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The Effect of Payment Reversibility on E-commerce and Postal Quality

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Abstract. In this paper we develop a stylized model of competition between brick-and-mortar merchants and online retailers. An offline transaction, matching payment with delivery, is without risk for both the seller and the buyer. In an online transaction the seller faces the potential risk of non-payment while the buyer risks failed delivery. The effects of these two risks depend on the reversibility of payment. While traditional payment systems for e-commerce are reversible, virtual currencies like Bitcoin offer irreversible transactions. This shifts the risk from the receiver of the payment to its sender. The paper explores the effect of payment reversibility on competition between offline and online merchants and on the importance of postal quality for e-commerce. It finds that payment irreversibility may strengthen e-commerce due to reduced overall risk. Moreover, under reasonable conditions, postal operators have stronger incentives for quality since it affects volumes more strongly if payment is irreversible.

1 Introduction

In contrast to the most prevalent traditional payment systems, transactions in virtual currencies are irreversible, which shifts the risk of a transaction from the receiver of the payment to its sender. This paper explores the effect of virtual currencies on competition between online and offline merchants.

Traditionally, commerce has been conducted in physical shops, where merchant and customer interact directly. The purchase of the good is carried out over the counter: the customer chooses a good and the merchant proceeds the payment. Good and payment are thus exchanged simultaneously. In contrast, electronic commerce (e-commerce) takes place only indirectly between the customer and the merchant via an online platform. The crucial difference between traditional commerce and e-commerce consists in the dissolution of temporal and spatial unity of the purchasing process, the merchant and the customer. On behalf of the merchant this separation necessitates software enabling virtual goods display, shopping basket and secure payment systems as well as a delivery channel. For the customer, e-commerce merely requires access to the internet. By eliminating the physical interaction component of traditional commerce, e-commerce also enables producers to act as merchants directly linked to customers without retail merchants as intermediaries.

Research on e-commerce has recently been reviewed and classified by Wang and Chen (2010). With 5% scientific enquiries on e-commerce in the category of economics, the topic is still comparably small. Salient economic e-commerce themes that have recently been studied include pricing, reputation and comparison with retail commerce. For instance, Stahl (2000) developed a game-theoretic model in which pricing and advertising levels of online merchants are studied. Saastamoinen (2009) found empirical evidence that very large and small merchants in e-commerce may benefit most form reputation in competition. Lee and Tan (2003) proposed a model of consumer choice between online and physical purchase, in which their choice depends on the service and product risks of the respective good. In particular and not surprisingly, they concluded that consumers tend to buy less from less known online merchants. Fahy (2006) considered a dupoloy between an online and physical firms, and inferred that the advantage of one commerce format over the other depends on the degree of differentiation between the firms' products as well as on the extent of customer search.

In recent years, e-commerce has become a blooming and fast-growing field of business activity and it has significantly challenged traditional commerce. In the year 2011, global B2C e-commerce sales added up to approximately 961 billion US Dollars (Interactive Media in Retail Group, 2012). Still, the e-commerce market continues to expand in 2013 with 18% yearly growth rates in Europe and 16% in the United States (International Post Corporation,2014). In terms of welfare, total gains for EU consumers from lower online prices and increased online choice are estimated to amount to 204.5 billion Euro, which is roughly equivalent to 1.7% of the EU's gross domestic product (Civic Consulting, 2011). From the point of view of postal operators, the rise of e-commerce provides attractive growth opportunities via parcel delivery services. It constitutes a relief in times of declining letter mail demand due to e-substitution from email and othe electronic means of communication. Indeed, the parcel sector of postal operators has done strikingly well in the last few years. For instance, the corresponding revenue as well as parcel volume of USPS increased both by 14 % from the year 2010 to 2012 (United States Postal Service, 2013). In the EU, the share of e-commerce shipments in B2C volumes amounts to 60% in 2012 (Copenhagen Economics, 2013). The increase in parcel volumes and the decline in letter mail delivery is illustrated in Figure 1.

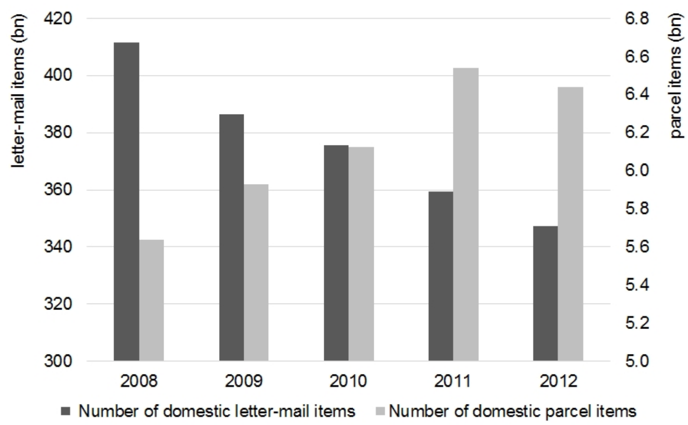

Fig. 1. Global delivery volumes 2008–2012 (Source: UPU, 2013)

Yet, there still exists some obstacles for e-commerce. In particular, FTI Consulting (2011) found that cross-border e-commerce is still rather weak. Delivery quality and payment issues can be considered to be the two most significant obstacles for e-commerce. According to Copenhagen Economics (2013), problems related to delivery services are a key reason for not buying online. For example, in their survey, delivery-related problems are responsible for 68% of the situations where e-shoppers have added items to their shopping chart, but abandoned it before sending off the order. Postal quality thus plays an important role for the success and further growth of e-commerce. Moreover, the security and reliability of the payment channel is essential for e-commerce. Credit card payment as one of the main payment channel in e-commerce, exhibit several weaknesses: online merchants are confronted with the risk that payment be reversed after they have delivered. Empirically, this risk is significant. According to CyberSource (2013), the estimated loss to online payment fraud amounted to 3.5 Billion US Dollars in 2012 for North America (USA & Canada), where charge-backs accounted for 43 % of all fraud claims. See Figure 2 for the development of losses due to card fraud over the past years. The issues of merchants associated with credit cards have been addressed from a theoretical point of view by, for instance, Hayashi (2006), Chakravort and To (2007), as well as Wright (2012). The losses due to card fraud result from the reversibility of online payments and the risk of theft of data related to the payment system (e.g. credit card data theft).

Fig. 2. Losses from card fraud (Source: The Nielsen Report, 2013)

Only recently, a novel payment system has been put forward: virtual currencies, especially their most prominent offshoot Bitcoin. It was developed by Nakamoto (2008) and set up in 2009 as an open-source software which is entirely decentralized, being based on a peer-to-peer network. It is a payment system with its own currency. In contrast to conventional currencies, Bitcoin is not issued or guaranteed by a central bank and does not enjoy a status as legal tender. Instead, the monetary base grows algorithmically; newly created Bitcoins (seigniorage) are awarded to those users who contribute to secure the network by performing cryptographic functions. By halving the number of newly rewarded Bitcoins at regular intervals, the money supply is capped at 21 million units. As a currency, Bitcoin is freely exchangeable for traditional currencies at a floating (and currently very volatile) exchange rate.

Bitcoin as a payment system does not rely on centralized institutions either. Each user is able to send and receive Bitcoins on his own without financial intermediaries. As a result, payments in Bitcoin are irreversible and cannot be revoked. With regards to e-commerce, Bitcoin as a payment system provide several advantages. Due to its peer-to-peer nature and independence of financial intermediaries, the Bitcoin technology generally facilitate trade. In particular, e-commerce involving cross-border transactions benefits from Bitcoin not being bound to specific countries. Besides, virtual currencies also enable consumers without access traditional payment systems, e.g. credit cards or banking services, to participate in e-commerce. With Bitcoin, there is no credit card number that a malicious actor can collect in order to impersonate someone. In fact, it is even possible to send a payment without revealing one's identity, almost like with physical money.

Arguably the most immediate effect virtual currencies like Bitcoin can exert on e-commerce is linked to their property of payment irreversibility. Transactions in virtual currencies cannot be reversed, but only refunded by the receiving party. Being as quick and private as cash, virtual currencies are capable of bringing these advantages form traditional commerce to e-commerce and to resolve the problem of payment reversibility of card payments faced by online merchants. Payment irreversibility of virtual currencies reallocates risk from merchants to the consumers, since they may not receive the purchased goods. However, the extent of this risk is lessened by a reputation incentive for online merchants (and involved posts) to correctly dispatch and deliver, respectively. Indeed, compared to consumers, merchants have a much stronger incentive to maintain a reputation of trust.

Another type of risk is the highly volatile exchange rate of virtual currencies when traded for traditional currencies. However, there are liquid exchanges and payment providers that exchange between currencies instantaneously. Hence, in order to trade in virtual currencies, no exposure to their exchange rate risk is necessary.

In this paper we study the effects of the shift of risk from merchants to consumers in a model of competition between an online merchant and a bricks-and-mortar (offline) merchant. The paper proceeds as follows: in Section 2 our basic model of horizontally differentiated offline and online merchants is laid out. Two scenarios are then considered in turn. Section 3 studies the welfare effects of online payment irreversibility without the presence of postal operators. Section 4 extends the model by assuming a postal operator to deliver online merchandise and studies the effects of delivery quality on the demand for the online merchant. Section 5 concludes.

2 The Model

The model represents the competitive situation of retail merchants offering their goods to consumers (B2C commerce). Suppose a duopoly between two horizontally differentiated firms, an offline merchant, formally denoted as *off*, and an online merchant, formally denoted as *on*. The two merchants are differentiated by the delivery method (direct or via mail) and its consequences discussed further below. A representative consumer's utility function is assumed to be as follows:

$$u(q_{off}, q_{on}, m) = m + q_{off} - \frac{\beta}{2}q_{off}^2 + \varphi q_{on} - \frac{\beta}{2}\varphi^2 q_{on}^2 - \alpha\beta\varphi q_{off}q_{on},$$

where m denotes the amount of money spent on other goods; $\beta > 0$ is a parameter affecting the slope of the derivable demand curve; and $\varphi \in [0, 1]$ is a quality measuring whether and how the goods are received by the consumer thus taking into account the possibility of failed dispatch or delivery (either by the merchant or a postal operator) to the consumer. The parameter φ therefore formally represents the differentiation characteristics of the two goods. As the offline merchant trades directly over the counter, uncertainty about delivery only affects goods purchased from the online merchant. The last term denotes the perceived degree of differentiation i.e. it reflects the fact that the two products are not perfect substitutes but differentiated, with the parameter $\alpha \in [0, 1]$ being closer to zero, the higher the extent of differentiation, and with $\alpha = 1$ representing the case of the two goods being perfect substitutes.

As only the relative prices matter, the good m representing the amount of money spent on all other goods is fixed as numéraire good with price index $p_m = 1$. The consumer's budget constraint is then given by

$$p_{off}q_{off} + p_{on}q_{on} + m = I,$$

where I denotes his income.

Constrained utility maximization yields the demand functions for the two differentiated products:

$$q_{off}(p_{off}, p_{on}) = \frac{1}{\beta\varphi(1-\alpha^2)}(\varphi - \alpha\varphi - \varphi p_{off} + \alpha p_{on});$$

$$q_{on}(p_{off}, p_{on}) = \frac{1}{\beta\varphi^2(1-\alpha^2)}(\varphi - \alpha\varphi + \alpha\varphi p_{off} - p_{on}).$$

The two firms have the following profit functions:

$$\pi_{off} = (p_{off} - c_{off})q_{off}(p_{off}, p_{on});$$

$$\pi_{on} = (\psi p_{on} - c_{on})q_{on}(p_{off}, p_{on}),$$

where c_{off} and c_{on} are the two firm's unit costs, respectively, and the parameter $\psi \in [0, 1]$ is a probability measure representing payment reversibility. It denotes the probability that the online merchant obtains the payment and customers do not reverse their payments after having received their order. Payment irreversibility simply sets $\psi = 1$. Profit maximization induces the following price reaction functions for the two firms:

$$p_{off}(p_{on}) = \frac{1}{2\varphi}(\varphi - \alpha\varphi + \alpha p_{on} + \varphi c_{off});$$

$$p_{on}(p_{\mathit{off}}) = \frac{1}{2\psi}(\varphi\psi - \alpha\varphi\psi + \alpha\varphi\psi p_{\mathit{off}} + c_{on}).$$

The resulting optimal prices for the two firms are

$$p^*_{\mathit{off}} = \frac{1}{\varphi\psi(4-\alpha^2)}(2\varphi\psi - \alpha\varphi\psi - \alpha^2\varphi\psi + \alpha c_{on} + 2\varphi\psi c_{\mathit{off}});$$

$$p^*_{on} = \frac{1}{\psi(4-\alpha^2)}(2\varphi\psi - \alpha\varphi\psi - \alpha^2\varphi\psi + \alpha\varphi\psi c_{\mathit{off}} + 2c_{on}).$$

In our analysis, we make the following assumptions:

1. Offline transactions are irreversible; delivery is immediate.
2. Online transactions are possibly reversible. If payment is reversible, consumers will reverse their payment if they do not receive the purchased good or only in faulty condition. Hence, with reversible payment there is no risk on the buyer's side.
3. With online transactions there is a possibility of non-delivery. If payment is irreversible, there is no risk on the seller's (merchant's) side.

3 Basic Case

In the basic case we abstract from postal quality. We compare the two situations in which payments for online commerce are reversible and irreversible, respectively. The following Table 1 gives an overview of these two situations.

Table 1. Basic Case without Postal Quality

	Payment Reversibility		*Payment Irreversibility*	
Online Merchant	$\varphi = 1$	$\psi \leq 1$	$\varphi \leq 1$	$\psi = 1$

If payments are reversible, the online merchant has to commit to dispatch and delivery (or equivalent consumer compensation), since consumers would otherwise reverse their payments. Also, there is no postal operator who may delay delivery or damage the good, hence $\varphi = 1$. However, consumers may defraud merchants, i.e. not pay even though they receive their purchased goods, therefore $\psi \leq 1$. With irreversibility, consumers cannot revoke their payments. Hence, it is the consumer who may be defrauded by the merchant who does not deliver after payment.

Under payment reversibility the optimal prices of the two firms are as follows:

$$p^{rev}_{\mathit{off}} = \frac{\psi\left(\alpha^2 + \alpha - 2c_{\mathit{off}} - 2\right) - \alpha c_{on}}{(\alpha^2 - 4)\,\psi};$$

$$p_{on}^{rev} = \frac{\psi\left(\alpha^2 + \alpha - \alpha c_{off} - 2\right) - 2c_{on}}{\left(\alpha^2 - 4\right)\psi}.$$

Quantities are

$$q_{off}^{rev} = \frac{\alpha c_{on} + \psi\left(-\alpha^2 - \alpha + \left(\alpha^2 - 2\right)c_{off} + 2\right)}{\left(\alpha^2 - 4\right)\left(\alpha^2 - 1\right)\beta\psi};$$

$$q_{on}^{rev} = \frac{\left(\alpha^2 - 2\right)c_{on} - \psi\left(\alpha^2 + \alpha - \alpha c_{off} - 2\right)}{\left(\alpha^2 - 4\right)\left(\alpha^2 - 1\right)\beta\psi}.$$

Comparing the prices and the quantities of the two firms in the reversibility situation yields

$$p_{off}^{rev} - p_{on}^{rev} = \frac{c_{on} - \psi c_{off}}{\alpha\psi + 2\psi};$$

$$q_{off}^{rev} - q_{on}^{rev} = \frac{\psi c_{off} - c_{on}}{\left(\alpha^2 + \alpha - 2\right)\beta\psi}.$$

As a result, $p_{on}^{rev} > p_{off}^{rev}$ iff $c_{on} < \psi c_{off}$. Hence, if online payments are reversible and if costs are approximately symmetric ($c_{on} \approx c_{off}$), then the online merchant will generally charge a higher price than the offline merchant to compensate for the risk of non-payment by the customer. Consequently, the online merchant's quantity is lower than the offline merchant's quantity.

With irreversibility, the optimal prices of the two firms are as follows:

$$p_{off}^{irrev} = \frac{\varphi\left(\alpha^2 + \alpha - 2c_{off} - 2\right) - \alpha c_{on}}{\left(\alpha^2 - 4\right)\varphi};$$

$$p_{on}^{irrev} = \frac{\varphi\left(\alpha^2 + \alpha - \alpha c_{off} - 2\right) - 2c_{on}}{\alpha^2 - 4}.$$

Quantities are

$$q_{off}^{irrev} = \frac{\alpha c_{on} + \varphi\left(-\alpha^2 - \alpha + \left(\alpha^2 - 2\right)c_{off} + 2\right)}{\left(\alpha^2 - 4\right)\left(\alpha^2 - 1\right)\beta\varphi};$$

$$q_{on}^{irrev} = \frac{\left(\alpha^2 - 2\right)c_{on} - \varphi\left(\alpha^2 + \alpha - \alpha c_{off} - 2\right)}{\left(\alpha^2 - 4\right)\left(\alpha^2 - 1\right)\beta\varphi^2}.$$

Comparing the prices and the quantities of the two firms in the irreversibility situation yields

$$p_{off}^{irrev} - p_{on}^{irrev} = \frac{\varphi\left(c_{off}(\alpha\varphi - 2) - \left(\alpha^2 + \alpha - 2\right)(\varphi - 1)\right) - c_{on}(\alpha - 2\varphi)}{\left(\alpha^2 - 4\right)\varphi};$$

$$q_{off}^{irrev} - q_{on}^{irrev} = \frac{\varphi\left(\alpha^2((c_{off} - 1)\varphi + 1) - \alpha(c_{off} + \varphi - 1) - 2\varphi c_{off} + 2\varphi - 2\right) + c_{on}\left(-\alpha^2 + \alpha\varphi + 2\right)}{\left(\alpha^2 - 4\right)\left(\alpha^2 - 1\right)\beta\varphi^2}.$$

A direct comparison in general terms is not instructive. Assuming that $c = c_{\mathit{off}} = c_{on}$ the comparisons simplify to

$$p_{\mathit{off}}^{irrev} - p_{on}^{irrev} = \frac{(\varphi - 1)\left(\alpha(\varphi + 1)c - \left(\alpha^2 + \alpha - 2\right)\varphi\right)}{\left(\alpha^2 - 4\right)\varphi} > 0;$$

$$q_{\mathit{off}}^{irrev} - q_{on}^{irrev} = \frac{(\varphi - 1)\left(\left(\alpha^2 - 2\right)(\varphi + 1)c - \left(\alpha^2 + \alpha - 2\right)\varphi\right)}{\left(\alpha^2 - 4\right)\left(\alpha^2 - 1\right)\beta\varphi^2} > 0, \text{ if } c > \frac{(\alpha^2 + \alpha - 2)\varphi}{(\alpha^2 - 2)(1 + \varphi)}.$$

Hence, if online payments are irreversible and with symmetric cost, the online merchant's price is lower than the offline merchant's in order to compensate consumers for their risk of non-delivery. Yet, consumers demand a higher quantity from the offline merchant due to imperfect online delivery if costs are sufficiently high, i.e. if $c > \frac{(\alpha^2+\alpha-2)\varphi}{(\alpha^2-2)(1+\varphi)}$.

Comparing the two situations in e-commerce with payment reversibility and irreversibility respectively in terms of prices and quantities yields the following results:

$$p_{\mathit{off}}^{irrev} - p_{\mathit{off}}^{rev} = \frac{\alpha c_{on}(\varphi - \psi)}{\left(\alpha^2 - 4\right)\varphi\psi};$$

$$p_{on}^{irrev} - p_{on}^{rev} = \frac{(\varphi - 1)\psi\left(\alpha^2 + \alpha - \alpha c_{\mathit{off}} - 2\right) - 2c_{on}(\psi - 1)}{\left(\alpha^2 - 4\right)\psi};$$

$$q_{\mathit{off}}^{irrev} - q_{\mathit{off}}^{rev} = \frac{\alpha c_{on}(\psi - \varphi)}{\left(\alpha^2 - 4\right)\left(\alpha^2 - 1\right)\beta\varphi\psi};$$

$$q_{on}^{irrev} - q_{on}^{rev} = \frac{(\varphi - 1)\varphi\psi\left(\alpha^2 + \alpha - \alpha c_{\mathit{off}} - 2\right) - \left(\alpha^2 - 2\right)c_{on}\left(\varphi^2 - \psi\right)}{\left(\alpha^2 - 4\right)\left(\alpha^2 - 1\right)\beta\varphi^2\psi}.$$

Hence, in market equilibrium, not only the online merchant's price is affected by the (irr-)reversibility of its payments, but also the offline merchant's price. It can be reasonably assumed that $\psi \leq \varphi$, i.e. the payment moral in the situation with payment reversibility does not exceed delivery quality in the case with irreversible payments. Intuitively, the online merchant risks losing his reputation and future business if he defrauds customers, while postal operators have an incentive to provide a high quality due to competitive pressure. In contrast, consumers may illegitimately reverse payments without any significant consequences. Under this assumption, the offline merchant's price is lower under a payment irreversibility online scheme compared to a system with payment reversibility. Moreover, the quantity of the offline merchant will be lower, too. Payment irreversibility in e-commerce thus has an adverse effect on the offline merchant.

If $c_{\mathit{off}} > \alpha + 1 - \frac{2}{\alpha}$, then the online merchant charges a lower price with payment irreversibility than with reversibility. This is the case if the offline merchant has a high cost, i.e. whenever the online merchant is comparatively competitive. If the offline merchant's cost is not too low, then the online merchant's price is lower with payment irreversibility than with reversibility since there is no longer a risk associated with reversed payment. Moreover, suppose $\psi \leq \varphi^2$ ensuring that $(\varphi - 1)\varphi\psi\left(\alpha^2 + \alpha - \alpha c_{\mathit{off}} - 2\right) - \left(\alpha^2 - 2\right)c_{on}\left(\varphi^2 - \psi\right) > 0$. Hence, if the online merchant's quality is sufficiently high, then consumers' online demand is higher under payment irreversibility.

4 Results with Postal Quality

In the above considerations, we have assumed that it is only the online merchant's behavior which affects whether his products are correctly delivered. In reality, delivery quality also depends on the postal operator who conveys the parcel and may delay delivery or damage the parcel. In this Section, such effects are taken into account by allowing $\varphi \leq 1$ also in the situation with reversible payment (see Table 2). This implies that the goods purchased online may not arrive on time or in good order due to the postal operator's fault which in turn degrades perceived quality. The probability of correct delivery in the case of payment irreversibility, which is denoted by σ, becomes even lower, since then also the online merchant may not be reliable, i.e. not dispatch correctly. Hence, delivery quality $\sigma < \varphi$ represents the possibilities of both the online merchant's and the postal operator's failure.

Table 2. Model with Postal Quality

	Payment Reversibility		*Payment Irreversibility*	
Online Merchant	$\varphi \leq 1$	$\psi \leq 1$	$\sigma \leq 1$	$\psi = 1$

With payment reversibility, the optimal prices and quantities of the two merchants are

$$p_{\mathit{off}}^{rev} = \frac{1}{\varphi\psi(4-\alpha^2)}(2\varphi\psi - \alpha\varphi\psi - \alpha^2\varphi\psi + \alpha c_{on} + 2\varphi\psi c_{\mathit{off}});$$

$$p_{on}^{rev} = \frac{1}{\psi(4-\alpha^2)}(2\varphi\psi - \alpha\varphi\psi - \alpha^2\varphi\psi + \alpha\varphi\psi c_{\mathit{off}} + 2c_{on});$$

$$q_{\mathit{off}}^{rev} = \frac{\alpha c_{on} + \varphi\psi\left(-\alpha^2 - \alpha + \left(\alpha^2 - 2\right)c_{\mathit{off}} + 2\right)}{\left(\alpha^2 - 4\right)\left(\alpha^2 - 1\right)\beta\varphi\psi};$$

$$q_{on}^{rev} = \frac{\left(\alpha^2 - 2\right)c_{on} - \varphi\psi\left(\alpha^2 + \alpha - \alpha c_{\mathit{off}} - 2\right)}{\left(\alpha^2 - 4\right)\left(\alpha^2 - 1\right)\beta\varphi^2\psi}.$$

Comparing the prices and the quantities of the two firms in the reversibility situation yields

$$p_{\mathit{off}}^{rev} - p_{on}^{rev} = \frac{\varphi\psi\left((\alpha\varphi-2)c_{\mathit{off}} - \left(\alpha^2+\alpha-2\right)(\varphi-1)\right) - (\alpha-2\varphi)c_{on}}{\left(\alpha^2-4\right)\varphi\psi};$$

$$q_{\mathit{off}}^{rev} - q_{on}^{rev} = \frac{\varphi\psi\left(\alpha^2((c_{\mathit{off}}-1)\varphi+1) - \alpha(c_{\mathit{off}}+\varphi-1) - 2c_{\mathit{off}}\varphi + 2\varphi - 2\right) + c_{on}\left(-\alpha^2+\alpha\varphi+2\right)}{\left(\alpha^2-4\right)\left(\alpha^2-1\right)\beta\varphi^2\psi}.$$

Again assuming that $c = c_{\mathit{off}} = c_{on}$ the comparisons simplify to

$$p_{\mathit{off}}^{rev} - p_{on}^{rev} = \frac{\left(\alpha\left(\varphi^2\psi-1\right) - 2\varphi(\psi-1)\right)c - \left(\alpha^2+\alpha-2\right)(\varphi-1)\varphi\psi}{\left(\alpha^2-4\right)\varphi\psi};$$

$$q_{\mathit{off}}^{rev} - q_{on}^{rev} = \frac{\left(\alpha^2\left(\varphi^2\psi-1\right) + \alpha(\varphi-\varphi\psi) - 2\varphi^2\psi + 2\right)c - \left(\alpha^2+\alpha-2\right)(\varphi-1)\varphi\psi}{\left(\alpha^2-4\right)\left(\alpha^2-1\right)\beta\varphi^2\psi}.$$

Hence, if $\alpha(\varphi^2\psi-1) < 2\varphi(\psi-1)$, then $p_{\mathit{off}}^{rev} > p_{on}^{rev}$. Moreover, if $\alpha^2\left(\varphi^2\psi-1\right) + \alpha(\varphi-\varphi\psi) - 2\varphi^2\psi + 2 < 0$, then $q_{\mathit{off}}^{rev} < q_{on}^{rev}$.

With payment irreversibility the optimal prices and quantities of the two firms are

$$p_{\mathit{off}}^{irrev} = \frac{\sigma\left(\alpha^2+\alpha-2c_{\mathit{off}}-2\right) - \alpha c_{on}}{\left(\alpha^2-4\right)\sigma};$$

$$p_{on}^{irrev} = \frac{\sigma\left(\alpha^2+\alpha-\alpha c_{\mathit{off}}-2\right) - 2c_{on}}{\alpha^2-4};$$

$$q_{\mathit{off}}^{irrev} = \frac{\alpha c_{on} + \sigma\left(-\alpha^2-\alpha+\left(\alpha^2-2\right)c_{\mathit{off}}+2\right)}{\left(\alpha^2-4\right)\left(\alpha^2-1\right)\beta\sigma};$$

$$q_{on}^{irrev} = \frac{\left(\alpha^2-2\right)c_{on} - \sigma\left(\alpha^2+\alpha-\alpha c_{\mathit{off}}-2\right)}{\left(\alpha^2-4\right)\left(\alpha^2-1\right)\beta\sigma^2}.$$

Comparing the prices and the quantities of the two firms for the situation with irreversible payment yields the following expressions:

$$p_{\mathit{off}}^{irrev} - p_{on}^{irrev} = \frac{\sigma\left(c_{\mathit{off}}(\alpha\sigma-2) - \left(\alpha^2+\alpha-2\right)(\sigma-1)\right) - c_{on}(\alpha-2\sigma)}{\left(\alpha^2-4\right)\sigma};$$

$$q_{\mathit{off}}^{irrev} - q_{on}^{irrev} = \frac{\sigma\left(\alpha^2((c_{\mathit{off}}-1)\sigma+1) - \alpha(c_{\mathit{off}}+\sigma-1) - 2\sigma c_{\mathit{off}} + 2\sigma - 2\right) + c_{on}\left(-\alpha^2+\alpha\sigma+2\right)}{\left(\alpha^2-4\right)\left(\alpha^2-1\right)\beta\sigma^2}.$$

In the case that $c = c_{off} = c_{on}$ the comparisons simplify to

$$p_{off}^{irrev} - p_{on}^{irrev} = \frac{(\sigma - 1)\left(\alpha(\sigma+1)c - \left(\alpha^2 + \alpha - 2\right)\sigma\right)}{\left(\alpha^2 - 4\right)\sigma} > 0;$$

$$q_{off}^{irrev} - q_{on}^{irrev} = \frac{(\sigma - 1)\left(\left(\alpha^2 - 2\right)(\sigma+1)c - \left(\alpha^2 + \alpha - 2\right)\sigma\right)}{\left(\alpha^2 - 4\right)\left(\alpha^2 - 1\right)\beta\sigma^2} > 0, \text{ if } c > \frac{(\alpha^2 + \alpha - 2)\sigma}{(\alpha^2 - 2)(1+\sigma)}.$$

Hence, if online payments are irreversible and with symmetric cost, the online merchant's price is lower than the offline merchant's price in order to compensate consumers for their risk of non-delivery. Yet, consumers demand a higher quantity from the offline merchant due to imperfect online delivery if costs are sufficiently high, i.e. if $c > \frac{(\alpha^2+\alpha-2)\sigma}{(\alpha^2-2)(1+\sigma)}$.

The difference between the situations with reversible and irreversible payments in e-commerce in terms of price and quantity are

$$p_{off}^{irrev} - p_{off}^{rev} = \frac{\alpha c_{on}(\sigma - \varphi\psi)}{\left(\alpha^2 - 4\right)\sigma\varphi\psi};$$

$$p_{on}^{irrev} - p_{on}^{rev} = \frac{\psi\left(\alpha^2 + \alpha - \alpha c_{off} - 2\right)(\sigma - \varphi) - 2c_{on}(\psi - 1)}{\left(\alpha^2 - 4\right)\psi};$$

$$q_{off}^{irrev} - q_{off}^{rev} = \frac{\alpha c_{on}(\varphi\psi - \sigma)}{\left(\alpha^2 - 4\right)\left(\alpha^2 - 1\right)\beta\sigma\varphi\psi};$$

$$q_{on}^{irrev} - q_{on}^{rev} = \frac{\sigma\varphi\psi\left(\alpha^2 + \alpha - \alpha c_{off} - 2\right)(\sigma - \varphi) - \left(\alpha^2 - 2\right)c_{on}\left(\sigma^2 - \varphi^2\psi\right)}{\left(\alpha^2 - 4\right)\left(\alpha^2 - 1\right)\beta\sigma^2\varphi^2\psi}.$$

The offline merchant's price will be higher under e-commerce payment irreversibility iff $\sigma < \varphi\psi$, yet its quantity will then still be higher compared to the offline merchant's quantity if payment in e-commerce is reversible. The price of the online merchant will be lower under payment irreversibility, if c_{off} is not too small or definitely if $c_{off} \geq 1$. If $\psi \leq (\frac{\sigma}{\varphi})^2$, then the e-commerce quantity is higher with payment irreversibility. Hence, payment irreversibility has a positive effect on e-commerce if payment moral under reversibility is low – a condition that seems to be in line with the empirical facts about credit card fraud.

As shown above, postal quality affects the outcome of competition between offline and online merchants. The stronger the effect of postal quality on the online merchant's volume, the stronger is the incentive for the post to invest in quality. The marginal effect of delivery quality on e-commerce quantity is evaluated for the two situations with payment reversibility and payment irreversibility. Note that σ represents the online merchant's and the post's combined quality, while φ represents only the post's delivery quality (since dispatch by the online merchant is guaranteed by payment reversibility).

$$\frac{\partial q_{on}^{rev}}{\partial \varphi} = \frac{\varphi\psi\left(\alpha^2 + \alpha - \alpha c_{off} - 2\right) - 2\left(\alpha^2 - 2\right)c_{on}}{\left(\alpha^2 - 4\right)\left(\alpha^2 - 1\right)\beta\varphi^3\psi}$$

$$\frac{\partial q_{on}^{irrev}}{\partial \sigma} = \frac{\sigma\left(\alpha^2 + \alpha - \alpha c_{off} - 2\right) - 2\left(\alpha^2 - 2\right)c_{on}}{\left(\alpha^2 - 4\right)\left(\alpha^2 - 1\right)\beta\sigma^3}$$

Hence, if $\psi \leq (\frac{\sigma}{\varphi})^3$, then $\frac{\partial q_{on}^{rev}}{\partial \varphi} \geq \frac{\partial q_{on}^{irrev}}{\partial \sigma}$ due to $\sigma < \varphi$: The marginal effect of delivery quality on the consumers' demand for the online good is stronger if they can reverse their payment. However, loosely speaking, if consumers' payment moral is rather high and/or the merchant's reliability is rather low, then the effect of delivery quality on demand can be higher in the case of payment irreversibility compared to payment reversibility. Intuitively, with irreversible payment, it is the perceived risk of incorrect delivery that deters customers from ordering online. Since the marginal effect of increased delivery quality on online volume is decreasing, an increase in postal quality strongly affects volume if merchant reliability is low.

5 Conclusion

In this paper we developed a stylized model of competition between brick-and-mortar merchants and online retailers with which we explore the effect of virtual currencies on prices and quantity as well as the importance of postal delivery quality for e-commerce. An offline transaction, matching payment with delivery, is without risk for both the seller and the buyer. In an online transaction the seller faces the potential risk of non-payment while the buyer risks failed delivery. The effects of these two risks depend on the reversibility of payment.

While traditional payment systems for e-commerce are reversible, transactions in virtual currencies like Bitcoin are irreversible. This shifts the risk from the receiver of the payment to its sender. Hence, with reversible payment, the online merchant includes a surcharge to compensate for his risk of non-payment. With irreversible payment, the online merchant has to grant a discount compared to the offline merchant in order to compensate customers for their risk of failed delivery. Overall, under reasonable conditions, payment irreversibility strengthens e-commerce compared to reversible payment due to reduced overall risk.

With postal delivery of goods purchased online, quality of delivery is not fully controlled by the merchant, but also by the postal operator. The model suggests that postal quality is more important if payment is irreversible than with reversible payment under the condition that consumers' payment moral is high and/or the merchant's reliability is low. Moreover, with payment irreversibility postal operators may have stronger incentives for quality since it affects volumes more strongly than if payment is reversible.

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