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Imposing Choice on the Uninformed: The Case of Dynamic Currency Conversion[☆]

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ABSTRACT

Over the course of the past two decades, it has become a common experience for consumers authorizing an international transaction via credit card to be invited to choose the currency in which they wish the transaction to be executed. While this choice, made feasible by a technology known as *dynamic currency conversion (DCC)*, seems to foster competition, we argue that the opposite is the case. In fact, the unique pure-strategy equilibrium in a natural fee-setting game, with uninformed and possibly inattentive consumers, turns out to be highly asymmetric, entailing fees for the service provider that persistently 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.

1. Introduction

When a consumer uses a credit card to authorize an international transaction related to travel or online business, the currency requested for the settlement of the transaction may, in general, differ from the currency in which the credit card is denominated. Given that established payment networks such as Visa, Mastercard, etc., customarily convert foreign positions into the card holder's home currency, this problem in itself need not bother the consumer. Notwithstanding the existing solution that guarantees both convenience and predictable transaction costs, however, it has become increasingly common to let consumers choose their preferred currency of payment at the point of interaction. The technology that makes this choice feasible is known as *dynamic currency conversion (DCC)*. Proponents of DCC have pointed to the fact that consumers may feel more comfortable using their home currency, e.g., because the uncertainty regarding the exchange rate may be eliminated. Moreover, offering an additional alternative can arguably not be to the detriment of a rational decision maker. And indeed, over the years, DCC has become a standard for car rentals, restaurants, ATM operators, merchants, airlines, online shops, etc.

However, there are also downsides to DCC. Suppose that, upon presenting a credit card at the check-out of a Mexican hotel, a traveler from the U.S. is confronted with a checkbox form as shown in Figure 1. What the traveler may then not know (or may have problems recalling) is that, to avoid excessive costs, it is generally advisable to select the *local currency*. Indeed, if the payment is authorized in local currency, then the currency conversion is carried out by the payment network shown on the credit card, i.e., just as in the absence of the DCC option. In contrast, if the payment is authorized in the card holder's home currency, then the currency conversion is carried out by the service provider that operates the payment terminal, i.e., by an essentially *anonymous third party*. These important details are, however, not self-evident from the form shown in Figure 1. As a result, the traveler may lack the

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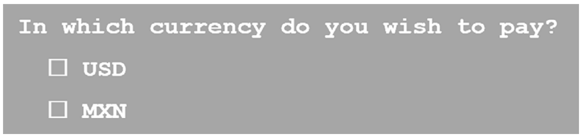

Fig. 1. Checkbox form on a payment terminal

informational basis for a good decision, making it difficult to avoid accidentally accepting the service provider's business proposition.[1] It should therefore not come as a surprise that consumer organizations around the globe have unanimously concluded that DCC is almost never beneficial for the card holder. Indeed, as will be discussed, this allegation has been confirmed by a large number of case studies.

In this paper, we study the economic mechanisms underlying DCC using established tools from applied microeconomic theory. Considered is a model of price competition with consumer search in the tradition of Salop and Stiglitz (1977). The basic setup allows for a finite number of card-issuing firms and a single DCC service provider.[2] It will be assumed that consumers know which fee is charged by which issuer. Consumers are likewise assumed to be informed about the potentially high fee that is charged by the service provider. Thus, card holders are aware of the "tourist trap."[3] However, in line with the literature on consumer search, we will assume that consumers need to spend a cost, possibly of a purely mental nature, to discover how the choice of currency determines the firm that carries out the currency conversion.

We consider two settings, one in which DCC is prohibited (or unavailable), and one in which no regulation applies. In either setting, the model admits a unique equilibrium in pure strategies. It turns out that the market outcome crucially depends 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 entails price dispersion across two fee levels. While the issuers bid each other down as before, the service provider actually benefits from that competition and chooses a fee that *persistently exceeds the monopoly level*. In fact, this conclusion does not change if consumers' attention is determined endogenously.[4]

It has long been understood that the market for credit cards is not very efficient (Ausubel, 1991; Brito and Hartley, 1995). However, the inefficiencies discussed in those papers relate to the level of interest rates on credit cards rather than to the level of fees charged for currency conversion. In our framework, the volume of cross-currency payment transactions is depressed by the excessive fees charged for DCC services. Therefore, the loss in consumer surplus exceeds the gain in profits for the service provider. Although this is a clear-cut case for regulation, we argue that the practical problem is not easily resolved. Specifically, the advent of the DCC technology seems to have created a global free-rider problem that has stifled national regulatory initiative. As will also be discussed, the coordinating power of a supranational institution (such as the EU) might, but need not help.

[1] Notably, a comparison of the alternatives remains tough even if the terminal shows the respective total in each currency as well as the exchange rate and fees applied by the service provider. The reason is that the missing link, the exchange rate applied by the issuer, is not known at the point of interaction. See also our discussion of product differentiation at the end of the paper.

[2] As will be explained, allowing for competition among service providers does not invalidate our conclusions.

[3] This useful term has been borrowed from Anderson and Renault (1999, p. 730).

[4] Montez and Schutz (2021) have shown that pricing above the monopoly level may be part of a mixed-strategy equilibrium with ex-post inefficient inventory choice. However, their result does not extend to equilibria in pure strategies.

Related literature. The present paper relates to three strands of the theoretical literature. First, in their analysis of *payment cards and platform competition*, Baxter (1983), Rochet and Tirole (2002), and Schmalensee (2002) explored the economic rationale and efficient level of interchange fees. In brief, interchange fees are paid by the merchant's bank to the card issuer and serve as a compensation for the benefits that merchants have when they accept electronic payments. As will be discussed, DCC fees might have an impact on the level of interchange fees. However, we could not find this point reflected in the literature, as surveyed by Chakravorti (2010), Verdier (2011), and Rysman and Wright (2014).

Second, our paper relates to the literature on *cognitive imperfections and choice complexity* (Spiegler, 2011; Armstrong and Vickers, 2012). With irrational consumers in the market, firms may deliberately create complexity to reduce the proportion of informed consumers in the market (Carlin, 2009; Ellison and Wolitzky, 2012; Piccione and Spiegler, 2012; Chioveanu and Zhou, 2013; Spiegler, 2014; Grubb, 2015). If all consumers are rational, however, firms do not obfuscate consumer choices in that way. Much earlier, Tversky and Kahneman (1981) introduced the term "framing" to explain preference reversal in objectively identical choice problems with different semantics. In the present paper, however, framing refers to the creation of an objectively different choice problem, viz. the choice of the payment currency instead of the choice between two firms.

Finally, our paper relates to the literature on *simultaneous search and equilibrium price dispersion*, as surveyed by Baye et al. (2006) and Anderson and Renault, 2018. Salop and Stiglitz (1977) assumed that consumers know the prices charged in the market but do not know what store sets what price. The consumer either purchases at random or spends a cost for getting informed about the store that charges the lowest price. While the setup is similar, the interpretation is different in our model. Here, consumers know which price is charged by which firm, but they do not know (or do not care) which alternative in their choice problem corresponds to which firm. Another distinction is that our assumptions imply prices strictly above the monopoly level, which is not feasible in Salop and Stiglitz's (1977) framework. In sum, we have not found prior work that has modeled imposed choice under uncertainty as a source of additional revenue.[5]

The remainder of the present paper is structured as follows. Section 2 outlines the institutional background. Section 3 presents the model. Section 4 derives the equilibrium. Section 5 concerns welfare and regulation. Section 6 offers extensions and further discussion. Section 7 concludes. All technical proofs have been relegated to an Appendix.

2. Institutional background

2.1. Dynamic Currency Conversion

Dynamic Currency Conversion (DCC) is a financial service devised for consumers that authorize transactions in an international context, e.g., when paying by card while traveling abroad, when withdrawing foreign banknotes from an ATM, or when making a payment in international online business (Barry, 2000; Nicholls, 2005). The service is automatically offered at the point of interaction when the payment tool detects that the currency of the transaction differs from the currency of the payment card (where the latter is derived from the six left-most digits of the card number,

[5] There is also some illuminating experimental work on DCC (Bouw, 2016; Gerritsen et al., 2014; 2023). For example, Bouw (2016) simulated an ATM withdrawal and attributed the observed preference for accepting the DCC option to ambiguity aversion. In Ewerhart and Li (2020), we explained randomized choice in the consumers problem based on a related concept.

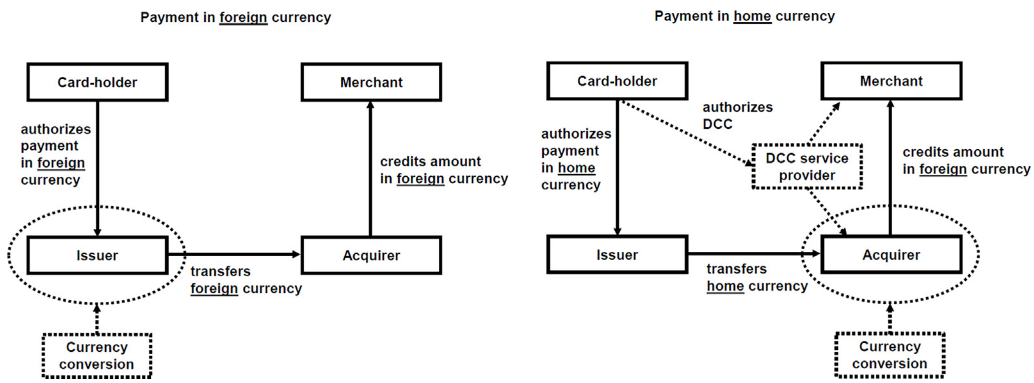

Fig. 2. Settlement of international card payments

i.e., from the *issuer identification number*). The consumer may then choose to pay in either currency. Companies with a large share of international retail business, such as car rental companies, were among the first to implement DCC in selected countries (Keck and Herman, 2005).

Figure 2, adapted from Rochet and Tirole (2002), illustrates the settlement of credit card transactions involving two currencies. If the card holder chooses to pay in foreign currency, then the 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, American Express, or Discover).[6] If, however, the card holder chooses to pay in home currency, then the conversion is carried out by the acquirer, i.e., by the merchant's bank that processes the foreign currency transaction. There are numerous DCC service providers operating at the international level, including Euronet, Elavon, Fexco, First Data, Monex, Planet Payment, Travelex, and many others.

Specific 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. These fees are collected by the acquirer but shared with merchant and DCC service provider.[7] Claims that the currency choice has been "overruled" (Mastercard, 2017) suggest that DCC is indeed quite attractive for local merchants. According to de Groen et al. (2018), DCC transactions generate the highest fees per transaction, followed by surcharges and interchange fees. However, interchange fees for cross-border payment card transactions may differ from those applied in national transactions (Vickers, 2005, p. 10). Elavon has been reported to process more than five billion transactions, valued at nearly \$450 billion, around the world per year. In comparison, Visa and Mastercard generated about \$7.2 billion and \$4.9 billion, respectively, in revenue from international fees during 2018 (Visa, 2019, p. 15; Mastercard, 2019, p. 44).

2.2. Consumer interest groups

Soon after its inception, DCC was under heavy attack from consumer interest groups on the grounds that it tends to add a substantial service fee on top of a disadvantageous exchange rate (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) 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."[8] The same study surveys a large number of case studies, covering issuer countries such as Germany, Norway, and the UK. These studies unequivocally confirm the view that making use of DCC is generally expensive, with mark-ups of 12 percent over the next best option not being uncommon. A follow-up study by Stiftung (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. For a point of reference, even the 1-3 percent fees that are regularly charged by issuers for international transactions have been considered abusive (Southern District of New York, 2003). Numerous media reports and studies asked why the scandal has not been ended (West, 2015; Bouyon and Krause, 2018; Goyens, 2018).

In sum, there is some evidence that DCC is used to extract excessive rents from consumers. The precise way in which this happens, however, is not particularly well-understood. Below, we offer a theory that explains how the rent extraction is accomplished, why competition for currency-related services does not eliminate the problem, and why the complaints have not triggered sufficient action by regulators.

3. The model

As mentioned before, we consider a variation of Salop and Stiglitz's (1977) model of price competition with simultaneous consumer search.

3.1. Firms competing for currency conversion

There are issuers, denoted by $i \in N \equiv \{1, \ldots, n\}$, and a single service provider, denoted by $i = S$.[9] Each of the $(n+1)$ competitors, $i \in N_S \equiv N \cup \{S\}$, chooses a fee $f_i \geq 0$ for currency conversion,

[6] In general, issuers (e.g., banks or credit unions) set the terms of the card and provide financial backing, while networks process transactions among merchants, acquirers, and issuers. American Express and Discover serve as both issuers and networks.

[7] In the main analysis, we will abstract from this institutional feature and assume instead that the service provider is the sole decision maker in this alliance. See, however, Section 6 for an extension in which several service providers compete for their role in the transaction business.

[8] The following quote from Flywire (2018) illustrates 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 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."

[9] Extensions of the basic model allowing for competition between service providers will be outlined in Section 6.

where decisions are made independently and simultaneously. The fee is understood broadly, so as to represent the total cost of currency conversion for the consumer. Thus, prices in the market are given by the $(n+1)$ fee levels $f_1, \ldots, f_n$, and f_S.

Let $c \geq 0$ denote the marginal cost of providing the conversion service. For convenience, we assume that c is constant. The service is initially assumed to be homogeneous, i.e., there is no differentiation across competitors.[10] Both the issuers and the service provider are risk-neutral and maximize expected profits. This specifies the objectives of the $(n+1)$ competitors in the case of $n = 2$ 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 its market share.

3.2. Consumer choice

There is a continuum of consumers. Each consumer either demands the service of currency conversion or chooses the outside option γ_0 (payment in cash, for instance). Demanding currency conversion means selecting an issuer $i \in N$ and a currency $\mu \in \{F, H\}$, where F and H refer to foreign currency and home currency, respectively. Thus, the consumer chooses an element $\gamma \in (N \times \{F, H\}) \cup \{\gamma_0\}$.

There are two states of the world, collected in the state space $\Omega = \{\omega_T, \omega_C\}$. The *true state*, ω_T, corresponds to the actual implementation of DCC, as explained in the Introduction. Thus, in ω_T, choosing F (choosing H) implies that the conversion is carried out by the issuer i at a price of f_i (by the service provider S at a price of f_S). However, in the *counterfactual state*, ω_C, the roles of the issuer and the service provider are exchanged, i.e., choosing F (choosing H) implies that the conversion is carried out by the service provider S at a price of f_S (by the issuer i at price f_i). If $\gamma = \gamma_0$, then there is no currency conversion and no fee.

3.3. The informational basis of consumer choice

Consumers can be of two types, informed and uninformed. If informed, the consumer knows that ω_T is the true state of the world, which allows him to select one of the $(n+1)$ firms. Specifically, to select any issuer $i \in N$, he may choose $\gamma = (i, F)$, whereas to select the service provider, he may choose $\gamma = (1, H)$, for instance. Indeed, if the home currency is chosen, the currency conversion is carried out by the service provider, and the choice of the issuer becomes irrelevant. Hence, the informed consumer's decision boils down to an element $\gamma \in N_S \cup \{\gamma_0\}$. If uninformed, however, the consumer does not know the state of the world. Unable to predict how the choice of the payment currency μ determines the fee applicable (f_S or f_i), the uninformed consumer randomly selects one of the currency options.[11] The uninformed consumer will, consequently, select an issuer $i \in N$ and then choose $\gamma = (i, F)$ and $\gamma = (i, H)$ with equal probability. Thus, the uninformed consumer's choice boils down to an element $i \in N \cup \{\gamma_0\}$.

3.4. Assumptions on demand

Given that consumers have unit demands in our model, market demand corresponds to the size of the subpopulation of consumers that possess a willingness-to-pay for currency conversion weakly exceeding the expected fee. Assuming that all consumers possess the same maximum willingness-to-pay, as Salop and Stiglitz (1977) do, would simplify the equilibrium analysis, but the welfare analysis would be misleading. Indeed, there would be no inefficiency if all consumers have identical valuations. We will therefore work with downward-sloping demand functions, as in Braverman (1980).

Let $D_I(f)$ and $D_U(f)$, respectively, denote the demand of the informed and uninformed consumers at the expected fee level $f \geq 0$. We will impose the following assumption on the differentiability and shape of these demand functions.

Assumption 1. (Demand for currency conversion)

(i) *$D_I \geq 0$ and $D_U \geq 0$ are weakly decreasing, continuous, as well as twice differentiable at positive demand levels, with $D_I' < 0$ and $D_U' < 0$;*
(ii) *$D_U(c) > 0$;*
(iii) *$D_U'' D_U - D_U'^2 \leq 0$ at positive demand levels.*

By condition (i), both demand components are nonnegative, weakly decreasing, and continuous. Furthermore, D_U and D_I are assumed twice differentiable and strictly downward-sloping when positive. In particular, each demand component may either vanish at some finite level or stay positive at arbitrary high levels. Condition (ii) requires that there are gains from trade for some of the uninformed consumers. Finally, condition (iii) says that D_U is log-concave in the interval where $D_U > 0$. This condition holds, in particular, if D_U is concave at positive demand levels. However, Assumption 1 is also consistent with convex demand.[12]

We denote by $\alpha \in [0, 1]$ the fraction of the consumer population that is informed. We will assume throughout that $\alpha \neq 1$, i.e., that some consumers are uninformed.[13]

4. Equilibrium analysis

This section studies the equilibrium set of the non-cooperative pricing game introduced above. Throughout, we restrict attention to Nash equilibria in pure strategies. We first consider the market without DCC, then analyze the 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 starting point for the analysis is the case in which the service provider has no access to the market. Thus, the currency conversion is known to be carried out by the chosen issuer, and each consumer effectively chooses from the set $N \cup \{\gamma_0\}$. As mentioned before, this scenario corresponds either to a situation in which a regulator prohibits the use of the technology, or else to a point in time at which the DCC technology was still unavailable (i.e., more than two decades ago).

As all fees are public information, and the distinction between uninformed and informed is eliminated, it is immediate to see that all consumers are able to select an issuer that offers the lowest fee

$$\underline{f} = \min\{f_1, \ldots, f_n\}. \quad (1)$$

This observation reflects our presumption that consumers are well-informed about card conditions and find it easy to choose their preferred issuer for international payments. In the case of a tie, we

[10] This simplifying assumption is made for convenience. As will be discussed, allowing for product differentiation does not invalidate our conclusions.

[11] Randomized choice does have substantial empirical support (Agranov and Ortoleva, 2017; Dwenger et al., 2018). In Section 6, we will develop a microfoundation of randomized choice based on endogenous attention.

[12] Using the notion of generalized concavity (Caplin and Nalebuff, 1991), Assumption 1 may be further relaxed without affecting our main conclusions. See Example 2 below for illustration, and Ewerhart and Li (2020) for a formal treatment.

[13] For $\alpha = 1$, all consumers are informed, and the $(n+1)$ competitors adhere to marginal cost pricing, as in Proposition 1 below.

assume that a consumer is equally likely to choose any of the best offers.[14] Thus, the model without DCC is seen to be equivalent to a traditional Bertrand game with constant marginal cost.

Proposition 1 (Bertrand competition)**.** *Impose Assumption 1, and suppose that the service provider has no access to the market. Then,* $f_1 = \cdots = f_n = c$*, i.e., all issuers set their fees equal to marginal cost.*

Proof. Omitted. □

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.

Following Salop and Stiglitz (1977), we assume that uninformed consumers randomize uniformly across alternatives perceived as equivalent, making it equally likely for them that the currency conversion is carried out by the chosen issuer or by the service provider.[15] Given that the consumer is still able to select the issuer with the most advantageous conditions, the expected fee for uninformed consumers is given as

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

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 equilibrium, in which the service provider charges a fee*

$$f_S^* = \arg\max_{f_S \geq 0} \frac{f_S - c}{2} \cdot D_U\left(\frac{f_S + c}{2}\right) \quad (3)$$

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

Proof. See the Appendix. □

Thus, when admitted to the market, the service provider sets a fee strictly above marginal cost and realizes a positive profit. Moreover, the anti-competitive two-price equilibrium is the unique equilibrium of the pricing game. Intuitively, the fact that uninformed consumers randomize creates a market segment that is captive for the service provider. As a result, the service provider finds it optimal to forgo the meager revenues from informed consumers, focusing instead exclusively on benefiting from the suboptimal choices made by the uninformed consumers.[16]

In comparison with Varian (1980), however, 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 *observed* 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 the transacting firm in the model of sales but may not know it in our framework. It is this difference that dramatically changes the nature of the equilibrium.

As discussed in Armstrong and Vickers (2012), assuming cognitive imperfections on the part of the consumers usually implies an externality between rational and naïve consumers. For instance, the increase of the share of rational consumers in the population may force firms to offer more competitive prices, making it harder 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.[17]

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

$$f^{\mathrm{M}} = \arg\max_{f \geq 0} (f - c) D_U(f). \quad (4)$$

In analogy to the proof of Proposition 2, one can show that under Assumption 1, the objective function in (4) admits a unique global optimum that is interior and, hence, is characterized by the first-order condition

$$(f^{\mathrm{M}} - c) D_U'\left(f^{\mathrm{M}}\right) + D_U\left(f^{\mathrm{M}}\right) = 0. \quad (5)$$

We refer to f^M as the *monopoly fee*. The following result was 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. See the Appendix. □

What is the intuition behind Proposition 3? As noted above, the randomization of uninformed consumers creates a captive market segment on which the service provider chooses to focus exclusively. Now, the uninformed consumers in that segment expect to pay the service provider's fee only with probability one half, and otherwise expect to benefit from the competition between the issuers. This averaging effect softens the impact of an increase in the service provider's fees on uninformed demand. As a result, the effective demand in the captive segment is strictly less elastic than in a monopolistic market.[18] With the service provider's trade-off biased in that way, the profit-maximizing fee set by the service provider strictly exceeds the monopoly level.

There is a simple way to validate the conclusion of Proposition 3. Comparing the optimization problem of the service provider (3) with that of the monopolist (4), we see that the service provider optimally sets

$$f_S^* = 2f^M - c. \quad (6)$$

For example, if $c = 0$, then the fee charged by the service provider is just twice as high as the monopoly fee. In general, rewriting relationship (6) and exploiting that $\underline{f} = c$ holds in equilibrium yields

[14] In fact, provided that any competitor tying on the lowest fee obtains a positive market share, the precise way in which ties are resolved does not matter for the equilibrium prediction.

[15] See also Diamond (1971) and Braverman (1980). In Section 6, we will review evidence and possible microfoundations of randomized choice.

[16] The fact that the service provider earns a positive profit relates our paper to the literature on the Bertrand paradox. For example, as pointed out by Dastidar (1995), the assumption of strictly increasing marginal cost may be used to obtain an equilibrium in a Bertrand game with positive profits. However, our set-up does not require that assumption. Relatedly, Spulber (1995) noted that asymmetric information regarding rivals' cost may allow to achieve positive profits. Again, our argument differs.

[17] However, 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.

[18] The elasticity-reducing effect of randomized demand is particularly evident in the example of isoelastic demand that will be discussed below as Example 2.

$$f^M = \frac{f_S^* + f}{2}, \tag{7}$$

i.e., the service provider sets f_S^* such that the uninformed consumer's expected cost for the currency conversion precisely equals the monopoly fee. Given that the issuers bid each other down to marginal cost, this indeed implies that $f_S^* > f^M$.[19]

An alternative proof is offered in the Appendix. There, Proposition 3 is derived by considering a parameterized model that embeds both our model and a hypothetical situation in which the service provider is a monopolist in the market for uninformed demand. The result is then obtained from an analysis of cross-derivatives, i.e., by applying methods of monotone comparative statics.

We illustrate the conclusion of Proposition 3 with two examples.

Example 1 (Linear demand)**.** Suppose that uninformed demand is given as

$$D_U(f) = \begin{cases} \left(1 - \frac{f}{f^{\max}}\right) \cdot D^{\max} & \text{if } f \leq f^{\max} \\ 0 & \text{if } f > f^{\max}, \end{cases} \tag{8}$$

where $D^{\max} > 0$ and $f^{\max} > c$ are exogenous parameters. Then, the monopoly price is $f^M = \frac{f^{\max}+c}{2}$, while the equilibrium fee chosen by the service provider is strictly higher, viz. $f_S^* = f^{\max}$.[20]

In the following example, we compare the mark-up of the monopolist with the mark-up charged by the service provider.

Example 2 (Isoelastic demand)**.** Suppose that

$$D_U(f) = f^{-\eta}, \tag{9}$$

where $\eta > 1$ is the elasticity of uninformed demand. While this specification does not satisfy Assumption 1, we show in the Appendix that our proofs easily extend to this case. To ensure a finite optimum, let $c > 0$. Then, the monopolist's mark-up over marginal cost as a percentage of price satisfies the standard relationship

$$\frac{f^M - c}{f^M} = \frac{1}{\eta}, \tag{10}$$

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

$$\frac{f_S^* - c}{f_S^*} = \left(1 + \frac{c}{f_S^*}\right) \cdot \frac{1}{\eta} > \frac{1}{\eta}. \tag{11}$$

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

5. Welfare analysis and regulation

In this section, we first derive the implications of DCC for producer surplus, consumer surplus, and aggregate welfare. The results are then used to identify a regulatory dilemma.

5.1. Producer surplus

As has been seen above, the service provider is in a very strong position. In fact, with respect to price, the service provider's situation looks even more comfortable than that of the ordinary monopolist. With respect to quantity, however, the service provider sells strictly less than the volume brought to the market by the 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 expected profit of 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. See the Appendix. □

For intuition, recall that the service provider sets f_S^* such that the uninformed consumer's expected cost for the currency conversion corresponds to the monopoly fee, i.e.,

$$f^M = \frac{f_S^* + c}{2}. \tag{12}$$

Rewriting (12) yields

$$f_S^* - c = 2(f^M - c). \tag{13}$$

Thus, the service provider's profit margin is just twice the monopolist's margin. But the service provider's quantity is, as a result of randomization, just half of the monopolist's output. An alternative proof provided in the Appendix is based on the idea of convexification discussed before.

5.2. Consumer surplus and aggregate welfare

Putting the pieces together, our analysis shows that the advent of DCC technology at an otherwise competitive market for currency conversion may cause 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 (7). □

While the mechanics underlying this result have been sufficiently explained, it should be kept in mind that the service provider's monopoly power ultimately originates from the ability to frame the card holder's problem. The framing further bears the potential of confusing the consumer because the option of choosing the home currency, which may be viewed a focal point, implies accepting the offer of the foreign service provider.

Given the pervasiveness of DCC, Corollary 1 may be considered a very strong conclusion. We will therefore critically review the assumptions underlying our analysis in Section 6. Before we do that, however, it seems appropriate to discuss the implications of Corollary 1 for policy making.

5.3. An international free-rider problem

Corollary 1 seems to suggest that regulators should find it straightforward to agree to globally prohibit DCC. Alternatively, regulators could promote mandatory disclosures, competition among service providers at the point of interaction, or voluntary self-restriction by merchants. However, this conclusion is flawed as it ignores the international dimension of the problem. Specifically, for a 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 Mexican regulator might listen more carefully to local hoteliers than to U.S. consumer interest groups. Thus, national supervisors should wish to prohibit DCC abroad but not domestically. 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.

[19] As will be seen in Section 6, endogenizing the attention of uninformed consumers on the potential cost of using DCC even exacerbates this effect.

[20] In a more flexible specification, the term in the brackets on the right-hand side of equation (8) is taken to the power of some $\rho \in (0, \infty)$. In particular, as D_U is strictly concave for $\rho \in (0, 1)$, the conclusion of Proposition 3 can be illustrated for that case as well.

Supranational regulators in the European Union may be in a similar situation as national regulators, given that the large majority of member countries uses the euro as official currency. However, on February 14, 2019, the European Parliament adopted a proposal implementing additional transparency for currency conversion in cross-border payments *between two EU countries* (European Commission, 2018). This suggests that the institutions of the EU are, in principle, capable to resolve the free-rider problem within member states. However, the restriction to EU countries shows that regulation on a global level is less straightforward to achieve.

We conclude the discussion with two caveats. First, suppose that the DCC model is embedded into a Rochet and 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. On a more speculative note, this might be beneficial for the consumers, but more research on this issue seems desirable. 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)). However, 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.

6. Extensions and further discussion

Our analysis has relied on several simplifying assumptions. The present section aims to clarify the extent to which relaxing those assumptions would affect our conclusions.

6.1. Rational inattention[21]

We assumed above that consumers randomize across currency options that they perceive as equivalent. Alternatively, randomized choice may be rationalized as a consequence of limited attention, following Matějka and McKay (2012). For an extension along these lines, let $\lambda > 0$ denote consumers' cost of information acquisition. This parameter is exogenous and proxies the level of attention that is needed to select the option with the lower fee. Thus, if λ is small (large), then dealing properly with DCC requires little (much) attention. Moreover, with endogenous attention, the probability that the consumer makes use of the inferior DCC option is strictly declining in the corresponding difference in fees, $f_S - \underline{f}$, where the functional form is of a logistic nature. Therefore, given that issuers bid each other down as before, the service provider's optimal fee in the model with endogenous attention solves

$$f_S^{\lambda} = \arg\max_{f_S \geq 0} \frac{(f_S - c)e^{-f_S/\lambda}}{e^{-f_S/\lambda} + e^{-c/\lambda}} \cdot D_U\left(\frac{f_S e^{-f_S/\lambda} + ce^{-c/\lambda}}{e^{-f_S/\lambda} + e^{-c/\lambda}}\right). \qquad (14)$$

Thus, endogenous attention introduces an additional effect into the service provider's problem. Raising f_S not only affects expected profit through its effects on the profit margin and the expected fee, as before, but now also through a lower probability that the consumer chooses the service provider's offer. An analysis of problem (14), which unfortunately is more involved than our earlier arguments, leads to the following observation.

Proposition 5. *There is a threshold $\lambda^{\#} > 0$ such that the service provider's expected profit in the model with endogenous attention is equivalent to that of the monopolist for $\lambda \geq \lambda^{\#}$, but strictly lower (yet still positive) for $\lambda \in (0, \lambda^{\#})$.*

Proof. See the Appendix. □

What the proposition above says is that our main conclusions continue to hold in a model with endogenous attention, provided that the cost of information acquisition is not too low.

6.2. Feedback and learning

With reference to the Salop-Stiglitz framework, Varian (1980) convincingly argued that persistently higher prices for homogeneous products are ultimately implausible. In principle, that critique extends to the present analysis, because our model is static and thereby excludes the possibility of learning. In the case of DCC, however, it may be hard to tell in retrospect if some other payment option should have been preferred. A regular credit card invoice, for instance, does not allow that sort of comparison. Thus, learning from past experiences might be slowed down to some extent.[22] But learning is, of course, feasible, e.g., for consumers that travel a lot. What can be anecdotally observed as well, is that in environments that allow for consumer feedback (e.g., at leading online market places), transparency about the DCC option is more commonplace than in environments where reputational concerns matter less (say, in airport cabs). Empirical research on such issues seems to be missing, however.

6.3. Countermeasures taken by issuers and payment networks

While national regulators and consumer protection agencies can often do little more than issue general warnings, we found that issuers and payment networks actually take countermeasures in a variety of dimensions. For instance, to build closer links to merchants' banks, Mastercard (2017) has introduced a performance rewards program for acquirers. In another example, the Australian Federal Court had ordered Visa to pay a record A$18m penalty for breaching exclusive dealing laws by preventing banks and third party providers from rolling out DCC services to new merchants (Australian Competition and Consumer Authority, 2015). A third and final dimension in which issuers and networks seek to win the competition is through influence activities. For example, issuers may suggest the choice of local currency to their customers. Thus, issuers and networks do perceive service providers as competitors and do what is in their might to raise their market share in the market for currency conversion.

6.4. Search costs, imperfect competition, and product differentiation

Marginal cost pricing among issuers might be a fragile equilibrium if small but positive search costs have the potential to trigger an unraveling of the market in analogy to the Diamond Paradox (Diamond, 1971; Stiglitz, 1979). While we acknowledge the general validity of this argument, we also believe that publicly available websites allow consumers to easily identify issuers with advantageous conditions. In contrast, comparisons of service providers are not commonly found, maybe because consumers are rarely in the position to choose between any two of them. For similar reasons, a national regulator might find it easier to implement a price cap on domestic issuers than on a large number of service providers that operate in numerous jurisdictions and currency areas.

Next, competition between issuers could be imperfect. For example, customers might care more about domestic transactions than about international transactions, but these services are tied from the consumer's perspective. Alternatively, there might be collusion among issuers. If competition is imperfect, then the service

[21] We are grateful to an anonymous referee for suggesting this extension.

[22] This view would also be in line with Ausubel (1991) observation that interests on loans on credit cards may be sticky at a high level.

provider's position weakens, resulting in a lower fee and lower profits for the service provider. As the service provider sets its fee f_S such that its average with $\underline{f}$ corresponds to the monopoly price in the uninformed market, f_S^* is declining in $\underline{f}$.[23] Moreover, using the envelope theorem, it is easy to check that

$$\frac{\partial}{\partial \underline{f}}\left\{\frac{f_S^*-c}{2}D_U\left(\frac{f_S^*+\underline{f}}{2}\right)\right\} = \frac{f_S^*-c}{4}D_U'\left(\frac{f_S^*+\underline{f}}{2}\right) < 0, \qquad (15)$$

i.e., the service provider's expected profit declines. However, even in the weaker position, the service provider charges a fee above the monopoly level as long as the fee charged by the issuers stays sufficiently low to make it unattractive for the service provider to target the segment of informed consumers.

Product differentiation might provide some justification for DCC. For example, the service provider might show an amount of the home currency and fix the exchange rate at the time of the transaction. For the consumer, this eliminates the exchange rate risk between payment and settlement, i.e., over a period of usually a few business days. Moreover, the consumer may find the information about the definite amount useful. Still, unless the exchange rate in the transaction is very unstable, it seems unlikely that, under full transparency, consumers would be willing to accept the substantial mark-up in exchange for these limited benefits. Further, as already mentioned in the Introduction, much of the usefulness of naming a definite amount is owed to the fact that the service provider fails to show the *expected* amount to be charged by the issuer. This information could probably be provided, at least in online shops, as is evident from the positive example of travel platforms that state a price estimate in the consumer's currency but inform at the same time that the payment will be settled in local currency at the end of the trip.

6.5. Competition among service providers

Why is competition among service providers not eliminating the problem? To answer this question, suppose that $k \geq 2$ service providers compete in an *ex-ante* stage before the payment stage, so that only one service provider is ultimately visible to the consumer. Suppose also that each service provider offers a sharing rule (between the merchant and the service provider) for the fees earned through the currency conversion. In that case, service providers would bid each other down to marginal cost and leave almost all the revenues from DCC to the merchant. Thus, with the merchant taking over the bargaining position of the service provider, the conclusions of our analysis would not change.[24]

7. Conclusion

The present paper adds support to the view that DCC service providers are able to extract excessive rents from international consumers by imposing an opportunistically framed choice upon them. By withholding crucial information that would allow possibly inattentive consumers to make a good decision, the service provider creates a situation in which a typically inferior alternative is chosen with positive probability. Given that competitive forces work among issuers and there is a lack of informative feedback following the interaction, this trick allows the service provider to persistently charge fees above the monopoly level. The existing technology available for cross-currency settlement may therefore overturn, and even reverse, the usual welfare-enhancing effect of competition. Policy responses are available, but our results suggest that an international free-rider problem makes it hard to resolve the issue. Our analysis thereby provides an explanation of why the DCC debacle has been ongoing for many years despite a sizable body of evidence.[25]

Our analysis complements the findings of the literature on interchange fees in payment networks. However, our observations might 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 should, in particular, reflect the issuer's share of the profits from DCC (as a fourth party besides merchant, acquirer, and service provider). Thus, our analysis suggests also an alternative explanation for why interchange fees have empirically been found to be higher than the efficient level (Wright, 2012; Bedre-Defolie and Calvano, 2013).

We did not address all aspects of DCC. For example, some of the cost components for currency conversion scale up with the number of transactions while others are linked to the amount. An extension along these lines might lead to additional conclusions. Further, one might wonder why reputational concerns do not induce merchants to shun DCC altogether. We will, however, leave a more careful analysis of such issues for future work.

Appendix A. Proofs

This Appendix contains proofs of Proposition 2 through 5, as well as details on Example 2.

Proof of Proposition 2. The proof has five steps.

A1. Profit functions

We start by deriving firms' expected profits from an informed consumer. Provided that the informed consumer's willingness-to-pay weakly exceeds the lowest fee in the market, $\min(\underline{f}, f_S)$, the expected profit of issuer $i \in N$ from that consumer is given by

$$\Pi_i^I(f_1,\ldots,f_n;f_S) = \begin{cases} \frac{f_i-c}{m} & \text{if } f_i = \underline{f} < f_S \\ \frac{f_i-c}{m+1} & \text{if } f_i = \underline{f} = f_S \\ 0 & \text{otherwise,} \end{cases} \qquad (16)$$

where m denotes the number of issuers that charge $\underline{f}$. Similarly, the expected profit of the service provider from the same informed consumer reads

$$\Pi_S^I(f_1,\ldots,f_n;f_S) = \begin{cases} f_S-c & \text{if } f_S < \underline{f} \\ \frac{f_i-c}{m+1} & \text{if } f_S = \underline{f} \\ 0 & \text{otherwise.} \end{cases} \qquad (17)$$

Next, we derive firms' expected profits from an uninformed consumer. The expected profit of issuer $i \in N$ from an uninformed consumer with willingness-to-pay weakly exceeding $E[f] = (\underline{f} + f_S)/2$ is given as

$$\Pi_i^U(f_1,\ldots,f_n;f_S) = \begin{cases} \frac{f_i-c}{2m} & \text{if } f_i = \underline{f} \\ 0 & \text{otherwise.} \end{cases} \qquad (18)$$

[23] Note that we treat $\underline{f}$ here as exogenous to the service provider's problem.

[24] In an alternative set-up, the merchant might consider making more than one DCC service provider visible to the consumer, in which case service providers would compete at the payment stage. This, however, is unlikely to happen, as it has the potential of reducing the merchant's revenue from DCC. Thus, in line with the evidence, the discussion suggests that competition between service providers is unlikely to play out to the benefit of the customer.

[25] With Regulation 2021/1230, the EU Commission decided against a complete ban of DCC, making its use instead contingent on more comprehensive consumer information at the point of interaction. However, such requirements still do not allow an informed decision because the *direct comparison* of effective cost, e.g., in terms of estimates of the respective totals on the consumer's account statement is not part of the policy amendments. We further believe that existing regulation does not close the feedback loop (Subsection 6.2). Neither does the regulation appear to restrain the service provider's monopoly power (Subsection 6.5).

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

$$\Pi_S^U(f_1, \ldots, f_n; f_S) = \frac{f_S - c}{2}. \tag{19}$$

It is now easy to derive a firm's total expected profit. Given that informed demand is given by $D_I(\min(\underline{f}, f_S))$ and uninformed demand by $D_U(E[f])$, the expected profit of an arbitrary firm $i \in N_S$ may be written as

$$\begin{aligned}\Pi_i(f_1, \ldots, f_n; f_S) = &\alpha D_I\big(\min(\underline{f}, f_S)\big)\Pi_i^I(f_1, \ldots, f_n; f_S)\\ &+(1-\alpha)D_U(E[f])\Pi_i^U(f_1, \ldots, f_n; f_S).\end{aligned} \tag{20}$$

A2. Existence of f_S^*

We claim that the service provider's objective function in problem (3),

$$\underline{\Pi}_S(f_S) = \frac{f_S - c}{2} \cdot D_U\left(\frac{f_S + c}{2}\right), \tag{21}$$

admits a maximum f_S^* in $[0, \infty)$. Clearly, $\underline{\Pi}_S(f_S) < 0$ for $f_S \in [0, c)$, while $\underline{\Pi}_S(f_S) \geq 0$ for $f_S \in [c, \infty)$. Therefore, any maximum of $\underline{\Pi}_S$ must lie in the interval $[c, \infty)$. By Assumption 1(ii), we have $D_U(c) > 0$. Hence, by continuity, there exists $\varepsilon > 0$ such that $\Pi_S(c + \varepsilon) > 0$. Since $\underline{\Pi}_S$ is continuous, it suffices to show that $\lim_{f_S \to \infty} \underline{\Pi}_S(f_S) = 0$. This, however, is obvious if $D_U(f_S) = 0$ at some finite $f_S > 0$. Otherwise, i.e., if $D_U(f_S) > 0$ for all $f_S \geq 0$, then logconcavity of D_U combined with $D_U' < 0$ implies that D_U is declining exponentially to zero as $f_S \to \infty$. Indeed, since $\ln D_U$ is strictly declining and concave, there exists $L > 0$ such that $\ln D_U(f_S) \leq \ln D_U(0) - L f_S$. Applying the exponential function on both sides of that inequality implies that $D_U(f_S) \leq D_U(0) \cdot \exp(-L f_S)$, as has been claimed. This proves the assertion. □

A3. Uniqueness of f_S^*

We claim that $\underline{\Pi}_S(f_S)$ is strictly quasiconcave on the subinterval of $[c, \infty)$ where $D_U\left(\frac{f_S+c}{2}\right) > 0$. For this, consider a fee level $f_S > c$ satisfying $D_U\left(\frac{f_S+c}{2}\right) > 0$ as well as the first-order condition

$$\frac{1}{2} \cdot D_U + \frac{f_S - c}{4} \cdot D_U' = 0, \tag{22}$$

where we dropped the arguments. By a standard condition for strict quasiconcavity (Diewert et al., 1981), it suffices to show that

$$\underline{\Pi}_S''(f_S) = \frac{1}{2} \cdot D_U' + \frac{f_S - c}{8} \cdot D_U'' < 0. \tag{23}$$

However, by Assumption 1, we have $D_U'' \leq D_U'^2/D_U < 2D_U'^2/D_U$. Hence,

$$\underline{\Pi}_S''(f_S) < \frac{1}{2} \cdot D_U' + \frac{f_S - c}{4} \cdot \frac{D_U'^2}{D_U} \tag{24}$$

$$= \frac{D_U'}{D_U}\left(\frac{1}{2} \cdot D_U + \frac{f_S - c}{4} \cdot D_U'\right) \tag{25}$$

$$= 0. \tag{26}$$

Therefore, by continuity, the function $\underline{\Pi}_S$ defined through equation (21) is indeed strictly quasiconcave on the subinterval of $[c, \infty)$ where uninformed demand is positive.

A4. Equilibrium property

Clearly, no issuer has an incentive to operate below marginal cost. Suppose that $f_i > c$ for some $i \in N$. Then, issuer i loses any business with the informed consumers. However, issuer i also loses any 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 (3), and does not attract any informed consumer because informed consumers know the state of the world and would select the lower fees offered by the issuers.

A5. Equilibrium uniqueness

To provoke a contradiction, suppose that there is an equilibrium with fees $f_1, \ldots, f_n$ and f_S that differs from the equilibrium described in the proposition. Extending the standard uniqueness argument underlying 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 because of their second-order preference for market share. But given that$f_1 = \cdots = f_n = c$, this implies that $f_S = f_S^*$ must hold in equilibrium. This concludes the proof of equilibrium uniqueness, and thereby, of the proposition. □

Proof of Proposition 3. When providing DCC as an option to potentially uninformed consumers, the service provider solves

$$f_S^* = \arg\max_{f \geq 0} \frac{f_S - c}{2} \cdot D_U\left(\frac{f_S + c}{2}\right), \tag{27}$$

with corresponding first-order condition

$$\frac{f_S^* - c}{2} \cdot D_U'\left(\frac{f_S^* + c}{2}\right) + D_U\left(\frac{f_S^* + c}{2}\right) = 0. \tag{28}$$

We convexify the two problems (3) and (4) by considering the hypothetical profit function

$$\Pi(f, q) = (f - c)\left(1 - \frac{q}{2}\right)D_U\left(\left(1 - \frac{q}{2}\right)f + \frac{q}{2}c\right), \tag{29}$$

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

$$f_q = \arg\max_{f \geq 0} \Pi(f, q), \tag{30}$$

and the corresponding first-order condition may be reduced to

$$(f_q - c)\left(1 - \frac{q}{2}\right)D_U' + D_U = 0, \tag{31}$$

where we dropped 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. Indeed, taking the cross-derivative of (29), evaluating at $f = f_q$, and finally exploiting the first-order condition (31) yields

$$\left.\frac{\partial^2 \Pi(f, q)}{\partial q \partial f}\right|_{f = f_q} = -\frac{f_q - c}{2}\left(1 - \frac{q}{2}\right)\left\{2D_U' + (f_q - c)\left(1 - \frac{q}{2}\right)D_U''\right\}. \tag{32}$$

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

$$\left.\frac{\partial^2\Pi(f,q)}{\partial f^2}\right|_{f=f_q} = \left(1-\frac{q}{2}\right)^2\left\{2D'_U + (f_q-c)\left(1-\frac{q}{2}\right)D''_U\right\} < 0. \quad (33)$$

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

Proof of Proposition 4. As in the proof of Proposition 3, we consider the convexified problem

$$\Pi^*(q) \equiv \Pi(f_q, q) = \max_{f\geq 0}\Pi(f,q), \quad (34)$$

for $q \in [0,1]$, where $\Pi(f,q)$ is defined by (29). Recall that, for $q = 0$ and $q = 1$, respectively, problem (34) corresponds to the problem of the monopolist and the service provider. A straightforward application of the envelope theorem delivers

$$\frac{\partial\Pi^*(q)}{\partial q} = \left.\frac{\partial\Pi(f,q)}{\partial q}\right|_{f=f_q} \quad (35)$$

$$= -\frac{f_q-c}{2}\left\{D_U + \left(1-\frac{q}{2}\right)(f_q-c)D'_U\right\}, \quad (36)$$

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

$$\left.\frac{\partial\Pi(f,q)}{\partial f}\right|_{f=f_q} = \left(1-\frac{q}{2}\right)\left\{D_U + \left(1-\frac{q}{2}\right)(f_q-c)D'_U\right\} = 0, \quad (37)$$

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

The following auxiliary result will be used in the proof of Proposition 5.

Lemma A.1. *For any $\lambda > 0$, the mapping*

$$\phi(f_S) = \frac{f_S - c}{1+e^{(f_S-c)/\lambda}} \quad (38)$$

is strictly quasiconconcave on $[c,\infty)$ and assumes its maximum in $(c+\lambda,\infty)$. Its maximum value is given by $\phi_{\max}(\lambda) = \lambda\phi_0$ for some $\phi_0 > 0$.

Proof. Taking the derivative yields

$$\phi'(f_S) = \frac{\lambda(1+e^{(f_S-c)/\lambda}) - (f_S-c)e^{(f_S-c)/\lambda}}{\lambda(1+e^{(f_S-c)/\lambda})^2} \quad (39)$$

$$= \frac{\lambda - (f_S - c - \lambda)e^{(f_S-c)/\lambda}}{\lambda(1+e^{(f_S-c)/\lambda})^2}. \quad (40)$$

Therefore, $\phi'(f_S) > 0$ if and only if either (i) $f_S \leq c+\lambda$ or (ii) $f_S > c+\lambda$ and

$$\frac{\lambda}{f_S-(c+\lambda)} > e^{(f_S-c)/\lambda}. \quad (41)$$

Noting that, considered as a function in f_S over the interval $(c+\lambda,\infty)$, the left-hand side of (41) is strictly declining, with values ranging over $(0,\infty)$, while the right-hand side is positive and strictly increasing, ϕ admits a unique interior maximum. The second claim follows from the fact that the maximum value of $\phi(f_S)/\lambda$ does not depend on λ. □

Proof of Proposition 5. Rewriting problem (14) yields

$$f_S^\lambda = \arg\max_{f_S\geq 0} \frac{f_S-c}{1+e^{(f_S-c)/\lambda}}\cdot D_U\left(\frac{f_S-c}{1+e^{(f_S-c)/\lambda}}+c\right). \quad (42)$$

Applying the substitution

$$\frac{\hat{f}_S-c}{2} = \frac{f_S-c}{1+e^{(f_S-c)/\lambda}}, \quad (43)$$

and exploiting Lemma A.1, problem (42) is seen to be equivalent to

$$\hat{f}_S^\lambda = \arg\max_{\hat{f}_S\geq 0} \frac{\hat{f}_S-c}{2}\cdot D_U\left(\frac{\hat{f}_S+c}{2}\right) \quad (44)$$

$$\text{s.t. } \frac{\hat{f}_S-c}{2} \leq \lambda\phi_0.$$

As shown in the proof of Proposition 2, the objective function in (44) is strictly quasiconcave. Therefore, the constrained problem admits a unique solution $\hat{f}_S^\lambda$, for any $\lambda > 0$. Moreover, there is a threshold value $\lambda^\# > 0$ such that the following holds true. For $\lambda > \lambda^\#$, the constraint is not binding, and there are precisely two solutions for f_S^λ. For $\lambda = \lambda^\#$, the constraint is binding with vanishing multiplier, and there is precisely one solution for f_S^λ. Finally, for $0 < \lambda < \lambda^\#$, the constraint is binding with positive multiplier and there again is precisely one solution for f_S^λ. In that case, the service provider's expected profit is strictly lower than the monopoly profit, approaching zero as λ goes to zero. □

Details on Example 2. As noted above, the isoelastic demand specification does not satisfy Assumption 1. Below, we outline the changes that need to be made to the proof of Proposition 2 to cover this case (the other proofs need no changes). A first change concerns the proof of existence of f_S^*. Specifically, we need to check the boundary condition

$$\lim_{f_S\to\infty}\frac{f_S-c}{2}\cdot D_U\left(\frac{f_S+c}{2}\right) = 0. \quad (45)$$

It suffices to show that

$$\lim_{f\to\infty} fD_U(f) = 0. \quad (46)$$

Indeed, if (46) holds, then also $cD_U(f)$ tends to zero as $f\to\infty$, so that (45) holds true. But relationship (46) is obvious in the isoelastic case where $D_U(f) = f^{-\eta}$ with $\eta > 1$. Second, we need to check that the unboundedness of D_U at zero does not interfere with existence. But $\underline{\Pi}_S < 0$ on the interval $(0,c)$. Third, to obtain uniqueness of f_S^*, we need to check that the isoelastic specification satisfies $D''_U D_U - 2D'^2_U < 0$. This, however, can be readily verified since

$$D''_U D_U - 2D'^2_U = \left(\eta(\eta+1) - 2\eta^2\right)D_U = -\eta(\eta-1)D_U < 0. \quad (47)$$

With these changes in place, the proof goes through as before. □

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