thus debit card Ramsey welfare

is equal to cash welfare in that high price region. Second, if $\lambda_d < 1$ then Ramsey welfare is increasing for negative merchant fees. Third, for small enough $c_d \geq 0$, non-negative debit card Ramsey welfare exists, for example $W_d^R(0) = 3\phi_1 I/2 > 0$ for $c_d = 0$. Solving $dW_d^R(f_d)/df_d = 0$ (and verifying the second-order conditions) yields the socially optimal merchant fee:

$$f_d^R(c_d, \rho, \lambda_d) = \frac{(1-\rho)(2(c_d+1)\lambda_d - 3c_d)\sqrt{\lambda_d(1-\rho)x_d(c_d,\rho,\lambda_d)}}{c_d(2c_d-3)+\lambda_d(-2\lambda_d-3\rho+5)}, \quad \text{where}$$

$$x_d(c_d,\rho,\lambda_d) = 3\lambda_d\left(-\left(2c_d^2+c_d+4\right)\rho+(c_d+1)\rho^2-2c_d+3\right)+2\lambda_d^2(c_d(\rho+2)+\rho-1)+9c_d\rho(c_d+\rho-1).$$

Solving $f_d^R(c_d,\rho,\lambda_d) = 0$ for c_d yields $\underline{c}_d^R$, and solving $f_d^R(c_d,\rho,\lambda_d) = 1-\rho$ gives $\bar{c}_d^R$. Fourth, equating $\underline{c}_d^R = \bar{c}_d^R$ and solving for λ_d yields $\overline{\lambda}_d = (3\rho-1)/2$. As long as $\lambda_d \leq \overline{\lambda}_d$, it holds that $\underline{c}_d^R \leq \bar{c}_d^R$. Hence, if $0 \leq c_d < \underline{c}_d^R$ then $f_d^R = 0$, else if $\underline{c}_d^R \leq c_d \leq \bar{c}_d^R$ then $0 \leq f_d^R(c_d,\rho,\lambda_d) \leq 1-\rho$. Fifth, if $1 < \lambda_d < \overline{\lambda}_d$, then $f_d^R = 0$ yields maximum Ramsey welfare, higher than cash welfare if $c_d \leq (1-\rho)/\rho$; otherwise $f_d^R = 1-\rho$ (no card use). When $\lambda_d = 1$ and $c_d = 0$ then the fee structure is fully neutral with constant Ramsey welfare $W_d^R = 3\phi_1 I/2$. Sixth, given f_d^R, that fixes merchant acceptance $\alpha(f_d^R)$ and merchant revenues, due to the zero-profit condition we must have $F_d^R(\alpha(f_d^R), f_d^R) \leq F_d^{\max}(f_d^R)$, since we can show that $\Pi_d^B(f_d^R) \geq 0$.

Proof of Lemma 3:
When $\lambda_d \leq \overline{\lambda}_d$ we verify that $0 < \underline{c}_d^R$ so that for $0 \leq c_d < \underline{c}_d^R$ we have $f_d^R = 0 < f_d^*$ and hence $\alpha^R = 1 > \alpha^*$. We can show that $\bar{c}_d^R = \bar{c}_d$ if $\lambda_d = 1$; if $\lambda_d \leq \overline{\lambda}_d$, it holds that $\bar{c}_d^R < \bar{c}_d$, so that for $\bar{c}_d^R \leq c_d < \bar{c}_d$ we find $f_d^R = 1-\rho > f_d^*$ and hence $\alpha^R = 0 < \alpha^*$.

Proof of Proposition 6:
Some algebraic manipulations verify that $f_d^R(c_d,\rho,\lambda_d) = f_d^*(c_d,\rho,\lambda_d)$ for $c_d = (1-\rho)/\rho$, and that for sufficiently large ρ both optimal fees are monotonically increasing in c_d, $0 \leq c_d \leq \bar{c}_d^R$.

Proof of Proposition 7:
First note that there is no card usage for $f_c \geq 1-\rho\phi_1$, and thus credit card Ramsey welfare is equal to cash welfare in that high price region. Second, if $\lambda_c < 1$ then Ramsey welfare is increasing for negative merchant fees. Third, for small enough $c_c \geq 0$, non-negative credit card Ramsey welfare exists, for example $W_c^R(0) = 3(\phi_1+\phi_2)I/2 > 0$ for $c_c = 0$. Solving $dW_c^R(f_c)/df_c = 0$ (and verifying the second-order conditions) yields the socially optimal merchant fee:

$$f_c^R(c_c,\rho,\phi_1,\phi_2,\lambda_c) = \frac{(2(c_c+1)\lambda_c+3c_c)(1-\rho\phi_1)\sqrt{(1-\rho\phi_1)x_c(c_c,\rho,\phi_1,\phi_2,\lambda_c)}}{c_c(3-2\lambda_c)+\lambda_c(\phi_1(2\lambda_c+3\rho-3)+2\lambda_c\phi_2-3\phi_2-2)}, \quad \text{where}$$

$$\begin{aligned} x_c(c_c,\rho,\phi_1,\phi_2,\lambda_c) \quad = \quad & (3c_c-2(c_c+1)\lambda_c)^2(1-\rho\phi_1) - \\ & (c_c((\lambda_c+3)\rho\phi_1+2\lambda_c-3)-\lambda_c((\rho-3)\phi_1-3\phi_2+2)) \times \\ & (c_c(2\lambda_c-3)+\lambda_c(\phi_1(-2\lambda_c-3\rho+3)-2\lambda_c\phi_2+3\phi_2+2)). \end{aligned}$$

Solving $f_c^R(c_c,\rho,\phi_1,\phi_2,\lambda_c) = 0$ for c_c yields $\underline{c}_c^R$, and solving $f_c^*(c_c,\rho,\phi_1,\phi_2,\lambda_c) = 1-\rho\phi_1$ gives $\bar{c}_c^R$. Fourth, equating $\underline{c}_c^R = \bar{c}_c^R$ and solving for λ_c yields $\overline{\lambda}_c = (3\rho\phi_1/(\phi_1+\phi_2)-1)/2$. As long as $\lambda_c \leq \overline{\lambda}_c$, it holds that $\underline{c}_d^R \leq \bar{c}_d^R$. Further, $\underline{c}_c^R \geq 0$ for all $0 \leq \rho \leq 1$ when $\phi_2 \geq 2/3(1-\phi_1)$. Hence, if $0 \leq c_c < \underline{c}_c^R$ then $f_c^R = 0$, else if $\underline{c}_c^R \leq c_c \leq \bar{c}_c^R$ then $0 \leq f_c^R(c_c,\rho,\phi_1,\phi_2,\lambda_c) \leq 1-\rho\phi_1$. Fifth, if $1 < \lambda_c < \overline{\lambda}_c$ (and $\phi_2 \geq \overline{\phi}_2$), then $f_d^R = 0$ yields maximum Ramsey welfare, higher than cash welfare if $c_c \leq ((1-\rho)\phi_1+\phi_2)/(\rho\phi_1)$; otherwise $f_c^R = 1-\rho\phi_1$ (no card use). When $\lambda_c = 1$ and $c_c = 0$ then the fee structure is fully neutral with constant Ramsey welfare

$W_c^R = 3(\phi_1 + \phi_2)I/2$. Sixth, given f_c^R, that fixes merchant acceptance $\beta(f_c^R)$ and merchant revenues, due to the zero-profit condition we must have $F_c^R(\beta(f_c^R), f_c^R) \leq F_c^{\max}(f_c^R)$, since $\Pi_c^B(f_c^R) \geq 0$.

Algebraic expression for F_T^{max} in section 6:

$$F_T^{max}(f_d, f_c) = \kappa I,$$

where $\kappa =$

$$\frac{{\phi_1}^2\rho^2 + \phi_1(f_d\phi_1 + f_c(\phi_1 - 2)(\lambda_c - 1) - 2)\rho + (f_c(\phi_1 - 1) - f_d\phi_1 + 1)(f_c(\lambda_c - 1) + 1)}{(f_c(\phi_1 - 1) - f_d\phi_1 + 1)(f_c(\lambda_c - 1) + 1) + \phi_1(f_d\phi_1 + f_c(\phi_1 - 1)(\lambda_c - 1) - 1)\rho}.$$

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