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**Imposing Choice under Ambiguity:
The Case of Dynamic Currency Conversion**

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Imposing Choice under Ambiguity: The Case of Dynamic Currency Conversion*

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Abstract. It is a common experience for present-day consumers making an international payment via credit or debit card to be invited to choose the currency in which they wish to have the transaction executed. While this choice, made feasible by a technology known as *dynamic currency conversion (DCC)*, seems to foster competition, we show that the opposite is the case. In fact, the unique pure-strategy Nash equilibrium in a natural fee-setting game turns out to be highly asymmetric, entailing fees for the service provider that always exceed the monopoly level. Although losses in welfare may be substantial, a regulatory solution is unlikely to come about due to a global free-rider problem.

Keywords. Dynamic currency conversion · Payment cards · Ambiguity aversion · Price competition · Monopoly · Free-rider problem

JEL-Codes. D21 – Firm Behavior: Theory; G21 – Banks, Depository Institutions, Micro Finance Institutions, Mortgages; G28 – Government Policy and Regulation; G53 – Financial Literacy

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1. Introduction

For about two decades by now, it has been common practice in international payment that users of a credit or debit card are invited to choose the currency in which they wish their transaction to be executed.¹ The technology allowing for this possibility, known as *dynamic currency conversion (DCC)*, relies on a protocol whereby the total in foreign currency is automatically converted to the card-holder's home currency. Proponents of DCC have pointed to the fact that consumers tend to feel more comfortable using their home currency because the uncertainty regarding the exchange rate in the moment of payment is eliminated. Moreover, traditional utility theory suggests that offering an additional alternative cannot be to the detriment of a rational decision maker. In contrast to such reasoning, however, consumer organizations have long warned that DCC is almost never beneficial to the card-holder. Indeed, this suspicion has found unequivocal validation through a large variety of case studies.²

In this paper, we study the economic mechanisms underlying dynamic currency conversion from the perspective of behavioral game theory. Considered is a model of price competition between a finite set of card-issuing firms and a single DCC service provider.³ Demand for currency conversion is assumed to originate from a heterogeneous population of ambiguity-averse consumers.⁴ Moreover, in contrast to a standard Bertrand setting, the

¹For example, when checking out of a hotel on a weekend trip to Canada, a traveler from the US could be invited to choose to pay either in US dollars or in Canadian dollars. This choice might be presented on the screen of a small terminal used for electronic payment.

²For references regarding this point, see the next section.

³Allowing for competition among several service providers does not invalidate our conclusions. See Section 6.

⁴Ambiguity aversion has been used before to capture the element of a home bias. See,

consumer’s choice has two dimensions. Specifically, the consumer chooses both (i) a payment card (i.e., the card-issuing firm), and (ii) the currency of payment, i.e., home currency vs. foreign currency. Payment in home currency implies that the currency conversion is carried out by the DCC service provider, whereas payment in foreign currency implies that the currency conversion is carried out by the selected issuer. While this mechanics might look natural, it is important to realize that the choice is *framed* because, unless informed about the standards of the international payments industry, the consumer is not able to identify the entity that will carry out the currency conversion.⁵

We consider two settings, one in which DCC is prohibited, and one in which no regulation applies. It is shown that, in either setting, the model admits a unique pure-strategy Nash equilibrium. However, the market outcome depends dramatically on whether DCC is prohibited or not. Without DCC, we obtain the classic prediction of Bertrand competition that issuers bid each other down to marginal cost. With DCC, however, the equilibrium takes a somewhat unusual form. Specifically, the service provider benefits from the competition among the issuers, and optimally chooses a fee strictly above the monopoly level.⁶

e.g., Epstein and Miao (2003) or Uppal and Wang (2003).

⁵We use the term “framing” here even though it is usually interpreted in a slightly different way. Tversky and Kahneman (1981) observed preference reversal in objectively identical choice problems with different semantics, such as stressing the percentage of patients that deceased in a treatment versus the percentage of patients that survived. In our example, the framing goes a bit further by creating an objectively different choice problem, viz. the choice of the payment currency instead of the choice between using DCC or not.

⁶Pricing above the monopoly level may be part of a mixed-strategy Nash equilibrium with ex-post inefficient inventory choice (Montez and Schutz, 2018), but this result does not extend to pure-strategy Nash equilibria.

From a welfare perspective, the excessive fee chosen by the service provider decreases the volume of cross-currency payment transactions below the efficient level, thereby leading to losses in consumer surplus larger than the additional profits for the service provider. Although this might appear as a clear-cut case for regulation, e.g., in the form of a general prohibition of DCC, it turns out that the problem is more intricate. Specifically, the analysis suggests that the advent of the DCC technology has created a global free-rider problem that effectively mutes any regulatory initiative. Our analysis might thereby help to explain why the regulatory response forcefully requested by consumer interest groups has not come about until today.

A crucial assumption that will be made below is that consumers are averse to ambiguity, and that they may optimally respond to such ambiguity by randomization. According to the multiple-priors model (Gilboa and Schmeidler, 1989), the decision maker ex-post adopts the prior probability distribution that minimizes her expected utility. One possible interpretation is that the individual is pessimistic and focuses on the worst-case scenario, as if playing against nature. Provided that ambiguity aversion is understood this way, the set of priors considered possible may be effectively reduced by randomly choosing one of the available options. Along these lines, randomization may indeed be seen as a rational response to ambiguity (Saito, 2015; Ke and Zhang, 2019), and we will follow this logic in our analysis.⁷

Related literature. The present paper is related to three strands of lit-

⁷Consistent with this theoretical prediction, some of our colleagues to whom we presented our theory “admitted” having had recourse to randomization when faced with the choice of currency in electronic payment. For evidence regarding preferences for randomized choice, see Agranov and Ortoleva (2017) and Dwenger et al. (2019), for instance.

erature. First, our analysis relates to the literature on payment cards and platform competition. Seminal work by Baxter (1983) and Rochet and Tirole (2002) explored the economic rationale and efficient level of interchange fees.⁸ While DCC is a revenue component from electronic payment that might matter for the efficient level of interchange fees, existing theoretical work has to our understanding avoided modeling currency conversion so far.⁹ Second, our paper relates to the strand of literature that has studied the market interaction between profit-maximizing firms and cognitively imperfect consumers.¹⁰ For example, Gabaix and Laibson (2006) have shown that prices for hidden add-ons such as printer cartridges may be excessive if some consumers are naïve. If all consumers are rational, however, firms do not shroud information. Our analysis suggests that shrouding in the sense discussed may be profitable for merchants if consumers are merely ambiguity-averse. Finally, our paper relates to the literature on equilibrium price distribution (Varian, 1980; Narasimhan, 1988; Chioveanu and Zhou, 2013). However, while the model of sales may be seen as a variant of the all-pay auction, our game is not easily interpreted in this way. E.g., we always find a unique pure-strategy Nash equilibrium. More generally, we have not found imposed choice under ambiguity as a revenue source being modeled in the existing literature.¹¹

⁸Interchange fees are paid by the merchant’s bank to the card issuer, and serve as a Coasean compensation for the benefits that merchants have when they accept electronic payments.

⁹See, in particular, the surveys by Chakravorti (2010), Verdier (2011), or Rysman and Wright (2014). One reason for this might be that the revenue base of domestic transactions may be larger than that of cross-currency transactions—even though the DCC fee level tends to be much higher than the level of interchange fees.

¹⁰A useful survey is Armstrong and Vickers (2012).

¹¹There are also some quite illuminating experimental papers on this issue. In particular, Bouw (2016) conjectured a role for ambiguity aversion in a simulated ATM withdrawal. See also Gerritsen et al. (2014, 2017).

The remainder of this paper is structured as follows. Section 2 reviews the institutional background. The model is introduced in Section 3. Section 4 contains the equilibrium analysis. Section 5 discusses welfare implications and the free-rider problem. Extensions of the model allowing for more than one service provider are outlined in Section 6. Section 7 concludes. An Appendix contains technical proofs.

2. Institutional background

2.1 Dynamic Currency Conversion

Dynamic Currency Conversion (DCC) is a service offered to consumers that are in the process of making international payments, e.g., when paying with a credit or debit card on a business trip, when withdrawing local currency from an ATM, or when authorizing a payment in international online shopping.¹²

With DCC, the consumer chooses just before the transaction whether she would like to pay in foreign currency or in her home currency. Behind the scenes, however, this choice determines the entity that carries out the currency conversion. If the card-holder pays in foreign currency, then the conversion is carried out by the card issuer.¹³ If, however, the card-holder

¹²The technical feasibility of DCC has been discussed in patent applications submitted around the beginning of the millennium. It seems that companies with a large share of international retail business, such as car rental companies, were the first to offer DCC in selected countries (cf. Keck and Herman, 2005). There are numerous DCC service providers at the international level, including *Elavon*, *Fexco*, *First Data*, *Monex*, *Planet Payment*, and *Travelex*, for instance.

¹³More precisely, the currency conversion is carried out by the payment network that the issuer relies upon (e.g., in the case of credit cards, this could be Visa, Mastercard, Discover or American Express). In general, issuers (e.g., banks and credit unions) set the terms of the card and provide financial backing, while networks process transactions among merchants, merchants' banks, and issuers. American Express and Discover serve as both issuers and networks.

pays in her home currency, then the conversion is carried out by the so-called acquirer, i.e., by the merchant’s bank that processes the foreign currency transaction. Figure 1 illustrates foreign currency transactions with and without DCC using the example of a card-holder paying a foreign merchant.

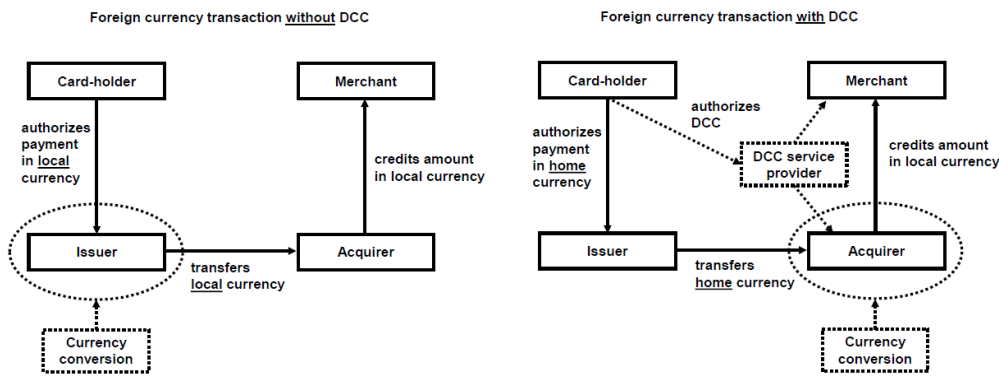


Figure 1. Foreign currency transaction with and without DCC

For card-holders, DCC offers the advantage that they can choose a legally binding price in their home currency as an alternative to the price in the foreign currency. For the acquirer, the advantage of DCC is that it creates an additional source of revenue.¹⁴ Finally, the advantage of DCC for the merchant is that the acquirer shares the revenue from the conversion service with her.¹⁵

According to de Groen et al. (2018), DCC transactions generate the high-

¹⁴Specific revenue components include foreign transaction fees, ATM network fees, currency conversion fees, DCC fees, and exchange rate margins, where the terminology may differ across institutions.

¹⁵Thus, merchant, acquirer, and service provider are three parties that earn a respective share of the revenues from DCC. Our theoretical framework will abstract from this institutional feature and assume the service provider as the sole decision maker in this alliance.

est fees per transaction, followed by surcharges and interchange fees.¹⁶ E.g., Elavon processes more than five billion transactions, valued at nearly \$450 billion, around the world per year. Visa and Mastercard generated about \$7.2 billion and \$4.9 billion revenues from international fees in 2018, respectively.¹⁷

2.2 Consumer interest groups

Soon after its inception, DCC was under heavy attack from consumer interest groups on the grounds that it implied a hefty service fee on top of a very disadvantageous exchange rate (e.g., Keck and Herman, 2005). This initial critique has never really ebbed away. In a recent position paper of the European consumer organization BEUC, Allix and Aliyev (2017, p. 2) summarized the complaint as follows: “When choosing the DCC option in card payments and ATM withdrawals, the consumer is financially worse off in practically every single case. It is almost impossible for a consumer to make an informed decision when presented with the DCC option, because of various nudging strategies put in place by the DCC service providers and merchants.”¹⁸ The same study surveys a large number of case studies, including

¹⁶However, interchange fees for cross-border payment card transactions may differ from those applied in national transactions (Vickers, 2005, p. 10).

¹⁷See Visa (2019, p. 15) and Mastercard (2019, p. 44).

¹⁸The following quote from Flywire (2018) might help to illustrate such nudging strategies. “Does the country of issuance of my credit card matter? — Yes, it’s important that you pay with a credit card issued in your home country, as we expect our customers to use cards denominated in their local currencies. Your credit card will be charged the amount, and in the currency of, your payment request. — If a different currency is used, your bank will need to convert the funds from your card to the currency selected in the payment request in order for us to receive it. This will result in additional charges for you. Please note that it is impossible for us to know if a credit card is denominated in any other currency, and additionally, we have no control over the conversion that your bank might perform.”

issuer countries such as Germany, Norway and the UK, in particular. These studies unequivocally confirm the view that DCC is generally expensive, with costs of 12 percent on top of the next best option being not uncommon. A recent follow-up study by Stiftung Warentest (2019) found the extreme case of 13.7 percent cost differential from paying in Euro rather than in Koruna at an ATM located in the Czech Republic. There are numerous media reports and studies that ask why the ongoing scandal is not finally brought to an end.¹⁹

In sum, there is quite some evidence that DCC is indeed used to extract excessive consumer rents. The precise way in which this is feasible, however, is not particularly well-understood. Below, we introduce an analytical framework that provides a rationale for how the rent extraction is accomplished, why competition for currency-exchange services does not eliminate the problem, and why the ongoing complaints have not triggered sufficient action by regulators.

3. The model

This section introduces our analytical framework, which may be described as a Bertrand model featuring an imposed choice on ambiguity-averse and potentially uninformed consumers.

3.1 *Firms competing for currency conversion*

Considered is a model of price competition involving $n \geq 2$ issuers, denoted by $i \in N \equiv \{1, \dots, n\}$, and a single service provider, denoted by $i = S$.

¹⁹See, e.g., West (2015), Bouyon and Krause (2018), or Goyens (2018), among many others.

Thus, each of the $(n + 1)$ competitors, $i \in N_S \equiv N \cup \{S\}$, independently and simultaneously chooses a fee $f_i \geq 0$ for currency conversion. Here, the fee variable is understood broadly, so as to represent the total cost of currency conversion for the consumer. Issuers and service provider are assumed to have access to the same technology for carrying out the currency conversion. Moreover, the service is homogeneous across competitors, i.e., there is no horizontal differentiation.²⁰ For convenience, marginal cost is assumed constant, and equal to $c \geq 0$. Both the issuers and the service provider are risk-neutral and maximize expected profits.²¹

3.2 Consumer choice

There is a continuum of consumers. Each consumer is perfectly informed about issuer fees f_1, \dots, f_n , and (if aware of its existence) also about the service provider's fee f_S . However, as discussed, consumers are not allowed to select one of the competitors from the set N_S . Instead, each consumer authorizing an international payment makes a two-dimensional choice

$$(i, \mu) \in N \times \{H, F\}, \quad (1)$$

where $i \in N$ denotes the issuer, and $\mu \in \{H, F\}$ denotes the payment currency. Moreover, by remaining silent about the fact that selecting $H =$ “home currency” rather than $F =$ “foreign currency” leads to the involvement of the service provider, the choice is *framed* in the sense of Tversky and Kahneman (1981).

²⁰The case of imperfect competition will be discussed later in the paper.

²¹This specifies the objectives of the competitors in the case of a duopoly between the issuers. However, to eliminate equilibria of limited interest when $n \geq 3$, we assume that, among fees that maximize expected profits, each competitor chooses the fee that maximizes her market share.

3.3 Ambiguity aversion

To capture the consumer's uncertainty when choosing the payment currency, we introduce a state space with two states,

$$\Omega = \{\omega_H, \omega_F\}. \quad (2)$$

In state ω_H , payment in home currency incurs weakly lower fees for currency conversion than payment in foreign currency, whereas in state ω_F , choosing payment in foreign currency incurs weakly lower fees than payment in home currency.²² Consumers are assumed to be ambiguity-averse in the sense of Gilboa and Schmeidler (1989). We denote by $p_H \in [0, 1]$ the consumer's prior probability that state ω_H obtains. For convenience, the set of beliefs in the multiple-priors model is assumed to be the entire set of feasible beliefs, i.e., $P = \{p_H \in [0, 1]\}$. In the case of a tie, we assume that a consumer is equally likely to choose any of the best offers.²³

Consumers can be of two types, informed and uninformed. While the informed consumer knows the state of the world, the uninformed consumer may be faced with a difficult decision under complete ambiguity.²⁴ We denote by $\alpha \in [0, 1]$ the ex-ante probability that a consumer is informed. The following result shows that the optimal response for the uninformed consumer typically entails randomization.

²²In an alternative set-up, the consumer is uncertain about the connection between the choice of the payment currency and the entity that carries out the currency conversion. The conclusions do not change. However, in the alternative set-up, consumers would be aware of the existence of a DCC service provider, which might be a somewhat strong assumption.

²³Provided that any competitor tying on the lowest fee expects a positive market share, the way in which ties are resolved does not matter for the equilibrium prediction.

²⁴This uninformedness may be optimal when the opportunity costs to collect the necessary information are too high for the consumer, e.g., because of time constraints.

Lemma 1. *If $f_S \neq \underline{f}$, then it is strictly optimal for the uninformed consumer to randomize over the currency options $\mu \in \{H, F\}$ available for payment, giving each choice the same probability.*

Proof. Note that

$$\frac{1}{2}p_H + \frac{1}{2}(1 - p_H) = \frac{1}{2} \quad (p_H \in P). \quad (3)$$

This implies that a randomizing agent eliminates the ambiguity in the belief. If the two choices yield different utility levels, this is strictly superior to living with the ambiguity. \square

Lemma 1 states that an uninformed consumer optimally eliminates the ambiguity in the belief through active randomization over payment currencies. If one alternative yields a lower fee than the other in state ω_H , and vice versa in state ω_F , then giving equal weight to both alternatives is strictly superior to sustaining the ambiguity.

As explained in Ke and Zhang (2019), the conclusion of Lemma 1 depends crucially on the consumer’s “subjective timing,” i.e., whether the move of Nature is envisaged to take place before or after the decision. In our analysis of DCC, we assume that the consumer believes that Nature moves *before* randomization. If the consumer believed instead that Nature moves *after* randomization, then she would still face ambiguity regardless of her choice. In our application, however, fees are fixed at the time of randomization, rendering one of the two states purely hypothetical. We therefore believe that our assumption is not entirely unreasonable for the application at hand.

3.4 Assumptions on demand

Let $D_I(f)$ and $D_U(f)$, respectively, denote the demand of the informed and uninformed consumers at any fee level $f \geq 0$.²⁵ Given that each consumer requests either one transaction or no transaction, demand corresponds to the size of the subpopulation of consumers that possess a willingness-to-pay weakly exceeding the fee. To ensure that the profit functions of the competing firms are well-behaved, we impose the following assumption on the differentiability and shape of the demand functions.

Assumption 1. (Demand for currency conversion)

- (i) D_I and D_U are nonnegative and nonincreasing on $[0, \infty)$, as well as twice differentiable at positive demand levels, with $D'_I < 0$ and $D'_U < 0$,²⁶
- (ii) $D_I(c) > 0$, $D_U(c) > 0$;
- (iii) D_U is ρ -concave, for some $\rho > -1$, at positive demand levels.

Part (i) is standard, where differentiability of, say, D_I at positive demand levels means that D_I is differentiable at any $f \geq 0$ such that $D_I(f) > 0$. It should be noted, however, that this condition entails that demand is responsive to fee levels.²⁷ Part (ii) captures that there are gains from trade for some of the informed and uninformed consumers, respectively. Finally, part (iii) requires that uninformed demand is not too convex. More specifically,

²⁵In an earlier version of the model, we assumed that all consumers possess the same maximum willingness-to-pay for a currency conversion. While the equilibrium analysis is simpler in that case, the welfare analysis becomes misleading: There is no inefficiency when consumers are homogeneous.

²⁶We allow for $\lim_{f \rightarrow 0} D_U(f) = \infty$ provided that $c > 0$.

²⁷This assumption is not implausible in our view. For example, a tourist can easily avoid using a payment card by having recourse to foreign bank notes or travellers' cheques. Further, in the absence of reasonable substitutes, a consumer may still decide to step back from the intended transaction altogether.

this condition is a strict variant of assuming that D_U is (-1) -concave in the sense of Caplin and Nalebuff (1991), which ensures that the service provider's problem has a unique solution.²⁸

4. Equilibrium analysis

This section studies the set of pure-strategy Nash equilibria of the non-cooperative pricing game introduced above. We first consider the market without DCC, then analyze the general case with DCC, and finally show that the service provider always charges a fee above the monopoly level.

4.1 The market without DCC

A natural point of reference for the analysis is the case in which the service provider has no access to the market. Depending on the interpretation, this corresponds either to a point in time at which the DCC technology was still unavailable (i.e., more than two decades ago), or to a situation in which regulators prohibit the use of the technology. We denote by

$$\underline{f} = \min\{f_1, \dots, f_n\} \tag{4}$$

the lowest fee chosen by any of the issuers (i.e., disregarding the service provider's fee f_S), and by m the number of issuers that charge precisely \underline{f} .

²⁸By definition, the ρ -concavity of D_U at positive demand levels requires that the transformed function $\varphi_\rho(D_U) = (D_U)^\rho/\rho$ is concave over the interval defined by $D_U > 0$, where a limit consideration takes care of the special case $\rho = 0$ (i.e., the case of log-concavity). Since we also impose that uninformed demand is twice differentiable at positive demand levels, part (iii) of Assumption 1 is equivalent to assuming that, for some $\rho > -1$, the inequality

$$D_U''(f)D_U(f) + (\rho - 1)D_U'(f)^2 \leq 0$$

holds for any $f \geq 0$ such that $D_U(f) > 0$.

Recall that \underline{f} is known to all consumers. Moreover, all consumers are able to select an issuer that offers the lowest fee \underline{f} .²⁹ Therefore, the model without DCC is seen to be equivalent to a traditional Bertrand game with constant marginal cost. The following result should, consequently, not be too surprising.

Proposition 1. (Bertrand competition) *Impose Assumption 1, and suppose that the service provider has no access to the market. Then, $m = n$ and $\underline{f} = c$, i.e., all the issuers set their fees equal to marginal cost.*

Proof.³⁰ (*Equilibrium property*) Suppose that all issuers but $i \in N$ set their fees equal to marginal cost, i.e., $f_j = c$ for all $j \in N \setminus \{i\}$. We have to show that i finds it optimal to likewise set $f_i = c$. Indeed, if $f_i = c$, then issuer i 's profit is zero. If $f_i > c$, however, then issuer i loses all of her demand. Therefore, issuer i cannot gain by raising f_i above marginal cost. Similarly, if $f_i < c$, then i raises her demand but incurs losses. The claim follows. (*Equilibrium uniqueness*) Clearly, there cannot be an equilibrium in which $\underline{f} < c$. Suppose, therefore, that $\underline{f} > c$. Then, there are two cases. If $f_i > \underline{f}$ for some $i \in N$, then issuer i could lower f_i to $\underline{f} - \varepsilon$, for $\varepsilon > 0$ small, and thereby attract the entire demand, which is positive by Assumption 1. If, however, all issuers charge $\underline{f} > c$, then any issuer i could deviate in this way. Therefore, $\underline{f} = c$ holds in any pure-strategy Nash equilibrium. Given the second-order lexicographic preference for market share, all issuers set their fees equal to marginal cost. \square

²⁹This observation reflects our general presumption that consumers are well-informed about card conditions and find it easy to switch between issuers. For a similar view, see Evans and Schmalensee (2005, p. 271), for instance.

³⁰The proof is well-known and given for completeness only.

4.2 The market with DCC

Suppose next that the service provider has access to the market. We will show that, in this case, the service provider's ability to frame the choice (possibly in collusion with the merchant) implies that there is no true competition between the issuers and the service provider.

By Lemma 1, the uninformed consumer randomizes between check boxes, making it equally likely to have the currency conversion carried out by the chosen issuer or the service provider. Thus, the expected fee for an uninformed consumer is given as

$$E[f] = \frac{1}{2} (f_S + \underline{f}). \quad (5)$$

Note that the condition for demanding the service, viz. that the uninformed consumer's willingness-to-pay must weakly exceed $E[f]$, marks the difference to existing models of Bertrand competition.

The following result characterizes the asymmetric equilibrium in the price-setting game with DCC service provider.

Proposition 2. *Impose Assumption 1, and suppose that the service provider has access to the market. Then, there is a unique pure-strategy Nash equilibrium, in which the service provider charges*

$$f_S^* = \arg \max_{f_S \geq 0} \left(\frac{f_S - c}{2} \right) \cdot D_U \left(\frac{f_S + c}{2} \right), \quad (6)$$

while the issuers all set their fees equal to marginal cost.

Proof. See the Appendix. \square

Thus, when admitted to the market, the service provider sets a fee strictly exceeding marginal cost, and makes a positive profit. Moreover, the anti-competitive equilibrium is the unique pure-strategy Nash equilibrium of the pricing game. Intuitively, the fact that uninformed consumers eliminate ambiguity by randomization renders their demand less price-elastic. As a result, the service provider finds it optimal to forgo the meager revenues from informed consumers, focusing instead exclusively on benefiting from the ex-post suboptimal choices made (and regretted) by the uninformed.³¹

While our model might appear similar to the model of sales (Varian, 1980), there is a crucial difference regarding the condition for purchase by uninformed consumers. Specifically, in the model of sales, uninformed consumers purchase from a randomly chosen store provided that the price in that store is low enough. In our setting, however, uninformed consumers, while likewise randomizing, request the service provided that the *expected* price is low enough. Put differently, the consumer knows what she is paying in the model of sales, but she does not know this in our framework. As shown above, this difference dramatically changes the nature of the equilibrium. For example, we find a pure-strategy Nash equilibrium, which is usually not feasible in a model of sales.

As discussed in Armstrong and Vickers (2012), assuming cognitive imperfections on the part of the consumers usually implies an externality between

³¹The fact that the service provider earns a positive profit relates our paper to the literature on the so-called Bertrand paradox. E.g., as pointed out by Dastidar (1995), the assumption of strictly convex costs may be used to obtain a Nash equilibrium in a Bertrand game with positive profits. However, our set-up does not require strictly convex costs. Relatedly, Spulber (1995) noted that asymmetric information regarding rival's costs may allow to achieve positive profits. Again, our argument differs.

rational and naïve consumers. E.g., the increase of the share of rational consumers in the population may force firms to offer more competitive prices, making it harder for firms to exploit naïve consumers. However, in our setting, there is no such externality. Uninformed consumers are exploited by the service provider regardless of how many informed consumers are around.³²

4.3 Pricing above the monopoly level

Suppose for the moment that a single firm offers the service of currency conversion to the uninformed segment of the consumer population. In that situation, the firm solves the problem

$$f^M = \arg \max_{f \geq 0} (f - c) D_U(f). \quad (7)$$

In analogy to the proof of Proposition 2, one can show that under Assumption 1, the objective function in (7) admits a unique global optimum that is interior and, hence, characterized by the first-order condition

$$(f^M - c) D'_U(f^M) + D_U(f^M) = 0. \quad (8)$$

We refer to f^M as the *monopoly fee*. The following result was somewhat unexpected to us.

Proposition 3. *Impose Assumption 1. Then, the service provider sets a fee strictly above the monopoly price level, i.e., $f_S^* > f^M$.*

Proof. When providing DCC as an option to potentially uninformed consumers, the service provider solves

$$f_S^* = \arg \max_{f \geq 0} \left(\frac{f_S - c}{2} \right) D_U \left(\frac{f_S + c}{2} \right), \quad (9)$$

³²However, if the competition among issuers is sufficiently imperfect, the externality may reappear because the service provider may then find it profitable to compete also for the informed demand.

with corresponding first-order condition

$$\left(\frac{f_S^* - c}{2}\right) D'_U \left(\frac{f_S^* + c}{2}\right) + D_U \left(\frac{f_S^* + c}{2}\right) = 0. \quad (10)$$

We convexify the two problems (7) and (9) by considering the hypothetical profit function

$$\Pi(f, q) = (f - c) \left(1 - \frac{q}{2}\right) D_U \left(\left(1 - \frac{q}{2}\right) f + \frac{q}{2} c\right), \quad (11)$$

where $q \in [0, 1]$. For $q = 0$, the function $\Pi(f, 0)$ represents the objective function of the monopoly, while for $q = 1$, the function $\Pi(f, 1)$ represents the objective function of the service provider when issuers price at marginal cost. For any $q \in [0, 1]$, the optimum is given by

$$f_q = \arg \max_{f \geq 0} \Pi(f, q), \quad (12)$$

and the corresponding first-order condition reads

$$(f_q - c) \left(1 - \frac{q}{2}\right) D'_U + D_U = 0, \quad (13)$$

where we drop the arguments. We also note that $f_0 = f^M$ and $f_1 = f_S^*$. To prove the proposition, it therefore suffices to show that the cross-derivative of $\Pi(f, q)$ is positive at f_q , for any $q \in [0, 1]$ (Milgrom and Shannon, 1994).

This, however, can be checked in a straightforward way.³³ \square

³³Indeed, taking the cross-derivative of (11), evaluating at $f = f_q$, and finally exploiting the first-order condition (13) yields

$$\frac{\partial^2 \Pi(f, q)}{\partial q \partial f} \Big|_{f=f_q} = -\frac{f_q - c}{2} \left(1 - \frac{q}{2}\right) \left\{ 2D'_U + (f_q - c) \left(1 - \frac{q}{2}\right) D''_U \right\}.$$

However, from the necessary second-order condition (see the proof of Proposition 2),

$$\frac{\partial^2 \Pi(f, q)}{\partial f^2} \Big|_{f=f_q} = \left(1 - \frac{q}{2}\right)^2 \left\{ 2D'_U + (f_q - c) \left(1 - \frac{q}{2}\right) D''_U \right\} < 0.$$

Since, for obvious reasons, $f_q > c$, this proves the claim.

We illustrate the conclusion of Proposition 3 with two examples.

Example 1. (Linear demand) Suppose that

$$D_U(f) = \begin{cases} \left(1 - \frac{f}{f^{\max}}\right) \cdot D^{\max} & \text{if } f \leq f^{\max} \\ 0 & \text{if } f > f^{\max}, \end{cases} \quad (14)$$

where $D^{\max} > 0$ and $f^{\max} > c$ are parameters. Then, the monopoly price is $f^M = \frac{f^{\max} + c}{2}$, while the fee chosen under competition among the issuers is $f_S^* = f^{\max}$. E.g., if $c = 0$, the fee charged by the service provider is twice as large as the monopoly fee.³⁴

Example 2. (Isoelastic demand) Suppose that uninformed demand is given as

$$D_U(f) = f^{-\eta}, \quad (15)$$

where $\eta > 1$ is the elasticity of uninformed demand. To ensure a finite optimum, we assume that $c > 0$.³⁵ Then, the monopolist's mark-up over marginal cost as a percentage of price satisfies the standard relationship

$$\frac{f^M - c}{f^M} = \frac{1}{\eta}, \quad (16)$$

whereas the service provider's mark-up is characterized by

$$\frac{f_S^* - c}{f_S^*} = \left(1 + \frac{c}{f_S^*}\right) \cdot \frac{1}{\eta} \quad (17)$$

$$> \frac{1}{\eta}. \quad (18)$$

In particular, we get that $f_S^* > f^M$, as predicted by Proposition 3.

³⁴This example extends in a straightforward way to a more flexible, but still log-concave specification of D_U in which the term in the brackets on the right-hand side of equation (14) is taken to the power of any $\gamma \in (0, \infty)$. In particular, as demand is strictly concave for $\gamma < 1$, the conclusion of Proposition 3 can be illustrated also in that case.

³⁵As demand is strictly convex in this case (in fact, not even log-concave), Example 2 exploits the full flexibility of Assumption 1.

The fairly strong conclusion of Proposition 3 is derived under the assumption that the issuers bid each other down to marginal cost. If, however, the competition among these firms is less than perfect, or similarly, if there is collusion among issuers regarding the fees for currency conversion, then the service provider's position weakens, resulting in a lower fee for the service provider. In that case, provided that the share of informed consumers is sufficiently large, the service provider might find it profitable to set her fee below the monopoly level so as to attract those informed consumers. However, even in the weakened position, the service provider will charge a fee above the monopoly level as long as the equilibrium fee level charged by the issuers stays sufficiently low to make it unattractive for the service provider to target the informed consumers.

5. Welfare and regulation

This section gauges the welfare implications of introducing DCC.

5.1 Welfare analysis

As has been seen above, the service provider is in a very strong position. In fact, with respect to pricing, her situation looks even more comfortable than that of the ordinary monopolist. However, with respect to quantity, the service provider sells only half of the volume brought to the market by the ordinary monopolist. It turns out that, in terms of expected profits, these two effects just balance out. Thus, regardless of the shape of uninformed demand, the service provider realizes precisely the same expected profit as an ordinary monopolist.

Proposition 4. *The service provider realizes expected profits equivalent to monopoly profits in the uninformed segment of the market for currency conversion.*

Proof. As in the proof of Proposition 3, we consider the convexified problem

$$\Pi^*(q) \equiv \Pi(f_q, q) \quad (19)$$

$$= \max_{f \geq 0} \Pi(f, q), \quad (20)$$

for $q \in [0, 1]$, where

$$\Pi(f, q) = (f - c) \left(1 - \frac{q}{2}\right) D_U \left(\left(1 - \frac{q}{2}\right) f + \frac{q}{2} c \right). \quad (21)$$

Recall that for $q = 0$ and $q = 1$, respectively, problem (20) corresponds to the problem of the monopolist and the service provider. A straightforward application of the envelope theorem delivers

$$\frac{\partial \Pi^*(q)}{\partial q} = \left. \frac{\partial \Pi(f, q)}{\partial q} \right|_{f=f_q} \quad (22)$$

$$= -\frac{f_q - c}{2} \left\{ D_U + \left(1 - \frac{q}{2}\right) (f_q - c) D'_U \right\}, \quad (23)$$

for any $q \in [0, 1]$. However, from the first-order condition,

$$\left. \frac{\partial \Pi(f, q)}{\partial f} \right|_{f=f_q} = \left(1 - \frac{q}{2}\right) \left\{ D_U + \left(1 - \frac{q}{2}\right) (f_q - c) D'_U \right\} \quad (24)$$

$$= 0, \quad (25)$$

so that $\partial \Pi^*(q)/\partial q = 0$ for all $q \in [0, 1]$. The claim follows. \square

There is an alternative way to prove Proposition 4, which may throw additional light on the main results of this paper. By directly comparing the

optimization problem of the service provider (9) with that of the monopolist (7), we see that the service provider optimally sets

$$f_S^* = 2f^M - c. \quad (26)$$

Rewriting this relationship, we obtain

$$f^M = \frac{f_S^* + f}{2}, \quad (27)$$

i.e., the service provider sets her fee f_S^* such that the uninformed consumer's expected cost for the currency conversion precisely equals the monopoly fee. Using these observations, it may be even more straightforward to verify that the service provider's expected profit must be the same as that of a monopolist in the uninformed market.

Putting the pieces together, our analysis predicts that the introduction of DCC into an otherwise competitive market for currency conversion creates a substantial loss in social welfare.

Corollary 1. *The market admittance of a DCC service provider lowers consumer surplus and aggregate welfare to the same degree as the introduction of a monopoly in the uninformed market segment.*

Proof. Immediate from Proposition 1 and relationship (27). \square

5.2 An international free-rider problem

At a superficial level, Proposition 1 seems to suggest that regulators should prohibit DCC.³⁶ However, this conclusion is flawed as it ignores the international dimension of the problem. Specifically, it must be noted that, for a

³⁶Alternatively, regulators could promote mandatory disclosure, competition among service providers, or voluntary self-restriction by merchants.

national regulatory authority, the identified gain in producer surplus arising from international payments is of a domestic nature, while the corresponding loss in consumer surplus from such transactions is of an entirely foreign nature. For instance, in the introductory example, the Canadian regulator might listen more intensely to local merchants than to US consumer interest groups. Thus, national supervisors should wish to prohibit DCC abroad but not domestically.³⁷ We argue that this lack of reciprocity, which we could not see reflected in the written accounts on DCC, creates a global free-rider problem that is not easily resolved.

There are two caveats, however. First, suppose that the DCC model is embedded into a Rochet-Tirole (2002) framework, so that issuers would request interchange fees from acquirers. These probably could be differentiated with respect to currency. Then, a share of the producer surplus would end up in the hands of the issuers, which might mitigate (but not eliminate) the problem. Another caveat is that, ultimately, the higher profits from DCC might help to provide stronger incentives to invest in socially desirable payment infrastructure (e.g., Reisinger and Zenger, 2019).³⁸

6. More than one service provider

A natural question to ask is why competition among service providers would not eliminate the problem of excessive fees. To answer this question, we briefly outline two possible extensions to $k \geq 2$ service providers.

³⁷Supra-national regulators in the European Union may be in a similar situation, given that the large majority of member countries uses the euro as official currency.

³⁸However, the extent to which these considerations matter depends on the relative bargaining power of the involved parties, which is an empirical issue that has, to our knowledge, not been investigated so far.

Extension A. Suppose first that service providers compete in an *ex-ante stage* before the payment stage modeled so far, so that only one service provider is visible to the consumer. Assume also that each service provider offers a sharing rule (between the merchant and the service provider) for the fees earned through currency conversions. In that case, service providers would bid each other down to marginal cost, and leave all the revenues from DCC to the merchant. However, the conclusions of our analysis do not change. The only change necessary to reflect the new assumption is that the merchant takes the role of the service provider.

Extension B. Suppose next that the DCC technology allows making more than one DCC service provider visible to the consumer, in which case service providers compete at the payment stage. Then, a straightforward extension of our analysis implies that the service providers would (again) bid each other down. As a result, there would be no excessive fees from DCC. While this sounds like a resolution of our problem, it must not be forgotten that the merchant, as a designer of the payment process, has no interest in allowing competition among service providers to occur at the payment stage, as this would bite into his own share of DCC profits.

7. Conclusion

The game-theoretic analysis conducted in the present paper adds support to the view that DCC service providers are able to extract substantial rents from cross-currency consumers by imposing an opportunistically framed choice upon them. For the consumer that is averse to ambiguity, and that lacks the informational basis for a good decision, conscious randomization may

be the only optimal way to respond. Provided that competitive forces work among issuers, this allows the service provider to charge fees strictly above the monopoly level. The specific technological environment of cross-currency payment may therefore overturn, and even reverse, the usual welfare-enhancing effect of competition. Policy responses are available, in principle, but our results suggest that a free-rider problem might make it hard to reach an international agreement. Our analysis thereby provides an explanation of the persistence of the DCC debacle despite the sizable body of evidence that has been collected by consumer interest groups.

It should be clear that our theory is complementary to the findings of the much richer literature on interchange fees in the tradition of Baxter (1983) and Rochet and Tirole (2002). However, our observation regarding the non-competitive nature of DCC may also have implications for the level of interchange fees. Specifically, to the extent that issuers possess market power vis-à-vis merchants, interchange fees resulting from international transactions would reflect the share of the profits from DCC that an issuer is able to extract (as a fourth party besides merchant, acquirer, and service provider). Thus, our analysis suggests also an alternative explanation for why interchange fees have often been found to be higher than the efficient level.³⁹

The present paper has not addressed all aspects of DCC. For example, by assuming that individual consumers have a unit demand for currency conversion, we have ignored the fact that some of the processing costs arise per transaction while others are linked to the amount. However, we tend to

³⁹See, e.g., Wright (2012) and Bedre-Defolie and Calvano (2013).

believe that incorporating this distinction would not lead to additional conclusions. Further, it might be of interest to study how competition among merchants interferes with the service provider's ability to extract extraordinary rents. We believe that such competition plays only a subordinate role in the global free-rider problem identified in the present analysis (e.g., because, for the merchant, the competitive gains from announcing that DCC is not applied are probably negligible compared to his profit share from DCC), but leave a more careful analysis of this issue for future work.

Appendix. Technical proofs

This appendix contains the proof of Proposition 2. The proof has five steps.

A.1 Derivation of aggregate demand

We start by considering informed and uninformed demand separately. An informed consumer knows the state of the world and, hence, is able to guarantee herself the lowest fee in the market, i.e., $\min(\underline{f}, f_S)$. Therefore, a total of $D_I(\min(\underline{f}, f_S))$ informed consumers request the currency conversion service. Provided that the informed consumer's willingness to pay for currency conversion weakly exceeds $\min(\underline{f}, f_S)$, the expected profit of issuer $i \in N$ from this consumer is given as

$$\Pi_i^I(f_1, \dots, f_n; f_S) = \begin{cases} \frac{f_i - c}{m} & \text{if } f_i = \underline{f} < f_S \\ \frac{f_i - c}{m + 1} & \text{if } f_i = \underline{f} = f_S \\ 0 & \text{otherwise.} \end{cases} \quad (28)$$

Similarly, the expected profit of the service provider from the same informed

consumer is given as

$$\Pi_S^I(f_1, \dots, f_n; f_S) = \begin{cases} f_S - c & \text{if } f_S < \underline{f} \\ \frac{f_i - c}{m+1} & \text{if } f_S = \underline{f} \\ 0 & \text{otherwise.} \end{cases} \quad (29)$$

The uninformed consumer does not know the state of the world. Randomizing her choice of μ , as predicted by Lemma 1, she anticipates an average fee level of

$$E[f] = \frac{\underline{f} + f_S}{2}. \quad (30)$$

Consequently, a total of $D_U(E[f])$ uninformed consumers request the service of currency conversion. The expected profit of issuer $i \in N$ from an uninformed consumer with willingness to pay weakly exceeding $E[f]$ is given as

$$\Pi_i^U(f_1, \dots, f_n; f_S) = \begin{cases} \frac{f_i - c}{2m} & \text{if } f_i = \underline{f}, \\ 0 & \text{otherwise.} \end{cases} \quad (31)$$

Similarly, the expected profit of the service provider from the same uninformed consumer is given as

$$\Pi_S^U(f_1, \dots, f_n; f_S) = \frac{f_S - c}{2}. \quad (32)$$

Using the type-specific profit functions derived above, it is now easy to spell out the aggregate demand for the competing firms. Specifically, the expected profit of issuer $i \in N$ is given as

$$\begin{aligned} \Pi_i(f_1, \dots, f_n; f_S) &= \alpha D_I(\min(\underline{f}, f_S)) \Pi_i^I(f_1, \dots, f_n; f_S) \\ &\quad + (1 - \alpha) D_U(E[f]) \Pi_i^U(f_1, \dots, f_n; f_S). \end{aligned} \quad (33)$$

Similarly, the service provider's expected profit is given as

$$\begin{aligned} \Pi_S(f_1, \dots, f_n; f_S) &= \alpha D_I(\min(\underline{f}, f_S)) \Pi_S^I(f_1, \dots, f_n; f_S) \\ &\quad + (1 - \alpha) D_U(E[f]) \Pi_S^U(f_1, \dots, f_n; f_S). \end{aligned} \quad (34)$$

A.2 Existence of f_S^*

We claim that the problem

$$\max_{f_S \geq 0} \left(\frac{f_S - c}{2} \right) \cdot D_U \left(\frac{f_S + c}{2} \right) \quad (35)$$

admits a solution f_S^* . By Assumption 1, the objective function in (35) is positive at $f_S = c + \varepsilon$, for $\varepsilon > 0$ small enough. Therefore, given that the objective function is continuous, the claim follows from the boundary condition

$$\lim_{f_S \rightarrow \infty} \left(\frac{f_S - c}{2} \right) \cdot D_U \left(\frac{f_S + c}{2} \right) = 0. \quad (36)$$

In fact, it suffices to show that

$$\lim_{f \rightarrow \infty} f D_U(f) = 0. \quad (37)$$

Indeed, if (37) holds, then also $c D_U(f)$ tends to zero as $f \rightarrow \infty$, so that (36) holds true. There are now two cases. If $D_U(f) = 0$ for some finite f , then (37) is immediate. Suppose, therefore, that $D_U(f) > 0$ for any $f \geq 0$. By Assumption 1, D_U is ρ -concave for some $\rho > -1$. Recall that smaller values of ρ correspond to less stringent conditions on D_U (Caplin and Nalebuff, 1991). Therefore, we may assume without loss of generality that $\rho \in (-1, 0)$. In this case, the strictly increasing transformation $\varphi_\rho(Q) = Q^\rho / \rho$ assumes negative values only (for $Q > 0$). Moreover, by Assumption 1, $D_U(c)$ is finite. Therefore, the transformed function $\varphi_\rho(D_U(f))$ is negative, strictly

declining, and concave on $[c, \infty)$. Hence, as illustrated in Figure 2, we find an absolute slope parameter $L > 0$ such that

$$\varphi_\rho(D_U(f)) \leq -Lf, \quad (38)$$

for any $f \geq c$. Rewriting (38) yields

$$fD_U(f) \leq \left(\frac{1}{L|\rho|f^{1-|\rho|}} \right)^{1/|\rho|}. \quad (39)$$

As the right-hand side of inequality (39) tends to zero as $f \rightarrow \infty$, this proves (37). The claim follows.

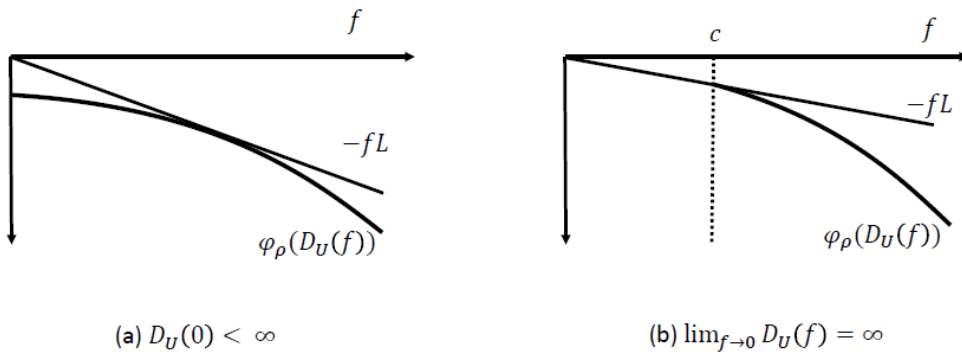


Figure 2. Determination of the slope parameter L

A.3 Uniqueness of f_S^*

We claim that the objective function in (6),

$$\underline{\Pi}_S(f_S) = \left(\frac{f_S - c}{2} \right) \cdot D_U \left(\frac{f_S + c}{2} \right), \quad (40)$$

is strictly quasi-concave on the subinterval of $(0, \infty)$ where uninformed demand is positive. Indeed, consider a fee level $f_S \geq c$ satisfying $D_U(f_S) > 0$ and $\underline{\Pi}'_S(f_S) = 0$. It suffices to show that $\underline{\Pi}''_S(f_S) < 0$ (Diewert et al., 1981).

Rewriting $\underline{\Pi}'_S(f_S) = 0$ yields

$$\left(\frac{1}{2}\right) \cdot D_U\left(\frac{f_S + c}{2}\right) + \left(\frac{f_S - c}{4}\right) \cdot D'_U\left(\frac{f_S + c}{2}\right) = 0. \quad (41)$$

By Assumption 1,

$$D_U\left(\frac{f_S + c}{2}\right) D''_U\left(\frac{f_S + c}{2}\right) - 2D'_U\left(\frac{f_S + c}{2}\right)^2 < 0. \quad (42)$$

Multiplying both sides of equation (42) by $1/D_U$ and subsequently using the first-order condition (41) delivers

$$\left(\frac{1}{2}\right) \cdot D'_U\left(\frac{f_S + c}{2}\right) + \left(\frac{f_S - c}{8}\right) \cdot D''_U\left(\frac{f_S + c}{2}\right) < 0 \quad (43)$$

or, equivalently, $\underline{\Pi}''_S(f_S) < 0$. Therefore, the function $\underline{\Pi}_S$ defined through equation (40) is indeed strictly quasi-concave on the subinterval of $(0, \infty)$ where uninformed demand is positive. Since the service provider can guarantee herself a positive payoff by charging a fee slightly above marginal cost, any global maximum must be in this subinterval. Hence, there is at most one maximizer.

A.4 Equilibrium property

Clearly, no issuer has an incentive to operate below marginal cost. Suppose that some issuer i raises its fee above marginal cost. Then, it clearly loses all its business with the informed consumers. However, it also loses all its business with the uninformed consumers, because those can still discriminate among issuers. Thus, issuer i has no incentive to deviate. As for the service provider, a deviation to some price level $f_S \leq c$ is never optimal. Similarly, a deviation to some price level $f_S \in (c, f_S^*) \cup (f_S^*, \infty)$ strictly lowers the profit from the business with the uninformed because f^* optimizes equation (6),

and does not attract any informed consumer because informed consumers know exactly the state of the world and would pick up the price offered by the issuers, i.e. c .

A.5 Equilibrium uniqueness

To provoke a contradiction, suppose that there is a pure-strategy Nash equilibrium with fees f_1, \dots, f_n and f_S that differs from the equilibrium described in the proposition. Extending the proof of uniqueness given in Proposition 1, it is not feasible that $\underline{f} \neq c$ in equilibrium. Hence $\underline{f} = c$, and all issuers set their fees equal to c because of the second-order lexicographic preference for market share. But given $f_1 = f_2 \cdots = f_n = c$, $f_S = f_S^*$ must hold in equilibrium. This concludes the proof of equilibrium uniqueness, and thereby, of the proposition. \square

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