Endogenous Credit-Card Acceptance in a Model of Precautionary Demand for Money

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Abstract

A credit-card acceptance decision by retailers is embedded into a simple model of precautionary demand for money. The model gives a new explanation for how the use of credit-cards can differ so widely across countries. Retailers' propensity to accept cards reduces the need for buyers to hold cash as the chance of a stock-out (of cash) is reduced. When retailers make their decision with respect to credit-card acceptance they do not take into account the effect that decision has on other sellers. This externality generates multiple equilibria over some portions of the parameter space.

1 Introduction

There are large differences in the propensity to use credit-cards across countries (see Table 1). Most notably, the Japanese carry as many cards as the Americans do but they use them far less frequently. The third column also shows that the hardware needed to use credit-cards, Electronic Funds Transfer at Point of Sale (EFTPOS), are much rarer in Japan than in other developed economies. This paper considers these facts in an equilibrium model of precautionary demand for money and endogenous credit-card acceptance by retailers.

	Number of credit-cards per capita	Number of Transactions per capita	Number of EFTPOS per 1000 Inhabitants
Canada	1.3	37.5	13.3
Japan	1.9	6.5	0.1
United Kingdom	0.8	22.6	11.8
United States	1.9	68.9	8.6

Table 1

Country Indicators on credit-card Transactions for 1999[1].

Casual observation might suggest that the difference between the Japanese and American outcomes could be a consequence of the low rates of personal crime and near zero nominal rates of interest in Japan. Indeed, the paper's results are consistent with this belief. However, the model provides an additional explanation. In their choice of whether or not to accept credit-cards, individual retailers do not take account of the impact of their decision on

[1]Data are from "Statistics on payment systems in the Group of Ten countries", Bank for International Settlements, March 2001.

other retailers. We show that this externality can generate multiple equilibria. We do not incorporate any technological (network) basis for this externality. Instead, it operates entirely through the market.[2]

The basic idea is that when there is an opportunity cost of holding cash and purchasing opportunities are stochastic, a buyer may have insufficient funds at her disposal to buy what she wants. Anticipating this possibility leads to a precautionary demand for money. To the extent that retailers accept credit-cards, the chance of such a 'stock-out' of funds is diminished. The more retailers accept cards, the less buyers are inclined to carry cash which in turn increases the incentives for other retailers to accept cards.

Although their results are somewhat obfuscated by the proliferation of methods of payment, more rigorous statistical analysis of card use across countries by Humphreys *et al* [1996] indicates that country specific dummies and past usage of particular means of payment are very important in explaining current usage. These results are at least consistent with the possibility of multiple equilibria. Still, the main point of this paper is to show that such multiplicity can emerge through spillovers that operate in the market rather then being technological. While some other theoretical work has been done on card versus cash use (see Rochet and Tirole [2002], Chakravorti and To [1999] and Markose and Loke [2003]) none of them explore the source of multiplicity of equilibrium emphasized in this paper.

One feature of real payments systems that confuses the applicability of our model is the issue as to where the model stands with respect to debit-cards. Are they cash or cards? As the facility to accept credit-cards is essentially the same as that required for debit-cards we view them both as *cards*. As we have a static model, how the buyer meets a payment made on the card is moot. What matters is that a retailer's propensity to accept

[2] See McAndrews and Rob [1996] for a discussion of network externalities in the context of electronic transaction systems.

any card depends on how much cash shoppers carry which in turn depends on the other retailers' propensity to accept cards. We use the term credit-card because they have historically been more important than debit-cards for larger purchases (for which precautionary money holdings seem relevant).

In the interest of expositional clarity, Section 2 describes a preliminary version of the model in which buyers and sellers are *ex ante* homogeneous. This is the simplest environment that is able to demonstrate the precautionary demand for money and the multiplicity of equilibrium described above. These equilibria, however, involve either exclusively cash transactions or exclusively card transactions. As such this first model is too stylized to provide a meaningful interpretation of Table 1. The model of Section 3 addresses this issue by allowing for different types of retailer distinguished by the average expense of the goods in which they trade. It is shown that the results of section 2 are robust this extension and that the use of both cash and cards in realized transactions is possible in equilibrium. A further implication of this analysis is that retailers of more expensive items are more likely to accept cards.

2 The Model with Homogeneous Buyers and Sellers

The economy comprises of a continuum of individuals divided into buyers and sellers. The mass of buyers is normalized to 1 and the mass of sellers is N. The economy lasts for one period. For the purpose of exchange, buyers and sellers are randomly assigned to each other so that the expected number of buyers who enter a particular seller's establishment is $\eta = 1/N$.[3]

[3] There is a large literature which uses the search and matching framework to address monetary issues (*e.g.* Kiyotaki and Wright [1991]). A dynamical version of our baseline model is relatively straightforward to formulate. For the purpose of the current paper,

Sellers have the ability to produce any size x of a non-storable and indivisible commodity at zero cost. They cannot consume their own output, but derive utility q, if they acquire q dollars from a buyer. At the start of the period they have to decide whether or not they will accept credit-cards. To be able to accept cards they have to incur the one-time installation cost, Θ.

Buyers have match specific preferences. In particular, consumption of a good of size x gives utility,

$$U(x;s) = \begin{cases} u(s) & \text{for } x \geq s \\ 0 & \text{for } x < s \end{cases}, \text{ where } s \sim F(s).$$

The value of s is drawn after the buyer meets a seller. The distribution function $F(.)$ is continuous with support $[0, \bar{s}]$ and density $f(.)$. The function $u(.)$ is increasing, concave and $u(0) = 0$. We will refer to the realization of s as the buyer's preferred size of purchase. Buyers are also endowed with a credit-card which is costless to carry so they keep it with them at all times. Credit-cards have no spending limit.

This framework is meant to capture the notion that when people go shopping they do not know for sure what they are going to buy and that goods may not be divisible. We want to model a precautionary demand for money so we have to allow for the possibility of buyers having insufficient cash to buy their preferred good. The easiest way to do this is to assume that retailers choose whether or not to accept credit-cards and the price at which commodities trade is exogenous to the environment.[4] Specifically, the price is normalized to 1 so that an item of size x costs x dollars.

however, all we need from the search environment is anonymity - a one period random assignment model is sufficient.

[4]Pricing in this environment could be the outcome of a price-posting game played by sellers (as in Green and Zhou [1998] or Jafarey and Masters [2003]). The result of this game would be a schedule that gives the price as a function of x. Analysis of such a model adds unnecessary complications and we would still have to assume that sellers had some way of committing to their pricing functions.

At the beginning of the period, the buyer receives a nominal income Y where $Y \geq \bar{s}$, and she decides the amount, m, she wants to keep in cash. The remainder is allocated into a non-liquid investment that yields r utils for every dollar invested. More generally, we think of r as capturing the opportunity cost of carrying cash. This can include the possibility of theft, loss or damage.

Under our assumptions, at any buyer-seller meeting a transaction will take place if either the buyer holds at least s dollars or the seller accepts credit-cards. Leftover cash balances have no value but we assume that buyers spend the least amount of cash possible in order to purchase their preferred size of good. This assumption could be justified by allowing for an infinitesimal value to holding unspent money.[5]

2.1 The Buyer's Problem

In their decision over m, buyers take into account the probability that the seller they meet accepts credit-cards. Because matching is random, this probability is equal to the average propensity with which sellers accept credit-cards, $\Phi \in [0, 1]$. The expected utility of being a buyer with cash holdings m, given Φ, is

$$V_b(m, \Phi) = r(Y - m) + (1 - \Phi) \int_0^m u(s)\, dF(s) + \Phi \int_0^{\bar{s}} u(s)\, dF(s), \quad (1)$$

and, the buyer's problem is to solve for

$$m(\Phi) \equiv \arg\max_m V_b(m, \Phi). \quad (2)$$

The necessary condition for achieving an interior solution is

$$-r + (1 - \Phi)\, u(m)\, f(m) = 0,$$

[5]Of course in a dynamical version of this model, the value to holding money at the end of the period would simply reflect its future purchasing power.

the sufficient condition for achieving an interior solution is given by

$$u(m) f'(m) + u'(m) f(m) < 0.$$

To simplify the analysis we will assume differentiability of $f(.)$ and that

$$\begin{aligned} u(0) f(0) - r &> 0 \\ u(\bar{s}) f(\bar{s}) - r &< 0 \\ \frac{f'(m)}{f(m)} &< -\frac{u'(m)}{u(m)} \quad \text{for all } m \end{aligned} \tag{3}$$

The first two conditions simply provide upper and lower bounds on the range of possible values of r. The first implies that for Φ close enough to 0 there is an interior solution. The second condition implies that the precautionary motive for cash holding will be active even when $\Phi = 0$ (i.e. $m(0) < \bar{s}$). The last restriction is equivalent to imposing concavity on the maximand in equation (1). It ensures that the range of permissible values of r is non-empty and that the solution is unique. Essentially, we require that high values of s are sufficiently improbable that at some point, even if no sellers accept cards, carrying more cash is not worth its opportunity cost in savings.

Under these assumptions $m(\Phi)$ is strictly positive whenever $(1 - \Phi) u(0) f(0) > r$; otherwise $m(\Phi) = 0$. Straightforward analysis implies that at an interior solution,

$$\frac{dm}{d\Phi} = \frac{u(m) f(m)}{(1 - \Phi)[u(m) f'(m) + u'(m) f(m)]} < 0.$$

That is, buyers' demand for money reacts negatively to changes in the probability of credit-card acceptance. As the number of sellers accepting cards increases, the probability that the buyer will not be able to acquire his preferred good falls. This lowers the return to holding cash. Notice that when credit-cards are always accepted by sellers ($\Phi = 1$) buyers have no reason to hold money, $m(1) = 0$.

Also,

$$\frac{dm}{dr} = \frac{1}{(1-\Phi)\left[u(m) f'(m) + u'(m) f(m)\right]} < 0.$$

As should be expected, the demand for money varies in the opposite way to the opportunity cost of holding cash.

2.2 The Seller's Problem

Let ϕ denote the propensity with which an individual seller decides to have the card-reading equipment installed. In general, sellers each choose a value of $\phi \in [0,1]$ taking the distribution of other sellers' choices as given.[6] The value of ϕ represents a randomization the outcome of which is realized prior to matching with buyers. That is, buyers will only meet sellers that either accept cards or not. After the realization of the randomization and the installation (or not) of the equipment, a seller's original choice of ϕ is irrelevant. Card acceptance cannot be made contingent upon the money holdings of any buyers that show up. This seems reasonable, buyers with insufficient cash are unlikely to wait around while a seller gets hooked up to a credit-card network.

In their choice of ϕ, sellers take as given, m, the amount of money being carried by the buyers. In principle, Φ, the propensity with which other buyers accept credit-cards could directly influence an individual seller's choice of ϕ through a 'network externality' (*e.g.* Θ could depend on Φ). However, here Φ, will only affect the choice of ϕ indirectly through its impact on m. Let $V_s(\phi, m)$ represent the value to being a seller who decides with probability ϕ to install the card reading equipment given all buyers carry m units of money. Then,

$$V_s(\phi, m) = \eta (1-\phi) \int_0^m s dF(s) + \phi \left[\eta \int_0^{\bar{s}} s dF(s) - \Theta\right],$$

[6] As we seek a symmetric equilibrium, we allow Φ to summarize the (degenerate) distribution of other sellers' values of ϕ.

Sellers solve for

$$\tilde{V}_s(m) \equiv \max_{\phi\in[0,1]} V_s(\phi, m).$$

This partial analysis of the model from the sellers' perspective reveals that ϕ is weekly decreasing in m. That is, if we define m_c such that

$$\int_0^{\bar{s}} sdF(s) - \int_0^{m_c} sdF(s) = \frac{\Theta}{\eta}$$

then

$$m > m_c \Rightarrow \phi = 0$$
$$m = m_c \Rightarrow \phi \in [0,1]$$
$$m < m_c \Rightarrow \phi = 1$$

2.3 Equilibrium

Definition 1 *A Market Equilibrium is a pair* (m^*, ϕ^*) *that solves*

1. $m^* = \arg\max_m V_b(m, \phi^*)$, *and,*
2. $\phi^* = \arg\max_\phi V_s(\phi, m^*)$.

Three types of equilibrium are possible: pure monetary, pure credit and mixed.

In a *pure monetary equilibrium*, sellers do not accept credit-cards, $\phi^* = 0$ and $m^* = m(0)$. It exists if accepting money (weakly) dominates credit-card acceptance when no other sellers accept cards. That is whenever Θ exceeds the critical value Θ_m such that

$$\Theta_m \equiv \eta \int_0^{\bar{s}} sdF(s) - \eta \int_0^{m(0)} sdF(s) \tag{4}$$

A *pure credit equilibrium* has the form $\phi^* = 1, m^* = 0$ and exists whenever accepting cards (weakly) dominates not accepting them when all other sellers are accepting cards. That is, Θ is less than Θ_c where

$$\Theta_c \equiv \eta \int_0^{\bar{s}} sdF(s) \tag{5}$$

In any *mixed strategy equilibrium* sellers are *ex ante* indifferent between accepting cards and not accepting them. Each seller is randomly chosen, with probability $\phi^* \in (0,1)$, to accept cards and $m^* = m(\phi^*)$ such that

$$\eta \int_0^{\bar{s}} s dF(s) - \eta \int_0^{m(\phi^*)} s dF(s) = \Theta$$

where $m(.)$ is defined in equation (2).

As $\Theta_m < \Theta_c$ the regions of existence of the pure credit and the pure monetary equilibria overlap. Moreover, as $m(\phi) \leq m(0)$, mixed strategy equilibria only exist for values of Θ between Θ_m and Θ_c.

This demonstrates, in the context of this highly stylized environment, the principal result of the paper. That despite buyers all being endowed with credit-cards, the propensity of their use can vary widely across similar economies. Multiplicity of equilibrium occurs because of the inability of sellers to coordinate on a particular adoption strategy. If no seller adopts the credit-card system, buyers carry a lot of cash and it is in no single seller's interest to deviate toward credit-card acceptance. On the other hand if all other sellers accept cards, buyers carry no cash and credit-card adoption is a dominant strategy.

While the mixed strategy equilibrium is more consistent with real economies in that both cash and cards are used in realized transactions, it is unstable under heuristic dynamics[7] and has pathological comparative statics (increases in Θ lead to more credit-card acceptance). The next section therefore provides an adaptation of this basic model in which the use of both cards and cash is observed in a pure strategy equilibrium.

[7] This is a static model, the *heuristic* dynamics referred to are as follows. Suppose for some reason some infinitesimally small but strictly positive subset of buyers is expected to bring too much money shopping with them. Then, sellers would no longer be indifferent between credit-card acceptance and rejection and the equilibrium would breakdown. The other two equilibria are robust to such considerations.

3 Two Types of Seller

Here we relax the assumption of *ex ante* homogeneity among sellers. Specifically, they now differ according to the expected expense of the items buyers want from them. Buyers who are assigned to a *small* seller draw s from F_s, buyers who are assigned to a *large* seller draw s from F_l. We assume F_l first-order stochastically dominates F_s. We also assume that restrictions (3) apply for each distribution. A proportion λ of sellers are small.

3.1 The Buyer's Problem

Buyers have to decide how much of Y they want to keep in cash bearing in mind the propensity, Φ_i, for a type i seller to accept credit-cards, $i = s, l$.

Let $\hat{V}_b(m, \Phi_s, \Phi_l)$ represent the expected utility from holding m units of money given Φ_s, and Φ_l, then

$$\begin{aligned} \hat{V}_b(m, \Phi_s, \Phi_l) &= r(Y - m) + \lambda \left[\int_0^m u(s)\, dF_s(s) + \Phi_s \int_m^{\bar{s}_s} u(s)\, dF_s(s) \right] \\ &\quad + (1 - \lambda) \left[\int_0^m u(s)\, dF_l(s) + \Phi_l \int_m^{\bar{s}_l} u(s)\, dF_l(s) \right]. \end{aligned} \tag{6}$$

where $\bar{s}_i$ is the supremum of the support of F_i, $i = s, l$. The buyer's problem is to solve for

$$m^*(\Phi_s, \Phi_l) \equiv \arg\max_m \hat{V}_b(m, \Phi_s, \Phi_l). \tag{7}$$

The necessary condition for achieving an interior solution, $m^* < \bar{s}_l$, is

$$\lambda(1 - \Phi_s)\, u(m)\, f_s(m) + (1 - \lambda)(1 - \Phi_l)\, u(m)\, f_l(m) = r.$$

It should be clear that conditions (3) imply existence and uniqueness of an interior solution.[8]

[8] It is possible that m^* can exceed $\bar{s}_s$. In this range, we take $f_s(s) = 0$.

3.2 The Seller's Problem

A maintained assumption is that Sellers' utility is linear in the size of object they sell. We use ϕ_i, $i = s, l$ to represent the probability with which an individual seller has card reading equipment installed. As in the previous model, sellers individually choose ϕ_i considering the cost of accepting credit-cards, Θ, and the buyer's money holdings m. Again, because there is no imposed network externality, other sellers' propensity to accept credit-cards will only enter the private seller's decision problem through the money holding of buyers.

A type i seller's expected utility is $V_{si}(\phi_i, m)$ where,

$$\begin{aligned} V_{si}(\phi_i, m) &= \eta(1-\phi_i)\int_0^m s dF_s(s) \\ &\quad + \phi_i\left[\eta\int_0^{\bar{s}_i} s dF_i(s) - \Theta\right]. \end{aligned}$$

Again, for any given value of Θ, this implies the existence of m_{ci} where

$$\eta\int_{m_{ci}}^{\bar{s}} s dF_i(s) = \Theta$$

so that

$$\begin{aligned} m > m_{ci} &\Rightarrow \phi_i = 0 \\ m = m_{ci} &\Rightarrow \phi_i \in [0,1] \\ m < m_{ci} &\Rightarrow \phi_i = 1 \end{aligned}$$

Stochastic dominance of F_l over F_s means that $m_{cs} \leq m_{cl}$.

3.3 Equilibrium

Definition 2 *A Market Equilibrium, with two types of firm is a triple,* $(m^*, \phi_s^*, \phi_l^*)$, *such that*

1. $m^* = \arg\max_m \hat{V}_b(m, \phi_s^*, \phi_l^*)$,

2. $\phi_i^* = \underset{\phi_i \in [0,1]}{\arg\max} V_{si}\left(\phi_i, m^*\right) \; for \; i = s, l$

We will focus the discussion on pure strategy equilibria of which there are, potentially, four - each seller type can either accept or reject credit-cards. That is, pure strategy equilibria can be summarized by $(\phi_s^*, \phi_l^*) \in \{0,1\} \times \{0,1\}$. We will posit an equilibrium and look for the range of acceptance of each equilibrium in Θ space given the other parameters and the functional forms of u, and F_i, $i = s, l$.

First, notice that $m_{cs} \leq m_{cl}$ means an equilibrium of type (1,0), in which small sellers accept cards and large ones do not, cannot exist. This leaves three possibilities for pure strategy equilibria:

(1) Pure credit equilibrium, type (1,1)

From (7) $m(1,1) = 0$, so $(\phi_s^*, \phi_l^*) = (1,1)$ is an equilibrium whenever it is individually rational accept cards given no one is carrying any money. As F_l stochastically dominates F_s, this is true for all $\Theta \leq \Theta_1$ where

$$\Theta_1 \equiv \eta \int_0^{\bar{s}_s} s dF_s\left(s\right).$$

(2) Pure monetary equilibrium, type (0,0)

From (7) $m(0,0) \equiv \hat{m}$ where

$$\lambda u\left(\hat{m}\right) f_s\left(\hat{m}\right) + \left(1 - \lambda\right) u\left(\hat{m}\right) f_l\left(\hat{m}\right) = r.$$

As type l sellers have the most to gain from credit-card adoption their decision to switch out of accepting money is critical to the existence of this equilibrium. In particular, for a type l seller to conform to this equilibrium we need $\Theta \geq \Theta_2$ where

$$\Theta_2 \equiv \eta \int_{\hat{m}}^{\bar{s}_l} s dF_l\left(s\right)$$

(3) Hybrid Equilibrium, type (0,1)

From (7) $m(0,1) \equiv m_1$ where

$$\lambda u\left(m_1\right) f_s\left(m_1\right) = r.$$

Existence requires that when buyers are carrying m_1 units of money, Θ is sufficiently large that small sellers do not choose to accept cards but is also sufficiently small that large sellers do choose to accept cards. That is, this equilibrium exists whenever Θ is in the range $[\Theta_3, \Theta_4]$ where

$$\Theta_3 \equiv \eta \int_{m_1}^{\bar{s}_s} sdF_s(s), \quad \Theta_4 \equiv \eta \int_{m_1}^{\bar{s}_l} sdF_l(s).$$

Stochastic dominance implies[9]

$$\int_{m}^{\bar{s}_l} sdF_l(s) \geq \int_{m}^{\bar{s}_s} sdF_s(s) \text{ for all } m$$

This means that $\Theta_3 \leq \Theta_4$. Each of the equilibria therefore exists for some range of Θ.

From (3) it follows that $\hat{m} \geq m_1$ so $\Theta_3 \leq \Theta_1$ and $\Theta_4 \geq \Theta_2$. This means that: at least one equilibrium exists for each value of Θ; the pure-credit and the hybrid equilibria coexist for values of Θ between Θ_3 and $\min\{\Theta_1, \Theta_4\}$; the pure-monetary equilibrium and the hybrid equilibrium coexist between $\max\{\Theta_2, \Theta_3\}$ and Θ_4.

If $\Theta_1 < \Theta_2$ (which happens if the seller types are sufficiently different), between Θ_1 and Θ_2 the hybrid equilibrium is the unique pure-strategy equilibrium. Otherwise the hybrid equilibrium coexists with at least one other equilibrium and all three equilibria coexist between $\max\{\Theta_2, \Theta_3\}$ and $\min\{\Theta_1, \Theta_4\}$.

The upshot from this section is that by allowing for multiple types of seller, pure strategy (i.e. dynamically stable) equilibria in which buyers anticipate making purchases with either cash or credit-cards can be supported.

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[9] Integration by parts yields

$$\int_{m}^{\bar{s}_i} sdF_i(s) = \bar{s}_i - mF_i(m) - \int_{m}^{\bar{s}_i} F_i(s)ds$$

The result follows as $\bar{s}_l \geq \bar{s}_s$ and $F_l(m) \leq F_s(m)$.

These equilibria always exist over a positive portion of the parameter space and involve larger sellers accepting cards while smaller ones do not. Equilibria in which larger sellers only accept cash while smaller ones accept cards are ruled out.

4 Concluding Remarks

We have developed a model that gives a new explanation for how the use of credit-cards can differ widely across countries. Stochastic purchasing opportunities lead to a precautionary demand for holding money. Holding credit-cards means that, to the extent sellers accept them, buyers can avoid stocking-out of funds to meet their purchases. Buyers propensity to hold cash is decreasing the probability that any seller accepts cards. This generates an externality between sellers because the incentive to accept cards increases as the amount of cash held by buyers falls.

The simplest environment exhibits two extreme pure-strategy equilibria in which either cards are never used or cash is never carried. As these outcomes are clearly counterfactual the environment was extended to include two-types of seller. In this model, it is shown that pure-strategy equilibria exist in which all buyers hold money even though some transactions are carried out using cards. In such equilibria, sellers of large items accept cards while sellers of small items require cash. As such, this extended environment also provides a testable empirical prediction: that, all else equal, retailers of more expensive items (such as furniture) are more likely to accept credit-cards than retailers of cheaper items (such as newspapers).

In order to focus on the above results the model was necessarily abstract. One direction to extend this analysis is the incorporation of a strategic role for the credit-card issuer. A more complete model should also allow for price effects. For instance, here we assume that the seller bears all the cost of the credit-card system. In realty, it is likely that sellers are able to pass some of the cost of the system on to buyer through increased prices. This could be true even if sellers are banned from explicitly charging different prices for goods bought with cards. Such explorations are left for future work.

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