Journal of Macroeconomics 47 (2016) 270–280

Contents lists available at ScienceDirect

Journal of Macroeconomics

journal homepage: www.elsevier.com/locate/jmacro

Who should bear the resource cost of electronic transaction?

Young Sik Kim[a], Manjong Lee[b,*]

[a] Department of Economics, Seoul National University, Gwanak-ro, Gwanak-gu, Seoul 151-742, South Korea
[b] Department of Economics, Korea University, Anam-dong, Seongbuk-gu, Seoul 136-701, South Korea

ARTICLE INFO

Article history:
Received 4 June 2015
Accepted 13 October 2015
Available online 22 November 2015

JEL Classification:
E31
E40
E42

Keywords:
Cash
Electronic payment
Resource cost

ABSTRACT

Using a search theoretic model of money, we examine an optimal allocation of the resource cost of electronic transaction. A transaction using cash incurs a buyer its carrying cost, while an electronic transaction incurs data-processing cost to the payment platform which then raises the resource cost from buyers or sellers using the electronic payment system. An equilibrium allocation of the resource cost implies the seller-take-all-burden scheme by which the payment platform can maximize the volume of electronic transactions by raising the resource cost only from sellers. However, the socially optimal allocation of the resource cost implies the buyer-take-all-burden scheme by which the resource cost should be raised only from buyers in order to maximize welfare.

1. Introduction

As the electronic means of payment such as credit card and debit card are used widely for in-store purchases, the cost of electronic transaction has called attention from retailers, consumers, payment networks, and policymakers. For those parties involved in electronic transactions (e.g., retailers, consumers, payment networks), this cost mainly consists of two parts: one is the resource cost incurred from record keeping and information processing on the transaction involved, and the other is the fees paid by one party to another. From the societal point of view, the latter is a zero-sum in the sense that the fees paid by one party are cancelled out by the fees received by another, whereas the former requires additional resources. Hence, policymakers who have an interest in an efficient allocation of resources have raised particular concerns about the resource cost of electronic transaction. (See, for instance, Hayashi and Keeton (2012);Schmiedel et al. (2012).)[1]

In this paper, we examine such a resource cost of electronic transaction due to information processing, which has the feature of a fixed per-transaction cost independent of the transaction amount. In order to do that, we consider a model economy in which debit-card transactions are available but unsecured credit-card transactions are ruled out. As pointed out properly by Lotz and Zhang (2013), there are vital distinctions between credit card and debit card. First of all, credit card is an unsecured "pay-later" card which involves the cost due to "payment guarantee services" other than the resource cost mentioned above. Partly due to this feature, credit-card fees are typically *ad valorem*. On the other hand, debit card is a "pay-now" card and there seems to be

* Corresponding author. Tel.: +82 2 3290 2223; fax: +82 2 3290 2200.
E-mail addresses: kimy@snu.ac.kr (Y.S. Kim), manjong@korea.ac.kr (M. Lee).

[1] There is a relatively large literature that has focused on the issues related to the surcharge and interchange fees (e.g., Rochet and Tirole (2002); Schmalensee (2002); Gans and King (2003); Wright (2004); Schwartz and Vincent (2006); Monnet and Roberds (2008); Prager et al. (2009); Bolt et al. (2010); Rochet and Wright (2010); Verdier (2011); Shy (2012), and Wright (2012)).

http://dx.doi.org/10.1016/j.jmacro.2015.10.010
0164-0704/

a wide agreement that a debit-card transaction incurs a fixed processing cost (e.g., Wang (2010)). This suggests that the cost of debit-card transaction is mainly composed of the resource cost that we are interested in.

We also note that in the real world, a payment platform (e.g., debit network) typically raises the resource cost only from retailers. We first investigate whether this is indeed an optimal scheme of raising the resource cost on the part of a payment platform who maximizes the usages or volume of electronic transactions. This appears to be a plausible objective of a payment platform, considering that debit networks, for example, charge a flat processing markup called a PIN-debit fee. We then ask the efficiency or social optimality of the payment platform's raising scheme by looking into the problem of a social planner who maximizes welfare defined as a lifetime discounted utility of a representative agent.

More specifically, we construct a standard search theoretic model in which money is essential as a medium of exchange and agents can make debit-card transactions via electronic transfer of money as well as cash transactions. In a decentralized market, sellers (retailers) first post prices and then a submarket is formed according to the posted prices. Buyers (consumers) direct their search toward a most attractive submarket where each buyer is randomly matched with a seller. In all pairwise meetings, trades are *quid pro quo* and either cash or checking account deposits should be transferred from a buyer to a seller. A cash transaction incurs cash-carrying cost to a buyer, whereas an electronic transaction incurs data-processing cost to the payment platform which then raises the cost from a buyer and a seller involved in the trade.

The main results are as follows. The payment platform should raise the resource cost only from sellers (seller-take-all-burden scheme) in order to maximize the volume of electronic transactions. Buyers are then willing to make transactions using an electronic payment instrument regardless of the magnitude of its resource cost because using cash only incurs its carrying cost without any benefit compared to using an electronic payment instrument. This prediction is consistent with the aforementioned observation from the real world: i.e., debit networks in the U.S. charge fees only on retailers but the retailers are not typically allowed to impose a surcharge for purchases made using debit cards.

In contrast, however, it turns out that a buyer-take-all-burden scheme is socially efficient. That is, in order to maximize the welfare, the resource cost should be raised only from buyers. Intuitively, a scheme that raises (a fraction of) the cost from sellers is distortionary in the sense that it decreases consumption as sellers eventually pass on the resource cost to buyers by charging a higher price of consumption goods. On the other hand, under the buyer-take-all-burden scheme, there is no room for such a pass-through channel and each buyer chooses the means of payment by comparing the cost incurred from a cash transaction with that from an electronic transaction.

In a nutshell, we show that there exists a wedge between an equilibrium allocation of the resource cost of electronic transaction and its efficient or socially optimal allocation. This is analogous to a strand of industrial-organization literature which shows a wedge between the profit-maximizing interchange fee and the welfare-maximizing interchange fee in the two-sided markets. (See, for instance, Verdier (2011) for an extensive survey.) In particular, Wright (2012) shows that a profit-maximizing card platform sets the fee in favor of cardholders so that retailers end up paying too much. This implies that social welfare can be improved upon by increasing card fees and reducing merchant fees, which basically shares the same spirit with the implications of our key results. The main difference is that we focus on the fixed social resource cost of electronic transaction rather than its private costs in the context of a macroeconomic model where money is essential as a medium of exchange in the presence of search frictions.

The paper is organized as follows. Section 2 describes the model economy. Section 3 characterizes a stationary monetary equilibrium. Section 4 compares the welfare across different equilibria and discusses an optimal cost-raising scheme that maximizes welfare. Section 5 discusses the robustness of our main result under different pricing mechanisms such as the generalized Nash bargaining and the Walrasian price taking. Section 6 summarizes the paper with a few concluding remarks.

2. Model

The background environment comes from Lagos and Wright (2005). Time is discrete and in each period, there are 2 subperiods, morning and afternoon. A unit mass of infinitely-lived agents trade the "CM-good" in a centralized market (CM) which opens in the morning and the "DM-good" in a decentralized market (DM) which opens in the afternoon. Both goods are divisible and perishable. There is another object called money that is divisible, durable and intrinsically useless.

In the morning, all agents can produce and consume the CM-good. The utility from consuming g units of the CM-good is given by $v(g)$ where $v'' < 0 < v'$, $v(0) = 0$, $v'(0) = \infty$, and $v'(\infty) = 0$. The disutility from producing g units of the CM-good is given by g according to a linear production technology. Upon opening the CM, new money is injected by lump-sum transfers. That is, the money stock evolves according to $M_t = \mu M_{t-1}$ where M_t denotes the stock of money in the period-t CM and $\mu > \beta$ with $\beta \in (0, 1)$ denoting the discount factor between the morning and the afternoon.[2] Each agent then trade in the CM and chooses the money balance that is carried into the afternoon. Money can be kept in the form of either cash or checking-account deposits. The information on checking accounts is managed by a payment platform (i.e., a provider of electronic payment service) which has technology for record keeping of the accounts only from the current CM to the next morning before the new CM opens. This limited record-keeping technology, as we will see later, makes us avoid unnecessary complexity by allowing electronic transactions only in the DM.

[2] The discounting is not between the afternoon and the next morning. As in Rocheteau and Wright (2005), for instance, all that matters is the total discounting between one period and the next.

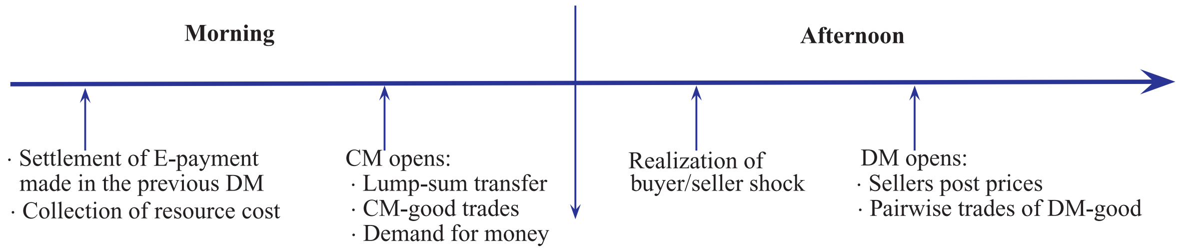

Fig. 1. Timing of events within a representative period.

At the beginning of each afternoon, an agent receives one of the two equally probable preference shocks such that with probability one half an agent can consume the DM-good but cannot produce the DM-good (i.e., a buyer) and with the remaining probability an agent can produce the DM-good but cannot consume the DM-good (i.e., a seller). The utility from consuming Q units of the DM-good is given by $u(Q)$ where $u'' < 0 < u'$, $u(0) = 0$, $u'(0) = \infty$, and $u'(\infty) = 0$. As in the CM, an agent suffers disutility Q from producing Q units of the DM-good.

After the realization of the preference shock (either a buyer or a seller), sellers competitively post prices of the DM-good. A submarket is then formed by a set of sellers posting the same price. Upon observing the posted prices of all submarkets, each buyer directs towards a submarket that posts the most attractive terms of trade. In each submarket, buyers and sellers are randomly matched according to the matching function $\alpha = \min\{1, \lambda\}$ and trade according to the posted price where λ denotes the ratio of sellers to buyers in the submarket.

Noting that the payment platform can record information only on transaction accounts, trading histories in pairwise meetings are private. Furthermore, agents cannot commit to future actions. Therefore, all trades in the DM are spot trades and buyers should transfer money in exchange for the DM-good. [3] A buyer can pay in cash (hereinafter "C-payment") by carrying it to the DM at the disutility cost of η per unit of real balance or by withdrawing it from her account at the same disutility cost.[4] This conveniently allows us to focus on the case where agents carry all the money from the CM to the DM in the form of deposits. (In Section 4, we also discuss the case in which sellers accepting cash incur some cash-handling cost.)

A buyer can also make a transaction using the electronic payment system (hereinafter "E-payment"), in which the payment platform checks the balance in the buyer's account and approves the transaction only if the balance is enough to make the transaction. An approved E-payment is cleared in the subsequent morning by transferring the relevant transaction amount from the buyer's account to the seller's account which incurs the platform per-transaction cost Ω in terms of the CM-good. This Ω contains the information-processing cost as well as a constant depreciation cost of the system. The platform chooses (τ_b, τ_s) to maximize the volume of electronic transactions where $\tau_b \in [0, 1]$ is the fraction of Ω raised from the buyer using E-payment and $\tau_s = (1 - \tau_b) \in [0, 1]$ is that from the seller using E-payment. E-payment traders pay the cost to the platform by producing the CM-good when the relevant E-payment is finally settled before the CM opens in the next period. At the settlement, the platform redeems the remaining balance in the account to each agent because the information on the existing accounts is wiped out once the new CM opens. Therefore, all the agents enter the CM with money only to carry out transactions using cash. As mentioned, this simplifies our analysis substantially because electronic transactions are made only in the DM.

Finally, an agent's period-t utility is assumed to be separable between the sub-periods such that

$$[v(g_t) - g_t - \tau_b\Omega\mathbb{I}^b_{t-1} - \tau_s\Omega\mathbb{I}^s_{t-1}] + \beta[u(Q_t) - Q_t - \eta z_t\mathbb{I}^c_t] \quad (1)$$

where $\mathbb{I}^b_{t-1} = 1$ ($\mathbb{I}^s_{t-1} = 1$) if and only if an agent as a buyer (seller) makes an electronic transaction in the previous DM at $t-1$, z_t represents the real balances of money carried into the DM, and $\mathbb{I}^c_t = 1$ if and only if an agent as a buyer in the current DM makes a cash transaction.

The timing of events within a representative period is summarized in Fig. 1. In the morning, E-payments made in the previous period are settled together with the collection of the fixed resource cost for E-payments from buyers and sellers involved in trades in the previous period. Then the CM opens and new money is injected in a lump-sum fashion. An agent trades the CM-good and chooses the money balance carried into the afternoon for trade in the DM. In the afternoon, the preference shock is realized so that each agent becomes either a buyer or a seller in the DM. Sellers then post prices and a submarket is formed by sellers posting the same price. Buyers direct their search toward a most attractive submarket where each buyer is randomly matched with a seller and chooses between C-payment and E-payment. Finally, a matched pair of buyer and seller trade according to the posted terms of trade.

[3] See, for instance, Kocherlakota (1998), Wallace (2001), Corbae et al. (2003), and Aliprantis et al. (2007).

[4] This disutility cost can be interpreted as capturing the inconvenience of carrying cash around, the risk of loss or theft, and the foregone interest (see, for instance, Baumol (1952); Tobin (1956); Humphrey (2004), He et al. (2008), and Monnet and Roberds (2008)).

3. Equilibrium

We here focus on a stationary monetary equilibrium in which the real balances of money in the CM are constant over periods: i.e., $\phi_{t-1}M_{t-1} = \phi_t M_t$ where ϕ is the real price of money in terms of the CM-good. Hereinafter we drop the time subscript t and index the next-period (previous period) variable by $+1$ (-1) if there is no risk of confusion.

3.1. Money demand

At the beginning of each morning, E-payments made in the previous DM are settled and checking-account balances are cleared. Agents then enter the CM where they trade the CM-good and choose the real balances of money to be carried into the DM in the afternoon. Let $W(z_m, z_e)$ denote the value function at the beginning of the *morning* for an agent having m units of money and e amount of unsettled E-payment balances whose real values in terms of the CM-good are respectively $z_m \equiv \phi m$ and $z_e \equiv \phi e$. Then, for a given (τ_b, τ_s), $W(z_m, z_e)$ can be expressed as

$$W(z_m, z_e) = \max_{(x,y,z_{\tilde{m}})} [\upsilon(x) - y + \beta V(z_{\tilde{m}})] \tag{2}$$

$$\text{s.t. } x + z_{\tilde{m}} + \tau_b \Omega \mathbb{I}^b_{-1} + \tau_s \Omega \mathbb{I}^s_{-1} = y + z_m + z_e + T. \tag{3}$$

Here $z_{\tilde{m}}$ is the real balance of money to be carried into the DM, x (y) is the CM-good consumption (production), and $T = \phi(\mu - 1)M_{-1}$ is the real lump-sum transfer. Notice that $z_e < 0$ denotes the case in which an agent as a buyer makes an electronic transaction in the previous DM ($\mathbb{I}^b_{-1} = 1$), whereas $z_e > 0$ implies $\mathbb{I}^s_{-1} = 1$. Finally, $V(z_{\tilde{m}})$ is the value function for an agent entering the DM with $z_{\tilde{m}}$, which is given by

$$V(z_{\tilde{m}}) = \frac{1}{2}[V^b(z_{\tilde{m}}) + V^s(z_{\tilde{m}})] \tag{4}$$

with $V^b(\cdot)$ and $V^s(\cdot)$ denoting the value function for a buyer and a seller in the afternoon, respectively. Substituting y from the constraint (3), we have

$$W(z_m, z_e) = (z_m + z_e + T) - [\tau_b \Omega \mathbb{I}^b_{-1} + \tau_s \Omega \mathbb{I}^s_{-1}] + \max_x \{\upsilon(x) - x\} + \max_{z_{\tilde{m}}} \{\beta V(z_{\tilde{m}}) - z_{\tilde{m}}\}. \tag{5}$$

The first order condition for x is

$$\upsilon'(x) = 1. \tag{6}$$

That is, all the agents consume x^* units of the CM-good such that $x^* = \arg\max[\upsilon(x) - x]$ regardless of (z_m, z_e). The first order condition for $z_{\tilde{m}} \in \mathbb{R}_{++}$ is

$$\beta V'(z_{\tilde{m}}) = 1 \tag{7}$$

which implies that there is no wealth effect and all the agents exit the CM with the identical real balances of money. Finally, the envelope condition is $W'_1 = W'_2 = 1$, implying that the value function $W(\cdot)$ is linear with respect to the net real balances of money ($z \equiv z_m + z_e$) as in a typical Lagos–Wright model with quasi-linear preference.

3.2. Trade and payment

At the beginning of the afternoon, the preference shock is realized such that a half of agents become sellers and the rest become buyers. When the DM opens, sellers post prices. Specifically, by posting price q, a seller commits to produce q units of the DM-good in exchange for a unit of real balance to be received before the beginning of the CM in the next period. A seller chooses q to maximize her payoff from the subsequent trade with a buyer. Hence, the value function for a seller with the real balances $z_{\tilde{m}}$ in the DM, $V^s(z_{\tilde{m}})$ in (4), should satisfy

$$V^s(z_{\tilde{m}}) = \max_q \{-z_{\hat{m}}\mu^{-1}q - \tau_s \Omega \mu^{-1}\mathbf{I} + W[z_{\tilde{m}}\mu^{-1} + z_{\hat{m}}\mu^{-1}(1 - \mathbf{I}), z_{\hat{m}}\mu^{-1}\mathbf{I}]\} \tag{8}$$

where $\mathbf{I} = 1$ ($\mathbf{I} = 0$) is the case where her trading partner (i.e., buyer) in a pairwise meeting chooses E-payment (C-payment) and $\hat{m}$ is the monetary payment from a matched buyer.

Notice that $z_{\hat{m}}\mu^{-1} - (z_{\hat{m}}\mu^{-1}q + \tau_s\Omega\mu^{-1})$ and $z_{\hat{m}}\mu^{-1} - z_{\hat{m}}\mu^{-1}q$ are respectively the seller's gains from a pairwise trade for $\mathbf{I} = 1$ and $\mathbf{I} = 0$. Hence, a seller is willing to participate in the DM for a trade with a buyer as long as $z_{\hat{m}}\mu^{-1} \geq (z_{\hat{m}}\mu^{-1}q + \tau_s\Omega\mu^{-1})$ for $\mathbf{I} = 1$ and $z_{\hat{m}}\mu^{-1} \geq z_{\hat{m}}\mu^{-1}q$ for $\mathbf{I} = 0$. Otherwise, it would be cheaper for a seller to acquire money in the next-period CM and hence there would be no reason to participate in the current DM.

Noting that sellers are identical and competitive, they eventually choose to post the same price q. This means that sellers all together form a single submarket where all buyers are willing to visit. Therefore, the measure of buyers (i.e., a half) is equal to the measure of sellers in the submarket, which immediately implies $\alpha = 1$ and each buyer is always matched with a seller. Notice also that, as we will see later, $\mu > \beta$ implies a strictly positive opportunity cost of holding money and hence an agent is not willing to carry the real balances into the DM in excess of $\bar{z}$ such that $\bar{z}\mu^{-1}q = Q^* = \arg\max[u(Q) - Q]$.

The seller's participation constraint from (8) for $\mathbf{I} = 0$, $z_{\hat{m}}\mu^{-1} \geq z_{\hat{m}}\mu^{-1}q$, yields

$$q \leq 1. \tag{9}$$

Similarly, the seller's participation constraint for $\mathbf{I} = 1$, $z_{\hat{m}}\mu^{-1} \geq (z_{\hat{m}}\mu^{-1}q + \tau_s\Omega\mu^{-1})$, yields

$$q \leq \frac{z_{\hat{m}} - \tau_s\Omega}{z_{\hat{m}}}. \tag{10}$$

Since a seller should post the price before she is matched with a buyer, (9) and (10) imply that the participation constraint for a seller in the DM is reduced to

$$q \leq (1 - \mathbf{I}_p) + \mathbf{I}_p\left(\frac{z_{\hat{m}} - \tau_s\Omega}{z_{\hat{m}}}\right) \tag{11}$$

where $\mathbf{I}_p$ is the probability that her matching partner(i.e., a buyer) will make E-payment. Then competition among the sellers subject to (11) makes them choose

$$q = (1 - \mathbf{I}_p) + \mathbf{I}_p\left(\frac{z_{\hat{m}} - \tau_s\Omega}{z_{\hat{m}}}\right). \tag{12}$$

Now, for a given posted price q, the value function for a buyer with $z_{\tilde{m}}$ in the DM, $V^b(z_{\tilde{m}})$ in (4), should satisfy

$$V^b(z_{\tilde{m}}) = \max_{\mathbf{I}}\{\mathbf{I}[u(\mu^{-1}z_{\tilde{m}}q) + W(z_{\tilde{m}}\mu^{-1}, -z_{\tilde{m}}\mu^{-1}) - \tau_b\Omega\mu^{-1}] + (1 - \mathbf{I})[u(\mu^{-1}z_{\tilde{m}}q) + W(0, 0) - \eta z_{\tilde{m}}]\}. \tag{13}$$

With a tie-breaking rule by which a buyer chooses E-payment if it does not make her worse off, (13) immediately implies that

$$\mathbf{I} = \begin{cases} 1 & \text{if } \tau_b\Omega\mu^{-1} \leq \eta z_{\tilde{m}}, \\ 0 & \text{otherwise} \end{cases} \tag{14}$$

where we use the linearity of W. According to (14), a higher inflation rate (μ) and a lower E-payment cost (Ω) are more likely to encourage E-payments, while a lower cash-carrying cost (η) will boost C-payments.

3.3. Collection of resource cost

We turn to the problem of the payment platform which chooses (τ_b, τ_s) to maximize the volume of electronic transactions. Since a buyer in the DM is willing to transfer all her money to a matched seller regardless of the choice of payment instruments (i.e, E-payment or C-payment), the volume of electronic transactions will be maximized if the frequency of E-payments is maximized. The payment platform then chooses $\tau_s = 1$ and $\tau_b = 0$ (seller-take-all-burden scheme) because $\mathbf{I} = 1$ in (14) for any $\eta \geq 0$ if $\tau_b = 0$. That is, if the platform raises the resource cost only from sellers, every buyer is willing to choose E-payment regardless of (Ω, μ, η).

Now, a stationary monetary equilibrium can be characterized as follows. Since $\tau_b = 0$, $\mathbf{I} = 1$ from (14) and then (12), together with $\mathbf{I}_p = 1$ and $\tau_s = 1$, implies

$$q_s^* = 1 - \frac{\Omega}{z_{\hat{m}}}. \tag{15}$$

This appears to be in line with the popular argument that if the platform charges a higher fee to sellers, buyers will use an electronic payment instrument more frequently and the price of good paid by buyers will increase (see, for instance, Wright (2012)). Also, the following value functions are obtained from (4) and (5):

$$W(z_m, z_e) = (z_m + z_e + T - \Omega\mathbb{I}^s_{-1}) + \{v(x^*) - x^*\} + \max_{z_{\tilde{m}}}\{\beta V(z_{\tilde{m}}) - z_{\tilde{m}}\} \tag{16}$$

$$V(z_{\tilde{m}}) = \frac{1}{2}\left[V^b(z_{\tilde{m}}) + V^s(z_{\tilde{m}})\right] \tag{17}$$

where, from (8) and (13), $V^s(z_{\tilde{m}})$ and $V^b(z_{\tilde{m}})$ are respectively given by:

$$V^s(z_{\tilde{m}}) = -\frac{z_{\tilde{m}}q_s^* - \Omega}{\mu} + W\left(\frac{z_{\tilde{m}}}{\mu}, \frac{z_{\tilde{m}}}{\mu}\right) \tag{18}$$

$$V^b(z_{\tilde{m}}) = u\left(\frac{z_{\tilde{m}}q_s^*}{\mu}\right) + W\left(\frac{z_{\tilde{m}}}{\mu}, -\frac{z_{\tilde{m}}}{\mu}\right). \tag{19}$$

Finally, (7) gives the following optimal condition for the real balances of money $z_{\tilde{m}}$:

$$\left(\frac{\mu - \beta}{\beta}\right) = \frac{1}{2}\left[u'\left(\frac{z_{\tilde{m}} - \Omega}{\mu}\right) - 1\right]\left(\frac{z_{\tilde{m}} - \Omega}{z_{\tilde{m}}}\right) \tag{20}$$

where $[(z_{\tilde{m}} - \Omega)/\mu] \equiv Q_{\tau_s=1} < Q^* \equiv \arg\max[u(Q) - Q]$ because $\mu > \beta$. The left-hand side in (20) is the opportunity cost of additional real balances, whereas the right-hand side is the marginal utility of consumption due to additional real balances net of the resource cost of electronic transaction. Notice that the consumption $Q_{\tau_s=1} \equiv (z_{\tilde{m}} - \Omega)/\mu$ in (20) indicates a distortionary feature of the seller-take-all-burden scheme ($\tau_s = 1$) in the sense that the resource cost (Ω) affects quantity consumed using the electronic payment instrument.

Proposition 1. *For given* (Ω, η, μ), *a stationary monetary equilibrium can be characterized as follows: (i)* $\tau_b = 0$ *and* $\tau_s = 1$, *(ii)* $\mathbf{I} = \mathbf{I}_p = 1$, *(iii)* $(x, q, W, V, z_{\tilde{m}})$ *satisfy (6) and (15)–(20), and (iv)* $\tilde{m}_t = M_t$ *for all t.*

This equilibrium prediction is broadly consistent with the common observation in the real world that, in order to expand the adoption of debit cards as much as possible, a debit network typically imposes a fixed per-transaction fee only on retailers.

4. Optimality of equilibrium allocation

In order to see whether the equilibrium allocation characterized in Proposition 1 is efficient, we here consider the problem of the social planner who chooses (τ_b, τ_s) to maximize welfare $\mathbf{W}$ defined as a lifetime discounted utility of a representative agent:

$$\mathbf{W} = \left(\frac{1}{1-\beta}\right)\left\{\frac{1}{2}[u(Q) - Q - \Omega\mathbf{I} - \eta z(1-\mathbf{I})] + [v(x^*) - x^*]\right\} \tag{21}$$

where z denotes the constant real balance of money in the relevant stationary equilibrium. Specifically, the social planner chooses (τ_b, τ_s) to maximize welfare given by (21) taking into account its effect on the equilibrium reactions of buyers and sellers in pairwise trades. The social planner's choice of (τ_b, τ_s) can be interpreted as raising the resource cost (Ω) only from sellers ($\tau_s = 1$) or only from buyers ($\tau_b = 1$) or from both buyers and sellers [$\tau_b \in (0, 1)$, $\tau_s \in (0, 1)$], so that the implied equilibrium yields the highest welfare.

We have already characterized a stationary monetary equilibrium with a seller-take-all-burden scheme ($\tau_s = 1$) in Proposition 1. In order to compare the welfare of an equilibrium for $\tau_s = 1$ with those for $\tau_s \in [0, 1)$ and find $\tau_s^* = \arg\max_{\tau_s \in [0,1]} \mathbf{W}$, we start with the characterization of an equilibrium with a buyer-take-all-burden scheme ($\tau_b = 1$ and $\tau_s = 0$).

4.1. Equilibrium with buyer-take-all-burden scheme

Suppose the social planner chooses to raise the resource cost (Ω) only from buyers ($\tau_b = 1, \tau_s = 0$). Then the seller's participation constraint (12) implies

$$q_b^* = 1. \tag{22}$$

This is the largest possible q subject to the seller's participation constraint so that buyers get the most favorable terms of trade. Unlike the seller-take-all-burden scheme, however, buyers in the DM now choose whether to use cash or an electronic payment instrument by comparing the magnitudes of cash-carrying cost (η) with electronic transaction cost (Ω).

4.1.1. Electronic transactions

We first characterize a stationary equilibrium for $\tau_b = 1$ where buyers in the DM make transactions by transferring money electronically. Since $\mathbf{I} = 1$ in this equilibrium, the value functions (4) and (5) should satisfy respectively

$$W(z_m, z_e) = \left(z_m + z_e + T - \Omega\mathbb{I}_{-1}^b\right) + \{v(x^*) - x^*\} + \max_{z_{\tilde{m}}}\{\beta V(z_{\tilde{m}}) - z_{\tilde{m}}\} \tag{23}$$

$$V(z_{\tilde{m}}) = \frac{1}{2}[V^b(z_{\tilde{m}}) + V^s(z_{\tilde{m}})] \tag{24}$$

where $V^s(z_{\tilde{m}})$ and $V^b(z_{\tilde{m}})$ are respectively given by the followings from (8) and (13):

$$V^s(z_{\tilde{m}}) = -\frac{z_{\tilde{m}} q_b^*}{\mu} + W\left(\frac{z_{\tilde{m}}}{\mu}, \frac{z_{\tilde{m}}}{\mu}\right) \tag{25}$$

$$V^b(z_{\tilde{m}}) = u\left(\frac{z_{\tilde{m}} q_b^*}{\mu}\right) + W\left(\frac{z_{\tilde{m}}}{\mu}, -\frac{z_{\tilde{m}}}{\mu}\right) - \frac{\Omega}{\mu}. \tag{26}$$

Finally, (7) implies that the real balances of money $z_{\tilde{m}}$ are implicitly determined by

$$\left(\frac{\mu - \beta}{\beta}\right) = \frac{1}{2}\left[u'\left(\frac{z_{\tilde{m}}}{\mu}\right) - 1\right] \tag{27}$$

where $\mu > \beta$ implies $(z_{\tilde{m}}/\mu) \equiv Q_{\tau_b=1}^e < Q^* \equiv \arg\max[u(Q) - Q]$. The left-hand side in (27) is the opportunity cost of additional real balances, whereas the right-hand side is the marginal utility of consumption due to additional real balances where the consumption is given by $Q_{\tau_b=1}^e \equiv (z_{\tilde{m}}/\mu)$. It is worth noting that, unlike the seller-take-all-burden scheme ($\tau_s = 1$), the buyer-take-all-burden scheme ($\tau_b = 1$) is no longer distortionary in the sense that the resource cost (Ω) does not affect quantity consumed using an electronic payment instrument.

The following proposition shows that under the buyer-take-all-burden scheme, this E-payment equilibrium is indeed the case if the cash-carrying cost (η) is sufficiently large.

Proposition 2. *If* $\eta \geq \frac{(\Omega/\mu^2)}{u'^{-1}[(2\mu-\beta)/\beta]}$, *buyers in the DM prefer E-payment to C-payment.*

Proof. Notice that $z_{\tilde{m}}\mu^{-1} = u'^{-1}[(2\mu-\beta)/\beta]$ from (27) and $\mathbf{I} = 1$ if $\eta \geq (\Omega/z_{\tilde{m}}\mu)$ from (14). These together immediately imply the claim. □

4.1.2. Cash transactions

We now characterize a stationary equilibrium for $\tau_b = 1$ where buyers in the DM make cash transactions. Since $\mathbf{I} = 0$ in this equilibrium, the value functions (4) and (5) should satisfy respectively

$$W(z_m, z_e) = (z_m + z_e + T) + \{v(x^*) - x^*\} + \max_{z_{\tilde{m}}}\{\beta V(z_{\tilde{m}}) - z_{\tilde{m}}\} \tag{28}$$

$$V(z_{\tilde{m}}) = \frac{1}{2}[V^b(z_{\tilde{m}}) + V^s(z_{\tilde{m}})] \tag{29}$$

where, from (8) and (13), $V^s(z_{\tilde{m}})$ and $V^b(z_{\tilde{m}})$ are respectively given by the followings:

$$V^s(z_{\tilde{m}}) = -\frac{z_{\tilde{m}}q_b^*}{\mu} + W\left(\frac{z_{\tilde{m}}}{\mu} + \frac{z_{\tilde{m}}}{\mu}, 0\right) \tag{30}$$

$$V^b(z_{\tilde{m}}) = u\left(\frac{z_{\tilde{m}}q_b^*}{\mu}\right) + W(0, 0) - \eta z_{\tilde{m}}. \tag{31}$$

Finally, from (7), the real balances of money $z_{\tilde{m}}$ are implicitly determined by

$$\left(\frac{\mu-\beta}{\beta}\right) = \frac{1}{2}\left[u'\left(\frac{z_{\tilde{m}}}{\mu}\right) - (1+\eta\mu)\right] \tag{32}$$

where again $(z_{\tilde{m}}/\mu) = Q^c_{\tau_b=1} < Q^* = \arg\max[u(Q) - Q]$ because $\mu > \beta$. Similar to (20), the left-hand side in (32) is the opportunity cost of additional real balances, whereas the right-hand side is the marginal utility of consumption due to additional real balances net of the cash-carrying cost.

It is worthwhile here to make comment on the assumption of cash-carrying cost. Some recent empirical studies such as Garcia-Swartz et al. (2006) and Schmiedel et al. (2012) suggest that sellers as well as buyers incur some cost in carrying out cash transactions. In order to consider this, suppose that a seller accepting cash also incurs cash-handling cost η_s per unit of real balance. Then the value functions $W(z_m, z_e)$ and $V^b(z_{\tilde{m}})$ are the same as (28) and (31), respectively. There is a slight change in $V^s(z_{\tilde{m}})$ as follows:

$$V^s(z_{\tilde{m}}) = W\left(\frac{z_{\tilde{m}}}{\mu} + \frac{z_{\tilde{m}}}{\mu}, 0\right) - \frac{z_{\tilde{m}}q_b^*}{\mu} - \eta_s z_{\tilde{m}}.$$

Also, the optimal condition characterizing the real balances $z_{\tilde{m}}$ is given by

$$\left(\frac{\mu-\beta}{\beta}\right) = \frac{1}{2}\left[u'\left(\frac{z_{\tilde{m}}}{\mu}\right) - (1+\tilde{\eta}\mu)\right]$$

where $\tilde{\eta} = \eta_s + \eta$. This is essentially identical to (32) which suggests that our analysis would not be changed qualitatively even if the seller's cash-handling cost is incorporated.

Now, the following proposition shows that under the buyer-take-all-burden scheme, this C-payment equilibrium indeed occurs if the E-payment cost (Ω) is sufficiently large.

Proposition 3. *If* $\Omega > \mu^2\eta Q^*$, *then buyers in the DM prefer C-payment to E-payment.*

Proof. From (14), $\mathbf{I} = 0$ if $\tau_b\Omega\mu^{-1} > \eta z_{\tilde{m}}$. Since $q = 1$ in the equilibrium, the upper bound of $z_{\tilde{m}}$ is given by $\bar{z} = \mu Q^*$ from the definition of $\bar{z}$ ($\bar{z}\mu^{-1}q = Q^* = \arg\max[u(Q) - Q]$). Therefore, the inequality of $\tau_b\Omega\mu^{-1} > \eta z_{\tilde{m}}$ always holds for $\tau_b = 1$ if $\Omega > \mu^2\eta Q^*$. □

In short, Proposition 2 and 3 imply that for $\tau_b = 1$, buyers might prefer C-payment to E-payment depending on the magnitudes of (Ω, η). This is in a stark contrast to Proposition 1 which implies that by adopting the seller-take-all-burden scheme ($\tau_s = 1$), the payment platform can maximize the volume of electronic transactions regardless of inflation rate, electronic transaction cost, and cash-carrying cost. That is, for $\tau_b = 0$, buyers in the DM are willing to choose E-payment regardless of (Ω, μ, η).

4.2. Optimal allocation scheme

We now compare the welfare across the equilibria we have characterized so far and find (τ_s, τ_b) that maximizes $\mathbf{W}$. As a preliminary step, the following lemma compares the welfare when the cash-carrying cost (η) is sufficiently large so that buyers in the DM are willing to choose E-payment under the buyer-take-all-burden scheme $(\tau_b = 1)$.

Lemma 1. *Suppose* $\eta \geq \frac{(\Omega/\mu^2)}{u'^{-1}[(2\mu-\beta)/\beta]}$. *Then* $\mathbf{W}_{\tau_s=1} < \mathbf{W}^e_{\tau_b=1}$.

Proof. Noting that buyers in the DM choose E-payment rather than C-payment if $(\Omega/\mu^2) \leq \eta u'^{-1}[(2\mu-\beta)/\beta]$ from Proposition 2, $\mathbf{I} = 1$ in (14). Then $(\mathbf{W}^e_{\tau_b=1} - \mathbf{W}_{\tau_s=1})$ can be simplified as

$$\mathbf{W}^e_{\tau_b=1} - \mathbf{W}_{\tau_s=1} = \left[\frac{1}{2(1-\beta)}\right]\left\{\left[u(Q^e_{\tau_b=1}) - Q^e_{\tau_b=1}\right] - \left[u(Q_{\tau_s=1}) - Q_{\tau_s=1}\right]\right\}.$$

Since $Q_{\tau_s=1} < Q^e_{\tau_b=1} < Q^*$ from (20) and (27), we have

$$\left[u(Q^e_{\tau_b=1}) - Q^e_{\tau_b=1}\right] - \left[u(Q_{\tau_s=1}) - Q_{\tau_s=1}\right] > 0$$

which immediately implies $\mathbf{W}^e_{\tau_b=1} - \mathbf{W}_{\tau_s=1} > 0$. □

That is, when the cash-carrying cost is sufficiently large, an equilibrium with the buyer-take-all-burden scheme $(\tau_b = 1)$ implies higher welfare than that with the seller-take-all-burden scheme $(\tau_s = 1)$. As explained in the previous section, $\tau_s = 1$ is distortionary in the sense that it decreases consumption via the resource cost (Ω), whereas $\tau_b = 1$ has no such a distortionary effect on consumption.

The following result shows that even in the case where E-payment cost (Ω) is sufficiently large, the buyer-take-all-burden scheme $(\tau_b = 1)$ still dominates the seller-take-all-burden scheme $(\tau_s = 1)$ due to the essentially same reason as in the case where the cash-carrying cost (η) is sufficiently large.

Lemma 2. *Suppose* $\Omega > \mu^2\eta Q^*$. *Then* $\mathbf{W}_{\tau_s=1} < \mathbf{W}^e_{\tau_b=1} < \mathbf{W}^c_{\tau_b=1}$

Proof. As regards the second inequality $(\mathbf{W}^e_{\tau_b=1} < \mathbf{W}^c_{\tau_b=1})$, it suffices to show that

$$\left[u\left(Q^c_{\tau_b=1}\right) - Q^c_{\tau_b=1}\right] - \left[u\left(Q^e_{\tau_b=1}\right) - Q^e_{\tau_b=1}\right] - \left(\eta z^c_{\tau_b=1} - \Omega\right) > 0. \tag{33}$$

From Proposition 3, buyers in the DM choose C-payment rather than E-payment if $\Omega > \mu^2\eta Q^*$. This, together with $Q^e_{\tau_b=1} > Q^c_{\tau_b=1}$ from (27) and (32), implies that

$$(\Omega - \eta z^c_{\tau_b=1}) > u(Q^e_{\tau_b=1}) - u(Q^c_{\tau_b=1}) > u(Q^e_{\tau_b=1}) - u(Q^c_{\tau_b=1}) - (Q^e_{\tau_b=1} - Q^c_{\tau_b=1})$$

which suggests the inequality in (33). The first inequality $(\mathbf{W}_{\tau_s=1} < \mathbf{W}^e_{\tau_b=1})$, as in Lemma 1, is the immediate consequence of $Q_{\tau_s=1} < Q^e_{\tau_b=1} < Q^*$ from (20) and (27). □

Based on Lemma 1 and 2, the following proposition concludes that the welfare under the buyer-take-all-burden scheme $(\tau_b = 1)$ is always greater than that in an equilibrium for any combination of τ_b and τ_s; i.e., $\arg\max_{\tau_b \in [0,1]} \mathbf{W} = 1$.

Proposition 4. *The optimal allocation scheme of* Ω *maximizing* $\mathbf{W}$ *is* $\tau_b = 1$.

Proof. Notice first that $\mathbf{W}_{\tau_b=1} > \mathbf{W}_{\tau_s=1}$ from Lemma 1 and 2. Hence in the below, we compare $\mathbf{W}_{\tau_b=1}$ and $\mathbf{W}_{\tau_b \in (0,1)}$. Suppose $\mathbf{I} = 1$ for both $\tau_b = 1$ and $\tau_b \in (0, 1)$. From (20) and (27), it is straightforward to see $\mathbf{W}^e_{\tau_b=1} > \mathbf{W}^e_{\tau_b \in (0,1)}$ with $Q^e_{\tau_b=1} > Q^e_{\tau_{b\in(0,1)}} = [(z_{\tilde{m}} - \tau_s\Omega)/\mu]$. If $\mathbf{I} = 0$ for both $\tau_b = 1$ and $\tau_{b \in (0,1)}$, τ_b is irrelevant and $\mathbf{W}^c_{\tau_b=1} = \mathbf{W}^c_{\tau_b \in (0,1)}$. If $\mathbf{I} = 1$ for $\tau_b = 1$ $(\Omega \leq \mu\eta z_{\tilde{m}})$, it cannot be the case that $\mathbf{I} = 0$ for $\tau_{b \in (0,1)}$ $(\tau_b\Omega > \mu\eta z_{\tilde{m}})$ because $\tau_b \in (0, 1)$. The remaining case is that $\mathbf{I} = 0$ for $\tau_b = 1$ and $\mathbf{I} = 1$ for $\tau_b \in (0, 1)$. For the case, the sign of $(\mathbf{W}^c_{\tau_b=1} - \mathbf{W}^e_{\tau_b \in (0,1)})$ depends on the sign of $\mathbf{X} \equiv [u(Q^c_{\tau_b=1}) - Q^c_{\tau_b=1} - \eta z_{\tilde{m}}] - [u(Q^e_{\tau_b \in (0,1)}) - Q^e_{\tau_b \in (0,1)} - \Omega]$. Then,

$$\begin{aligned}
\mathbf{X} &\equiv [u(Q^c_{\tau_b=1}) - Q^c_{\tau_b=1} - \eta z_{\tilde{m}}] - [u(Q^e_{\tau_b \in (0,1)}) - Q^e_{\tau_b \in (0,1)} - \Omega] \\
&= \Omega - \eta z_{\tilde{m}} - \{[u(Q^e_{\tau_b \in (0,1)}) - Q^e_{\tau_b \in (0,1)}] - [u(Q^c_{\tau_b=1}) - Q^c_{\tau_b=1}]\} \\
&> \Omega - \eta z_{\tilde{m}} - \{[u(Q^e_{\tau_b=1}) - Q^e_{\tau_b=1}] - [u(Q^c_{\tau_b=1}) - Q^c_{\tau_b=1}]\} > 0
\end{aligned}$$

where the first inequality in the third line is due to $Q^e_{\tau_b \in (0,1)} < Q^e_{\tau_b=1} < Q^*$ and the second inequality holds because $\mathbf{I} = 0$ for $\tau_b = 1$ implies $(\Omega - \eta z_{\tilde{m}}) > u(Q^e_{\tau_b=1}) - u(Q^c_{\tau_b=1}) - (Q^e_{\tau_b=1} - Q^c_{\tau_b=1})$ from Lemma 2. □

In short, from the societal perspective, the buyer-take-all-burden scheme $(\tau_b = 1)$ is optimal because it has no distortionary effect on consumption. This is in a sharp contrast to an optimal scheme for the payment platform that adopts the seller-take-all-burden scheme $(\tau_s = 1$) in order to maximize the volume of electronic transactions. The seller-take-all-burden scheme decreases consumption by essentially raising its price.

5. Alternative pricing mechanisms

Our key result is that there exists a wedge between an equilibrium allocation of the resource cost of electronic transaction and its efficient allocation where the terms of a bilateral trade are determined by a price-posting mechanism. In this section, we discuss the robustness of our main result to different pricing mechanisms such as the generalized Nash bargaining and the Walrasian price taking.[5]

5.1. Nash bargaining

We first consider the generalized Nash bargaining by which the terms of a bilateral trade are determined in the DM. First, if a buyer with the real balances of money z and the bargaining power θ chooses C-payment in the DM, the terms of trade $(Q, \tilde{z})$ are given by the solution to the following problem:

$$\max_{(Q,\tilde{z})}[u(Q)-\tilde{z}\mu^{-1}-\eta\tilde{z}]^{\theta}[-Q+\tilde{z}\mu^{-1}]^{(1-\theta)} \tag{34}$$

subject to $\tilde{z}\le z$ where we use the linearity of W. If the constraint does not bind, $Q=Q^*=\arg\max[u(Q)-Q]$. But if the constraint does bind ($\tilde{z}=z$), Q solves the following from the first order condition of (34):

$$z=\frac{(1-\theta)u(Q)+\theta u'(Q)Q}{\theta u'(Q)\mu^{-1}+(1-\theta)(\eta+\mu^{-1})}\equiv z(Q) \tag{35}$$

As shown in Rocheteau and Wright (2005), an agent in the CM holds the real balances $z^c=z(Q^c)$ with Q^c satisfying

$$\left(\frac{\mu-\beta}{\beta}\right)=\frac{1}{2}\left[\frac{u'(Q^c)}{z'(Q^c)}-\eta\mu-1\right] \tag{36}$$

where Q^c is uniquely characterized if $\lim_{Q\to 0}u'(Q)/z'(Q)=\infty$ and $u'(Q)/z'(Q)$ is strictly decreasing for all $Q<Q^*$.[6]

Second, if a buyer with z chooses E-payment in the DM, the terms of trade $(Q, \tilde{z})$ are given by the solution to the following problem:

$$\max_{(Q,\tilde{z})}[u(Q)-\tilde{z}\mu^{-1}-\tau_b\Omega\mu^{-1}]^{\theta}[-Q+\tilde{z}\mu^{-1}-\tau_s\Omega\mu^{-1}]^{(1-\theta)} \tag{37}$$

subject to $\tilde{z}\le z$. If the constraint does not bind, $Q=Q^*=\arg\max[u(Q)-Q]$. But if the constraint does bind ($\tilde{z}=z$), Q solves the following from the first order condition of (37):

$$z=\frac{(1-\theta)[u(Q)-\tau_b\Omega\mu^{-1}]+\theta u'(Q)[Q+\tau_s\Omega\mu^{-1}]}{\theta u'(Q)\mu^{-1}+(1-\theta)\mu^{-1}}\equiv z(Q). \tag{38}$$

It can be shown that an agent in the CM holds the real balances $z^e=z(Q^e)$ with Q^e satisfying

$$\left(\frac{\mu-\beta}{\beta}\right)=\frac{1}{2}\left[\frac{u'(Q^e)}{z'(Q^e)}-1\right]. \tag{39}$$

Then from (36) and (39), we have $Q^c<Q^e<Q^*$ because $u'(Q)/z'(Q)$ is strictly decreasing and $\mu>\beta$. In addition, a buyer chooses E-payment if $u(Q^e)-\tau_b\Omega\mu^{-1}\ge u(Q^c)-\eta z^c$. These together imply that if $\tau_b=0$ ($\tau_s=1$), buyers are always willing to choose E-payment regardless of (Ω, μ, η) and hence the seller-take-all-burden scheme maximizes the volume of electronic transactions.

However, the social welfare $\mathbf{W}$ in (21) is maximized with the buyer-take-all-burden scheme ($\tau_b=1$). That is, as in Proposition 4, suppose $\mathbf{I}=1$ for both $\tau_b=1$ and $\tau_b\in[0,1)$. Then, it is straightforward to see $\mathbf{W}^e_{\tau_b=1}>\mathbf{W}^e_{\tau_b\in[0,1)}$ because $\partial Q^e/\partial\tau_b>0$. If $\mathbf{I}=0$ for both $\tau_b=1$ and $\tau_b\in[0,1)$, τ_b is irrelevant and $\mathbf{W}^c_{\tau_b=1}=\mathbf{W}^c_{\tau_b\in[0,1)}$. If $\mathbf{I}=1$ for $\tau_b=1$ $[u(Q^e)-\Omega\mu^{-1}\ge u(Q^c)-\eta z^c]$, it cannot be the case that $\mathbf{I}=0$ for $\tau_b\in[0,1)$ $[u(Q^e)-\tau_b\Omega\mu^{-1}<u(Q^c)-\eta z^c]$ because $\tau_b\in[0,1)$. The remaining case is that $\mathbf{I}=0$ for $\tau_b=1$ and $\mathbf{I}=1$ for $\tau_b\in[0,1)$. For the case, the sign of $(\mathbf{W}^c_{\tau_b=1}-\mathbf{W}^e_{\tau_b\in[0,1)})$ depends on the sign of $\mathbf{X}\equiv[u(Q^c)-Q^c-\eta z^c]-[u(Q^e_{\tau_b\in[0,1)})-Q^e_{\tau_b\in[0,1)}-\Omega]$ and $\mathbf{X}>0$ can be shown by applying exactly the same argument as in Proposition 4.

5.2. Walrasian price taking

We now consider the Walrasian price taking with search frictions as in Rocheteau and Wright (2005). Specifically, we assume that a competitive market opens in the afternoon and agents queue randomly to enter this market. An agent entering the market observes the price p announced by the Walrasian auctioneer and then chooses to either demand Q_b as a buyer or supply Q_s as a seller. The probability of joining the market for a buyer is $\alpha/2$ and that for a seller is also $\alpha/2$ with $\alpha\in(0, 1)$ which captures

[5] We are indebted to the referee for suggesting this point.

[6] Lagos and Wright (2005) show that this is indeed the case if $u'(\cdot)$ is log-concave.

search frictions. By assuming the same number of buyers and sellers, we can conveniently interpret an exchange in this market as a bilateral one, although the price is determined in a competitive market.

The value function for an agent entering the CM with m amount of money and e amount of unsettled E-payment balances is

$$W(m,e) = (\phi m + \phi e + T) - \left[\tau_b \Omega \mathbb{I}^b_{-1} + \tau_s \Omega \mathbb{I}^s_{-1}\right] + \max_x \{v(x) - x\} + \max_{\tilde{m}} \{\beta V(\tilde{m}) - \phi \tilde{m}\}. \tag{40}$$

Here $V(\tilde{m})$ is the value function for an agent entering the DM with m amount of money, which is given by

$$V(m) = \frac{1}{2}[V^s(m) + V^b(m)] \tag{41}$$

where

$$V^s(m) = \{-Q_s - \tau_s \Omega \mu^{-1} \mathbf{I} + W_{+1}[m + pQ_s(1-\mathbf{I}), pQ_s\mathbf{I}]\} \tag{42}$$

$$V^b(m) = \max_{\mathbf{I}} \{\mathbf{I}[u(Q_b) + W_{+1}(m, -pQ_b) - \tau_b \Omega \mu^{-1}] + (1-\mathbf{I})[u(Q_b) + W_{+1}(m - pQ_b, 0) - \eta \phi m]\}. \tag{43}$$

In equilibrium, $Q = Q_b = Q_s = M/p$ by the goods-market and money-market clearing conditions. Then (43) implies that (14) holds here. This immediately implies that the seller-take-all-burden scheme ($\tau_b = 0$) maximizes the volume of electronic transactions.

Now, from (42), a seller chooses $Q_s > 0$ for $\mathbf{I} = 0$ if $pQ_s\phi_{+1} \geq Q_s$ or $p \geq (1/\phi_{+1})$. Similarly, a seller chooses $Q_s > 0$ for $\mathbf{I} = 1$ if $pQ_s\phi_{+1} \geq Q_s + \tau_s \Omega \mu^{-1}$ or $p \geq (1/\phi_{+1})[1 + (\tau_s \Omega \mu^{-1}/Q_s)]$. Hence, the auctioneer announces the price p given by

$$p = \frac{1}{\phi_{+1}} \left(1 + \frac{\tau_s \Omega \mu^{-1} \mathbf{I}_p}{Q_s}\right) \tag{44}$$

where $\mathbf{I}_p$ is the fraction of buyers who choose E-payment. Then, from (41)–(44) together with the first order condition for $\tilde{m} \in \mathbb{R}_{++}$ ($\beta V'(\tilde{m}) = \phi$), we obtain

$$\frac{2(\mu - \beta)}{\beta} = \begin{cases} [u'(Q_{\tau_s=1}) - 1] \dfrac{Q_{\tau_s=1}}{Q_{\tau_s=1} + \Omega \mu^{-1}} & \text{for } \mathbf{I} = 1 \text{ and } \tau_b = 0 \\ \left[u'\left(Q^e_{\tau_b=1}\right) - 1\right] & \text{for } \mathbf{I} = 1 \text{ and } \tau_b = 1 \\ \left[u'\left(Q^c_{\tau_b=1}\right) - (1 + \eta\mu)\right] & \text{for } \mathbf{I} = 0 \text{ and } \tau_b = 1 \end{cases} \tag{45}$$

which then implies $Q_{\tau_s=1} < Q^e_{\tau_b=1} < Q^*$ and $Q^c_{\tau_b=1} < Q^e_{\tau_b=1} < Q^*$. It is now straightforward to show that our previous results from Proposition 1 to Proposition 4 continue to hold and hence the buyer-take-all-burden scheme maximizes the social welfare $\mathbf{W}$ in (21).

6. Concluding remarks

In this paper, we have explored an optimal allocation of a fixed resource cost of electronic transaction in a standard search theoretic monetary model in which other than cash, agents can make transactions via electronic transfer of money such as debit-card transactions. In a stationary monetary equilibrium, the payment platform can maximize the volume of electronic transactions by raising the resource cost only from sellers. On the other hand, the social planner's problem implies that the resource cost should be raised only from buyers in order to maximize welfare. Intuitively, under the scheme that raises (a fraction of) the resource cost from sellers, sellers are willing to pass on it to buyers by charging higher prices, whereas the buyer-take-all-burden scheme has no such a distortionary-effect channel.

Our results can be interpreted as supporting the repeal of the no-surcharge rule. If sellers can pass on the cost of accepting cards to buyers without any extra cost, the resource cost imposed to sellers will be eventually borne by buyers in the form of a surcharge. Then even under the seller-take-all-burden scheme, sellers do not need to pass their burden from accepting cards on the price of consumption goods itself. In addition, since the buyers' choice between cash and cards is now irrelevant to the raising scheme, an inefficiency resulting from excessive usage of cards in the seller-take-all-burden scheme would also disappear.

One of the simplifying assumptions we made is the quasi-linear preference in the CM which renders the distribution of money degenerate in the DM. In order to see whether a degenerate distribution is critical, suppose that now new money is injected at the beginning of the DM into some fraction of buyers as in the limited participation models. Then under the buyer-take-all-burden scheme, it is likely that the poor buyers are willing to choose C-payment while the rich buyers are willing to choose E-payment due to the proportional cash-carrying cost. However, under the seller-take-all-burden scheme, all the buyers are willing to choose E-payment regardless of their money holdings. It is then straightforward to see that a non-degenerate distribution does not change our main results qualitatively: i.e., the buyer-take-all-burden scheme strictly dominates the seller-take-all-burden scheme because Lemma 1 and 2 imply that the convex combination of $\mathbf{W}^e_{\tau_b=1}$ and $\mathbf{W}^c_{\tau_b=1}$ is greater than $\mathbf{W}_{\tau_s=1}$. This claim is consistent with Huang et al. (2014) in which they study a monetary model augmented with distribution of money holdings to see an economy-of-scale effect of electronic transactions. By way of numerical examples, they illustrate that the solution to the Ramsey problem is the buyer-take-all-burden scheme.

Acknowledgments

We would like to thank Ping Wang (the editor) and the anonymous referee for their helpful comments and suggestions. Manjong Lee gratefully acknowledges the financial support from the National Research Foundation of Korea Grant funded by the Korean Government (NRF-2014S1A3A2044238). Young Sik Kim acknowledges that this work was supported by 'Overseas Training Expenses for Humanities & Social Sciences' through Seoul National University (SNU) in 2015.

References

Aliprantis, C., Camera, G., Puzzello, D., 2007. Anonymous markets and monetary trading. J. Monet. Econ. 54, 1905–1928.
Baumol, W., 1952. The transactions demand for cash: an inventory theoretic approach. Q. J. Econ. 66, 545–556.
Bolt, W., Jonker, N., Renselaar, C., 2010. Incentives at the counter: an empirical analysis of surcharging card payments and payment behaviour in the Netherlands. J. Bank. Financ. 34, 1738–1744.
Corbae, D., Temzelides, T., Wright, R., 2003. Directed search and monetary exchange. Econometrica 71, 731–756.
Gans, J., King, S., 2003. The neutrality of interchange fees in payment systems. Top. Econ. Anal. Policy 3 (1), 1–47.
Garcia-Swartz, D., Hahn, R., Layne-Farrar, A., 2006. The move toward a cashless society: calculating the costs and benefits. Rev. Netw. Econ. 5, 199–228.
Hayashi, F., Keeton, W., 2012. Measuring the Costs of Retail Payment Methods Economic Review, Second Quarter, 2012. Federal Reserve Bank of Kansas City, pp. 37–77.
He, P., Huang, L., Wright, R., 2008. Money, banking, and monetary policy. J. Monet. Econ. 55, 1013–1024.
Huang, P., Kim, Y.S., Lee, M., 2014. Optimal Allocation of Social Cost for Electronic Payment System: A Ramsey Approach. Institute of Economic Research, Korea University.Discussion Paper Series 1402
Humphrey, D., 2004. Replacement of cash by cards in us consumer payments. J. Econ. Bus. 56, 211–225.
Kocherlakota, N., 1998. Money is memory. J. Econ. Theory 81, 232–251.
Lagos, R., Wright, R., 2005. A unified framework for monetary theory and policy analysis. J. Polit. Econ. 113, 463–484.
Lotz, S., Zhang, C., 2013. Paper or Plastic? Money and Credit as Means of Payment. CEPP.Discussion Paper Series
Monnet, C., Roberds, W., 2008. Optimal pricing of payment services. J. Monet. Econ. 55, 1428–1440.
Prager, R., Manuszak, M., Kiser, E., Borzekowski, R., 2009. Interchange Fees and Payment Card Networks: Economics, Industry Developments, and Policy Issues. Finance and Economics Discussion Series 2009-23. Federal Reserve Board.
Rochet, J., Tirole, J., 2002. Cooperation among competitors: some economics of payment card associations. Rand J. Econ. 33, 549–570.
Rochet, J., Wright, J., 2010. Credit card interchange fees. J. Bank. Financ. 34, 1788–1797.
Rocheteau, G., Wright, R., 2005. Money in search equilibrium, in competitive equilibrium, and in competitive search equilibrium. Econometrica 73, 175–202.
Schmalensee, R., 2002. Payment systems and interchange fees. J. Ind. Econ. 50 (102–122), 847–870.
Schmiedel, H., Kostova, G., Ruttenberg, W., 2012. The Social and Private Costs of Retail Payment Instruments: A European Perspective. Occasional Paper Series No. 137. European Central Bank.
Schwartz, M., Vincent, D., 2006. The no surcharge rule and card user rebates: vertical control by a payment network. Rev. Netw. Econ. 5 (1).
Shy, O., 2012. Who Gains and Who Loses from the 2011 Debit Card Interchange Fee Reform?. Federal Reserve Bank of Boston.Public Policy Discussion Papers No. 12-06
Tobin, J., 1956. The interest-elasticity of transactions demand for cash. Rev. Econ. Stat. 38, 241–247.
Verdier, M., 2011. Interchange fees in payment card systems: a survey of the literature. J.. Econ. Surv. 25, 273–297.
Wallace, N., 2001. Whither monetary economics? Int. Econ. Rev. 42, 847–870.
Wang, Z., 2010. Regulating Debit Cards: The Case of Ad Valorem Fees. Economic Review First Quarter, 2010. Federal Reserve Bank of Kansas City,, pp. 71–93.
Wright, J., 2004. The determinants of optimal interchange fees in payment systems. J. Ind. Econ. 52, 1–26.
Wright, J., 2012. Why payment card fees are biased against retailers. Rand J. Econ. 43, 761–780.