Your network or mine? The economics of routing rules

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Abstract

In many markets, including payment cards and telecommunications, service providers operate networks that support customer transactions with each other. When the two sides of a transaction belong to more than one network in common, the question of which network will carry the transaction arises. We show that the answer depends on a combination of who has the formal authority to choose and the parties' network subscription decisions. Our central finding is that granting formal authority to one side of the market can increase the extent to which transactions run over the network preferred by the other *side of the market. We also characterize competing networks' equilibrium choices of routing rules and prices.*

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Acknowledgements

The authors wish to thank John Morgan, Patrick Rey, Jean-Charles Rochet, Theresa Sullivan, two anonymous referees, an editor, and seminar participants in Berkeley and Toulouse for helpful comments. Financial support from the Willis H. Booth Chair in Banking & Finance and the Sarin Chair in Strategy & Leadership is gratefully acknowledged.

1. Introduction

In many markets, service providers operate networks that support the interactions of their customers. Examples include payment systems, telecommunications networks, advertiser-supported media, and social clubs.[1] Absent network interconnection and interoperability, two users must belong to the same network in order to transact with one another. Often, however, a single user can participate in multiple networks. When two users wish to transact with one another and they participate in multiple networks in common, the question arises, who decides which network carries the transaction? The answer is the subject of this paper.[2]

An example helps fix ideas. A credit or debit card network can be thought of as facilitating transactions between retail merchants on one side and card-issuing banks or card-holding consumers on the other.[3] A notable feature of the credit and debit card industries is that a typical merchant accepts cards that run over several different networks and a typical consumer holds a portfolio of cards that are collectively capable of running over multiple networks. Indeed, in the United States, at least, many financial institutions issue debit cards where each card is capable of running over multiple networks. Consequently, when a consumer presents his or her debit card to a merchant to make a purchase, it is often possible to complete a given transaction over several different debit networks. This raises the issue of who chooses the specific network used.

The answer depends, in part, on the technology used to authenticate the cardholder at the time of the transaction. The leading authentication methods today are signature and personal identification number (PIN). It is estimated that between 65 and 80 percent of debit cards are

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[1] Settings in which suppliers match two sides of a transaction have become known as two-sided markets. There has been considerable work on two-sided markets in recent years. Notable examples include Armstrong (2004), Caillaud and Jullien (2001, 2003), Doyle and Smith (1998), Hahn (2003), Hermalin and Katz (2004), Jeon et al. (2004), Kim and Lim (2001), Laffont et al. (2003), Rochet and Tirole (2003, 2004), Squire (1973), and Srinagesh and Gong (1996). Papers specifically considering the two-sided-market aspects of card payment systems include Schmalensee (2002), Tieman and Bolt (2003), Guthrie and Wright (2003), and the papers discussed by Rochet (2003) in his survey.

[2] Like us, Caillaud and Jullien (2001, 2003) and Rochet and Tirole (2003) consider competition between networks. These papers do not, however, focus on the question of routing rules, as they each assume a specific routing rule, which is taken as fixed *exogenously.* Our focus, instead, is on the endogenous determination of routing rules. Moreover, Caillaud and Jullien and Rochet and Tirole's papers assume the members of one or both sides of the market have homogenous preferences *vis-à-vis* the networks. In contrast, much of our attention is on situations in which the members of each side have heterogenous preferences *vis-à-vis* the networks.

[3] Actual debit networks are somewhat more complicated. Financial institutions that issue cards and acquire transactions for merchants are the actual members of a debit network. Cardholders are customers of the card-issuing banks, while merchants are customers of the acquiring banks. Moreover, physical routing decisions may be made by merchant processors, who handle the mechanics of routing transactions. Our simplified setting captures the important economic forces that underlie the routing issue.

both PIN and signature enabled, and the choice between modes of authentication is typically made by the consumer, subject to incentives provided by merchants and card issuers.[4] If the consumer chooses signature authorization, then there is no additional network choice because any given card is associated with at most one signature network. But if a consumer chooses to use PIN-authentication, then there typically is a second choice to be made. The average merchant location that accepts PIN debit accepts the cards of approximately three different PIN debit networks.[5] And the average debit card can be run over 1.7 PIN debit networks.[6] Hence, when a consumer presents his or her PIN debit card, there is often a choice of which PIN debit network to use. This choice is determined by contractual agreements between debit networks and their merchant and issuer members, not the debit card holder.[7] The specification of which PIN network is used when there are multiple networks available is known as a routing rule.

There are several types of routing rule:

- ISSUER ROUTING: Transactions are routed according to issuer instructions.
- MERCHANT ROUTING: Transactions are routed according to merchant instructions.
- NETWORK ROUTING: A network requires that any transaction that can go over it must go over it; that is, if both the issuer and merchant are affiliated with a network utilizing this routing rule, then they must transact over it.[8]

Although not formally a routing rule, it is evident that if a merchant or issuer participates in only one debit network, then that exclusivity has the effect of choosing the routing.[9] Hence, we will

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[4] EFT Data Book 2004, *ATM & Debit News,* September 11, 2003, at 3; *The Nilson Report,* No. 785, April 2003, at 6-7; Dove Consulting, *Debit Issuer Survey: Cardholder Fees and Industry Outlook,* August 2, 2002, at 16.

[5] Calculation based on data reported in EFT Data Book 2004, *ATM & Debit News,* September 11, 2003; *The Nilson Report,* No. 785, April 2003; NYCE, “NYCE Statistics,” available at www.nyce.net/newsroom_stats.html; Star, “About Star,” available at www.star.com/?go=about.glance; and Visa, *Visa Quarterly Report*, August 2003, available at www.usa.visa.com/media/global/Q22003.pdf.

[6] Calculations based on data reported in EFT Data Book 2004, *ATM & Debit News,* September 11, 2003.

[7] In the case of merchants, the formal contractual relationship with the network may actually be between the network and a financial institution (acquiring bank) that represents the merchant in dealings with the network.

[8] At present, STAR, the largest PIN debit network, uses network routing, while the NYCE network and several others use issuer routing. We are not aware of any network that utilizes merchant routing. In the past, because their owners also owned competing debit networks, MasterCard and Visa discouraged use of their debit networks, Maestro and Interlink, by positioning them as networks of last resort. Maestro now offers issuer routing, while Interlink reportedly relies on volume discounts to encourage exclusivity.

[9] Although we are not aware of any other routing rules used in practice, in theory there could be several other

also explore the effects of a network's imposing the requirement that a merchant or issuer or both belong uniquely to that network.

Below, we present our model using language appropriate to debit card networks. However, some of the same issue also arises in other contexts. As noted above, for example, merchants often accept the credit cards of multiple networks. Although credit card issuers typically pick a single network for a given card to run over, a consumer may carry multiple credit cards in his or her wallet and choose which card to present when making payment at a merchant. Hence, credit cards networks can be thought of as having cardholder routing. The broader issue of choosing among payment instruments (*e.g.,* cash versus check versus debit card versus credit card) can also be viewed in these terms.

Similar issues arise in communications networks. For example, many people subscribe to both wireline and mobile telephone networks. The costs and benefits of message exchange incurred by the sender and receiver may depend on which network is used to complete a call. In this case, there is caller routing: through his or her choice of the number to dial, the caller determines whether the call is completed over a fixed-line or wireless network. The called party can influence the choice of routing both through his or her network subscription choices and by the choice of how widely to disseminate his or her different telephone numbers.

Routing issues also arise on the Internet because many local Internet service providers (ISPs) and web-hosting services are connected to multiple Internet backbone service providers.[10] Shipping represents another example of routing choice; sometimes merchants choose the routing, sometimes consumers are given the choice, and the parties have some choice as to which networks they belong (*e.g.,* in the US, a consumer with a post office box has effectively chosen not to belong to the DHL or FedEx networks). Retail stores, which are distribution networks that allow consumers to transact with manufacturers, provide an additional example of routing choices. Lastly, the choice of the word processing program in which to write a collaborative paper on routing rules is a further example in which parties have to choose a common network over which to transact.

As the examples above illustrate, the choice of routing is determined by a combination of

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routing rules, such as stochastic assignment of routing authority, or a network might offer a menu of routing options rather than a single option as in the text. Suppose, for example, that issuers tended to be of two types: those with medium valuations of both networks and those with a high value of one network and a low value of the other. A network might sort its customers by offering a menu in which issuer routing had a higher transactions price than did network routing.

[10] Crémer et al. (2000) provide an analysis of an ISP's incentives to connect to multiple Internet backbones.

formal authority (*i.e.,* which party is delegated the right to choose a network), network subscription decisions, and the distribution of information about available options. Our focus is on the interplay between formal authority and subscription decisions. We assume that the party with routing authority (or its agent) knows the set of options available for completing any given transaction. In the payment card industry, consumers rely on point-of-sale signage, and merchants and issuers rely on electronic databases. Similarly, electronic and paper directories are generally available in the telecommunications sector.[11]

We characterize users' equilibrium membership decisions for each of the routing rules identified above. Our central finding is that granting formal authority to one side of the market can increase the extent to which transactions run over the network preferred by the *other* side of the market. Intuitively, the side that does not have formal authority has stronger incentives to subscribe solely to its preferred network, which trumps the other side's formal authority.

We also characterize the networks' equilibrium choices of routing rules. Our focus is on the case in which all of the routing rules above are available to the networks, as is true of the debit-card industry. We establish conditions under which competing networks adopt routing rules that delegate the choice to one side of the market rather than imposing network routing or exclusivity. Intuitively, a delegated routing regime serves to get many people on both networks, which lessens the all-or-nothing type of competition that exists with network routing or exclusivity. Moreover, because many people join both networks, the volume of trade is greater.

In some of the industry examples discussed above, not all of the routing options that are logically feasible are technically, legally, or politically feasible. For instance, suppose that a merchant accepts a variety of payment instruments, including cash, checks, and specific brands of credit cards. The merchant typically will lack both the knowledge of which of those payment instruments are held by a given customer and the authority to demand that the customer reveal that information. Consequently, merchant routing and network routing will be infeasible. Similarly, with retail stores, only consumer routing and manufacturer exclusivity are generally feasible. Nonetheless, the insights of our analysis with respect to the interplay of formal authority and network subscription decisions continue to apply. Moreover, we present a simple normal-form game for routing-rule choices, and one can readily strike rows and columns from this analysis to apply it to specific market settings

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[11] We note that the decision to have an unlisted mobile or home telephone number can be modeled as choosing not to be on that network for purposes of receiving calls.

with more limited sets of potential routing rules.

Our analysis proceeds as follows. In the next section, we present a simple model of routing choice and network competition. We solve the model working backward in time, beginning with an analysis of consumers' network connection decisions in Section 3. We examine network price competition in Section 4. The choice of routing regime and the equilibrium in the overall game are characterized in Section 5, which also examines the welfare properties of alternative equilibria. After considering two extensions and one detailed special case of the model in Section 6, the paper closes with a brief concluding section.

2. A model

Two sides of a market need a network over which to complete a transaction. Let A denote a member of the one side (*e.g.,* a PIN debit card issuer) and B denote a member of the other side (*e.g.,* a merchant). Assume the two have been paired and that they wish to conduct a transaction with one another. There are two networks, denoted X and Y, over which transactions can potentially be completed. A and B can actually complete a transaction over a given network only if they both belong to that network.

Let a_z and b_z denote the gross consumption benefits enjoyed by A and B, respectively, if the transaction is completed over network z, $z \in \{X, Y\}$. If no transaction is completed, then the payoff to each side is zero.

We assume that the gross benefits, a_z and b_z, are exogenously fixed. This assumption implies that A and B do not go outside of the arrangements defined by their network contracts by negotiating side payments that depend on the choice of network.[12] This assumption holds when the networks ban such transfers (as some payment networks do) or when parties use the networks to conduct low-value transactions with a large number of trading partners and transaction and bargaining costs would outweigh the potential benefits of inter-user transfers.[13]

Consumption benefits are randomly distributed.[14] We assume that $(a_X, a_Y) \sim F_A$ on the

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[12] For an analysis of some of the consequences of relaxing this assumption, see Gans and King (2003).

[13] If A is a card holder and B a merchant, for example, then this assumption implies that the price B charges A for his or her purchase is unaffected by the network used to complete the transaction, which is typically the case in the United States. This assumption also applies to telephone calls between households, where there are typically no direct monetary transfers between callers.

[14] In the debit context, different valuations can be interpreted as the extent to which merchants and issuers care about underlying differences in non-price network characteristics, such as consumer perceptions of the networks'

rectangle $\mathcal{I}_A \subset \mathbb{R}^2_+$ and $(b_X, b_Y) \sim F_B$ on the rectangle $\mathcal{I}_B \subset \mathbb{R}^2_+$.[15] Unless stated otherwise, we assume that the distribution functions are differentiable, with positive derivatives everywhere on the interior of their respective support rectangles. We also assume that (a_X, a_Y) and (b_X, b_Y) are distributed independently of each other; that is, knowledge of one side's preferences does not provide information about the other side's preferences.

The marginal costs of completing a transaction, c, are constant across all transactions and networks. We also assume the networks incur no fixed costs to add members.

It is taken to be common knowledge that the structure of the game is as follows:

1. The networks simultaneously choose their routing rules; specifically each network chooses to have issuer routing, merchant routing, network routing, or to require exclusive network membership. Each network sets a single routing rule (*i.e.,* we don't allow a network to offer different routing rules to different clients or to utilize the choice of routing rule for the purpose of price discrimination).[16]

2. After observing routing choices, the networks simultaneously choose their prices. In principle, these prices could include fixed membership (subscription) charges, as well as per-transactions charges. In the present analysis, we restrict attention to per-transactions charges, denoted by p_{zk}, where $z \in \{X, Y\}$ and $k \in \{A, B\}$.[17]

3. A and B learn the values of (a_X, a_Y) and (b_X, b_Y), respectively. These values are the private information of the individuals.

4. A and B simultaneously choose the networks to which to belong and — where they have the right — specify their routing choices. For example, if both networks implement issuer routing, then the issuer specifies which network has priority and that choice is recorded in the relevant routing databases.

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brand names, network reliability and accuracy, and the provision of ancillary services.

[15] For expositional convenience we limit attention to non-negative values, but nothing in the analysis relies on this assumption.

[16] A more general setup would permit each network to offer menus of routing rules and prices. The well-known difficulties of solving models of competition in menus make such a setup intractable. Moreover, we are unaware of any payment-card network offering different routing rules to different clients or as part of a menu.

[17] The total amounts collected by US debit networks through fixed fees levied on merchants and card issuers are very small in comparison with the amounts collected on a per-transaction basis.

5. A and B meet to conduct a transaction. If A and B are on different networks, then there is no transaction. If they have only one network in common, then the transaction is conducted on that network. If they have each joined both networks, then the network utilized is determined according to applicable routing rules. We assume that routing rules are always honored.[18] For expositional convenience, we also assume that a member of a network cannot refuse a feasible trade that satisfies the routing rules.[19]

6. Payoffs are realized.

Our equilibrium concept is Bayesian Nash equilibrium refined by imposing a Trembling Hand Perfection requirement.

Our welfare measure is total surplus. Trade should occur if and only if

$$\max_z a_z + b_z \geq c\,.$$

We refer to a situation in which trade fails to occur optimally as *trade inefficiency*. If trade is efficient, a transaction should be completed on network Y rather than network X if and only if

$$a_Y + b_Y \geq a_X + b_X\,. \tag{1}$$

We will refer to a trade that violates (1) as a *routing inefficiency*.

3. The connection-continuation game

We begin by solving the continuation game that arises once the networks have chosen their routing rules and prices, and users A and B have learned the values of (a_X, a_Y) and (b_X, b_Y), respectively.

The surplus levels A and B derive if the transaction is completed on network z are $s_{zA} \equiv a_z - p_{zA}$ and $s_{zB} \equiv b_z - p_{zB}$, respectively. It proves convenient to define

$$s_{hk} \equiv \max\{s_{Xk}, s_{Yk}\} \text{ and } s_{\ell k} \equiv \min\{s_{Xk}, s_{Yk}\}\,.$$

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[18] This assumption clearly is reasonable when the party with routing authority directly implements the physical routing (*e.g.,* under merchant routing). When the party with routing authority does not implement the physical routing (*e.g.,* a PIN debit network with a network routing rule), we assume there is a monitoring technology that supports enforcement. For example, PIN debit networks monitor and analyze merchants' traffic volumes to determine whether these volumes are what would be expected given the population of card holders if merchants were complying with applicable routing rules.

[19] Given that we do not allow users A and B to bargain with one another, and that the surplus one side derives from a transaction depends solely on the network and its price, relaxing the assumption would not change equilibrium payoffs or network utilization. It would, however, always have to be stated that users were not joining networks that offered them non-positive surplus or, equivalently, were joining them, but vetoing trade over them. Our assumption that merchants and issuers cannot veto feasible trades mirrors actual practice in payment-card systems.

When $s_{hk} > 0$, we can define the ratio of the surplus on the lower-surplus network to the higher-surplus network for party k:

$$r_k \equiv \frac{s_{\ell k}}{s_{hk}}\,.$$

In what follows, it should be understood that the prices have been set so that there is a positive probability that each of A and B can gain surplus from transacting over either network. That is, $\Pr\{s_{zk} > 0\} > 0$ for all (z, k) pairs.

There is never any gain to k from joining network z if $s_{zk} \leq 0$. Moreover, joining a network for which $s_{zk} \leq 0$ could be distinctly disadvantageous (*e.g.,* when $s_{Xk} > 0 \geq s_{Yk}$ but the operative routing rule requires that, if the parties are on both networks, trade be on Y). Given the possibility of trembles by the other party, party k does better not to join network z if $s_{zk} < 0$ because k can never be assured trade will not go over z. Because even trade that generates positive surplus with small probability beats a certainty of no trade, the possibility of trembles means that a strategy of joining neither network is strictly dominated if a party would derive positive surplus from completing a transaction on one or both networks.

We have established:

Lemma 1. For $k = A, B$:

(i) If $s_{hk} < 0$, then party k joins neither network.

(ii) If $s_{hk} > 0 > s_{\ell k}$, then party k must join network h and not join ℓ.

(iii) If $s_{\ell k} > 0$, party k must join at least one of the two networks.

As we will see, whether k joins X, Y, or both in case (iii) depends on the nature of the routing rules, among other factors. In what follows, we assume that user k stays off network z when $s_{zk} = 0$ (even if k controls the routing choice) because k can never benefit from joining z. In any case, $s_{zk} = 0$ is a measure-zero event, and its treatment is immaterial.

One-side-chooses routing

Some routing rules, such as issuer or merchant routing in the PIN-debit industry, grant one side of the transaction the right to set the network that will be utilized when both A and B belong to both networks. If both networks choose an issuer-routing rule or both choose a merchant-routing rule, then the interpretation of contracts between networks and their members is clear. However, if one network chooses merchant routing and the other chooses issuer routing, then contractual conflicts can arise. Suppose, for instance, that issuer A gives priority to network X under X's issuer-routing rule, but merchant B gives priority to network Y under Y's merchant-routing rule. There is no obvious way such conflicts should be resolved. In this subsection, we therefore limit attention to situations in which both networks have chosen the same routing rule.[20]

Without loss of generality, we consider only the case in which both networks give A the authority to choose the routing.[21] Clearly, when given the authority, A assigns priority to X if $s_{XA} > s_{YA}$ and Y if $s_{XA} < s_{YA}$. Moreover, given that A's selection governs when multiple networks are available, and given that B may tremble, the only rational strategy for A is to join any network for which $s_{zA} > 0$. Figure 1 illustrates A's network membership and routing choices as a function of its type. Observe that A's optimal strategy is independent of B's strategy.

The more subtle question is: What network membership choices does B make when both s_{XB} and s_{YB} are positive? Intuitively, even though A has formal routing authority, B can exercise control of routing by choosing to join solely its preferred network. The cost of doing so, however, is that A might not join that network, making it impossible to complete a transaction that would otherwise generate positive surplus for B.

To analyze B's network membership choice formally, consider the expected value of different choices, making use of A's equilibrium strategy and the distribution of (a_X, a_Y). Let α_X denote the resulting probability that A joins network X only, α_Y the probability that A joins network Y only, and α_{XY} the probability that A joins both networks. B's respective expected payoffs from joining X only, Y only, and both networks are

$$\begin{aligned}
\pi_X^B &= s_{XB}(\alpha_X + \alpha_{XY})\,, \\
\pi_Y^B &= s_{YB}(\alpha_Y + \alpha_{XY})\,, \text{ and} \\
\pi_{XY}^B &= s_{XB}\alpha_X + \alpha_{XY}\,(\,\lambda_X s_{XB} + \lambda_Y s_{YB}) + s_{YB}\alpha_Y\,,
\end{aligned}$$

where λ_z is the probability that A has assigned network z priority *conditional* on A's having chosen to join both networks. By definition, $\lambda_X + \lambda_Y \equiv 1$.

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[20] We return to this issue in Section 5 below.

[21] The analysis when B is given the authority is symmetric.

It is apparent that B joins both networks if and only if $\pi^B_{XY} \geq \pi^B_h$ (where h is the network that yields B the higher surplus and ℓ is the network that yields B the lower surplus). Using $s_{\ell B} = r_B s_{hB}$ and $\lambda_h = 1 - \lambda_\ell$, this condition is equivalent to

$$0 \leq \alpha_{XY} \lambda_\ell \left(r_B - 1 \right) + r_B \alpha_\ell \, . \tag{2}$$

From this last expression, we see that B should join both networks when B is largely indifferent between them (*i.e.,* r_B not too much less than one) or it is relatively likely that A will be on B's less-preferred network only (*i.e.,* α_ℓ large). Otherwise, B should join only its preferred network to avoid the risk of having to transact on its less-preferred network. Figure 2 illustrates B's strategy as a function of its preferences. The slopes of the rays $\overrightarrow{O'U}$ and $\overrightarrow{O'V}$ are

$$\frac{\alpha_{XY}\lambda_X + \alpha_X}{\alpha_{XY}\lambda_X} \text{ and } \frac{\alpha_{XY}\lambda_Y}{\alpha_{XY}\lambda_Y + \alpha_Y} \, ,$$

respectively (where the slopes derive from expression (2) above).

We have established:

Proposition 1. If A chooses the routing, then there exists a unique equilibrium of the connection-continuation game, which has the following properties:

(i) If $s_{hk} \leq 0$, k joins neither network, $k = A, B$;

(ii) If $s_{hk} > 0 \geq s_{\ell k}$, k joins network h only, $k = A, B$;

(iii) If $s_{\ell A} > 0$, then A joins both networks;

(iv) If $s_{\ell B} > 0$ and condition (2) holds, then B joins both networks; and

(v) If $s_{\ell B} > 0$ and condition (2) does not hold, then B joins only network h.

A sense for the nature of this equilibrium can be gained by considering the limiting case in which $p_{XA} = p_{YA} = 0$. In this case, all types of A join both networks and B therefore joins its preferred network only. In this limiting case, we see that although A has the nominal choice of routing, B actually has the real choice of routing: in equilibrium, A and B conduct their transaction on B's preferred network. In essence, A and B play a game of chicken in which only A's car has a steering wheel; not surprisingly, A is thus the "loser." Expressed another way, network membership decisions can trump formal authority over routing decisions, and a user who cannot control the routing choice has greater incentives to join solely his or her preferred network than does a user who can choose among networks on a transaction-by-transaction basis.

Figures 1 and 2 illustrate some of the welfare properties of this equilibrium. Let A_n and B_n denote specific types of A and B. Assume that $p_{zA} + p_{zB} = c$ for both z.[22] If A_1 is paired with B_1, then a trade inefficiency occurs; $a_Y + b_Y > c$, yet no transaction is completed. If A_2 is paired with B_2, then a routing inefficiency occurs; as drawn, $a_X + b_X > a_Y + b_Y$, yet the transaction is conducted on Y (B_2's preferred network). This distortion arises because B ignores the adverse effect on A from B's decision to force trade over Y by joining solely that network. Routing inefficiency also occurs when A_3 and B_3 are paired; $a_Y + b_Y > a_X + b_X$, yet the transaction is conducted on X (A_3's preferred network). Here, A ignores B's preferences when A picks the routing.

Network routing

An alternative regime for network selection when A and B have joined both networks is *network routing*, under which a network stipulates that, whenever possible, its members must conduct their transactions on it.

If both networks specify network routing, then conflict arises if A and B both subscribe to both networks. Because such conflict would lead to a breach of contract with at least one of the networks, we assume each party signs with at most one network when both networks impose network routing.[23] Observe, however, that if only one network adopts network routing, while the other adopts another routing regime (*e.g.,* merchant routing), then it is possible for a party to join both networks.

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[22] The figures illustrate the case in which $p_{XA} + p_{XB} = p_{YA} + p_{YB}$.

[23] If the parties could somehow coordinate, it would be possible for only one side (say A) to sign with at most one network, while the other side (B) could then sign with both with no risk of breach of contract. That case is, however, identical to a regime in which A is limited to exclusive membership in at most one network, which we consider below in our discussion of one-sided exclusivity.

Both networks adopt network routing

Suppose both networks have adopted network routing. The following lemma indicates that the resulting exclusivity could lead to tipping.

Lemma 2. Suppose that both networks implement network routing. If and only if

$$\Pr\{s_{zk} \leq 0 \text{ and } s_{z'k} > 0\} = 0$$

for $k = A$ and B, $z = X$ or Y, and $z' \neq z$, then there exists an equilibrium of the connection-continuation game in which any user who joins a network joins only network z.

The intuition underlying this result is straightforward. Consider an X-only equilibrium. If the condition stated in the lemma did not hold, a positive measure of types on one side of the market would have incentives to join network Y in hopes of trembles by the other side of the market. When the condition is satisfied, there is no reason for anyone to join network Y given that there is a vanishingly small probability that anyone from the other side of the market will be on that network as a potential trading partner. Observe the condition in Lemma 2 includes the special case in which, with probability one, both A and B derive positive surplus from trade regardless of network. In this case, both an X-only equilibrium and a Y-only equilibrium exist (*i.e.,* the market could tip in favor of either network). Moreover, interior pure-strategy equilibria can exist in addition to the corner equilibria.

We next consider the possibility of equilibria in which both networks obtain members. Specifically, we now assume that

$$\Pr\left\{s_{Xk} \leq 0 \text{ and } s_{Yk} > 0\right\} \times \Pr\left\{s_{Yk} \leq 0 \text{ and } s_{Xk} > 0\right\} > 0 \text{ for } k = A,\, B\,. \tag{3}$$

This assumption ensures that there are types of A and B that are realized with positive probability that choose to be on only network X and user types that are realized with positive probability that choose to be on only network Y.

Consider a B for whom $s_{hB} > 0$. This user's best response is join X if and only if $\alpha_X s_{XB} > \alpha_Y s_{YB}$. Recall, α_z is the equilibrium probability that A joins z only. From assumption (3) and Lemma 1, $\alpha_z > 0$ for both z. Figure 3 illustrates. The analysis and resulting picture for A are similar.

Observe from Figure 3 that we can conceive of B's best response as being the placement of the ray $\overrightarrow{O'U}$ that divides the join-X-only region from the join-Y-only region. Because that ray is always "hinged" at O', placing the ray is equivalent to choosing the angle $\theta \in [0°, 90°]$.

In the Appendix, we establish:

Proposition 2. Suppose both networks implement network routing and that assumption (3) holds. Then there is at least one pure-strategy equilibrium of the connection-continuation game. Any pure-strategy equilibrium has the following properties:

(i) If $s_{hk} \leq 0$, then k joins neither network, $k = A, B$;

(ii) If $s_{hk} > 0$, then k joins only network X if $s_{Yk} < s_{Xk} \tan(\theta_k)$, and k joins only network Y if $s_{Yk} \geq s_{Xk} \tan(\theta_k)$, $k = A, B$; and

(iii) The angles θ_A and θ_B lie in $(0°, 90°)$ and satisfy the relations

$$\tan(\theta_A) = \frac{\beta_X(\theta_B)}{\beta_Y(\theta_B)} \text{ and } \tan(\theta_B) = \frac{\alpha_X(\theta_A)}{\alpha_Y(\theta_A)},$$

where $\alpha_z(\theta_A)$ and $\beta_z(\theta_B)$ are the probabilities of realizing types of A and B, respectively, who join network z under condition (ii).

As we show by example, in Section 4 below, multiple pure-strategy of the connection-continuation game can exist when both networks adopt network routing.

Observe that the use of network routing can frequently lead to trade inefficiency. Because the two sides of the market have heterogeneous preferences and are forced to make exclusive choices, there can be many instances in which trade would be mutually beneficial, but the two sides have chosen to be on different networks and thus cannot transact.

Routing inefficiency is also possible unless all three of the following conditions are satisfied: (a) $\theta_A = \theta_B = 45°$; (b) $p_{XA} = p_{YA}$; and (c) $p_{XB} = p_{YB}$. Without conditions (b) and (c), the parties' choices of network will reflect the relative transactions prices of the two networks, rather than solely the gross consumption benefits. Condition (a) is needed to insure that neither A nor B is on its less preferred network. If one were, then routing inefficiency could readily arise. This possibility can be seen by considering types near the 45° line in Figure 3.

Only one network stipulates network routing

Now suppose that only one network, say X, stipulates network routing. Whether Y selects an A-chooses regime or a B-chooses regime is irrelevant because, whenever the transaction can go over both networks, the party with the choice must choose X to avoid breaching its contract with that network.[24]

In this regime, there cannot be equilibria in which only one network attracts members: If party k thought there were even a minuscule probability the other party would be on the other network (as well or only), then a measure of types of party k bounded away from zero would wish to be on both networks, as the ensuing analysis will confirm. Hence, a one-network-only-has-members equilibrium cannot be the limit of the equilibria as trembles go to zero. Intuitively, users who would get positive surplus from both networks, but prefer X, would never join only Y because joining X too would increase expected surplus if there were any chance that the other side of the market would join X. And users who would get positive surplus from both networks but preferred Y would never join solely network X because there would be positive option value from joining Y too.

In the Appendix, we construct an equilibrium in the connection-continuation game with the following characteristics:

Proposition 3. Suppose that network X stipulates network routing and network Y stipulates either A or B routing. Then, for $k = A, B$, there exists at least one pure-strategy equilibrium of the connection-continuation game. Any pure-strategy equilibrium has the following properites:

(i) If $s_{hk} \leq 0$, then k joins neither network;

(ii) If $s_{hk} > 0 \geq s_{\ell k}$, then k joins network h only;

(iii) If $s_{Xk} > s_{Yk} > 0$, then k joins both networks;

(iv) If $s_{Yk} > s_{Xk}\tan(\theta_k) > 0$, then k joins Y only; and

(v) If $s_{Xk}\tan(\theta_k) \geq s_{Yk} > s_{Xk} > 0$, then k joins both networks.

The angles θ_A and θ_B are in $[45^\circ, 90^\circ)$ and satisfy the relations

$$\tan(\theta_A) = \frac{\beta_X + \beta_{XY}(\theta_B)}{\beta_{XY}(\theta_B)} \text{ and } \tan(\theta_B) = \frac{\alpha_X + \alpha_{XY}(\theta_A)}{\alpha_{XY}(\theta_A)},$$

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[24] If network Y requires exclusivity from one side, then, as we show below, it would be as if both networks had required exclusivity from that side only. See the discussion of one-sided exclusivity.

where α_z and β_z are the probabilities of realizing types of A and B, respectively, who join only network z under condition (ii); $\alpha_{XY}(\theta_A)$ is the probability of realizing types of A who join both networks under conditions (iii) and (v); and $\beta_{XY}(\theta_B)$ is the probability of realizing types of B who join both networks under conditions (iii) and (v).

Figure 4 illustrate A's equilibrium strategy. The figure for B is similar. It is readily seen from the figure that both trade and routing inefficiency can arise in equilibrium.

There is an intuition among some debit industry participants that network routing leads to a network's getting a disproportionate share of the transactions because any transaction that could run over that network must run over that network. As we will now show, this intuition is seriously incomplete and, thus, misleading.

Consider the market shares of X and Y when they are otherwise in identical positions. That is, when they charge equal prices (*i.e.,* $p_{XA} = p_{YA} \equiv p_A$ and $p_{XB} = p_{YB} \equiv p_B$) and the distributions of consumer benefits are symmetric. A general analysis is intractable, but we can determine transactions shares for specific cases.

First, suppose that there is no intrinsic network differentiation and all of the mass for the types of both users A and B lies on their respective forty-five degree lines. Then any user who joins a network joins both. Thus, if network X alone implements a network routing rule, all of the transactions take place on that network, as suggested by the intuitive argument above.

Suppose, however, that the two sides' types are uniformly distributed on the unit square. In this case, it can be shown that

$$\begin{aligned}&\Pr\{\text{trade occurs on } Y\} - \Pr\{\text{trade occurs on } X\}\\ &\quad = \frac{(1-p_A)(1-p_B)(1-p_Ap_B)\left(Q - \sqrt{Q^2 - 8(1-p_A^2)(1-p_B^2)}\right)}{4(1+p_A)(1+p_B)}\,,\end{aligned} \tag{4}$$

where

$$Q \equiv 3 + p_A + p_B - p_Ap_B\,.$$

It is clear that expression (4) is positive, which means that Y's expected share of transactions exceeds X's.

Corollary 1. Suppose that network X stipulates network routing, but Y does not. If networks X and Y charge the same prices as one another, and both distributions of user types are uniform on the unit square, then the equilibrium expected probability of trade is higher on network Y than on X.

This result is a further illustration of the fact that network membership decisions can override formal authority. Specifically, a user who prefers X but would get positive surplus from a transaction on Y should join both networks because network Y will be used only as a last resort. However, a user that prefers Y may refuse to join X because joining could result in routing over X even when both users are members of Y. Thus, more users join only network Y than join only X.

By assuming that the prices are sufficiently low, we can generalize Corollary 1 to other distributions.

Corollary 2. Suppose that network X stipulates network routing, but Y does not. If networks X and Y charge the same prices, with $\Pr\{a_Y > p_A\} \times \Pr\{b_Y > p_B\} = 1$, and both distributions of user types are symmetric, with $\Pr\{a_X = a_Y\} = 0 = \Pr\{b_X = b_Y\}$, then the equilibrium expected probability of trade is three times higher on network Y than on X.

The logic underlying this result is as follows. Given $\Pr\{a_Y > p_A\} \times \Pr\{b_Y > p_B\} = 1$, a user will join at least one network with probability one. Because network X has network routing but Y does not, joining network Y is a free, but valuable option, and all users join Y. A user also joins network X if and only if $a_X > a_Y$ or $b_X > b_Y$. Because the distributions are symmetric, a transaction is thus completed on network X with probability $\Pr\{a_X > a_Y\} \times \Pr\{b_X > b_Y\} = 1/4$ and on network Y with probability 3/4.[25]

One-sided exclusivity

As already discussed, either A or B may choose to join only one of the two networks, and this exclusivity becomes a *de facto* routing rule. The networks could also require exclusivity as a condition of joining a network. Were one or both networks to require exclusivity of *both* sides of the market, the resulting continuation game would be identical to the game analyzed above in

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[25] This logic can be extended to symmetric distributions for which $\Pr\{a_X = a_Y\}$, or $\Pr\{b_X = b_Y\}$, or both are positive. Using the fact that $\Pr\{a_X > a_Y\} = \Pr\{a_X < a_Y\} = \frac{1}{2}(1 - \Pr\{a_X = a_Y\})$, one can show that network Y will complete more of the transactions unless at least $\sqrt{2} - 1 = .41$ of user types are indifferent between the two networks.

which both networks stipulate network routing. Hence, in this subsection, we restrict attention to continuation games in which one or both of the networks requires exclusive relationships with only *one* side of the market. In the debit card industry, for example, merchants typically accept cards issued on many networks, but card issuers are sometimes given incentives to issue cards on only one debit network.

There are three cases to consider:

1. Both networks require exclusivity of the same side of the market (*e.g.,* issuers).
2. One network requires exclusivity of A and the other requires exclusivity of B.
3. One network requires exclusivity of one side and the other network adopts one of the alternative routing rules.

In case 2, each side must choose only one network. Recall that, when both networks stipulate network routing, we assume that each user joins at most one network in order to avoid possible breach of contract. Hence, case 2 is equivalent to the continuation game in which both networks stipulate network routing, which was analyzed above.

In case 3, the user on one side of the market cannot belong to both networks. Hence, the routing regime choice of the network that doesn't require exclusivity is irrelevant. In particular, the situation is equivalent to one in which both networks require exclusivity of that side of the market: cases 1 and 3 yield the same continuation game.[26]

Consider case 1. Without loss of generality, suppose that both networks require A to make an exclusive choice of network. Given the prospect of trembles by A, B's strategy must be to join any network for which $s_{zB} > 0$ and not to join any network for which $s_{zB} < 0$. Observe that this strategy is optimal regardless of A's strategy.[27] Figure 5 illustrates.

Given B's strategy, A chooses the network that maximizes its expected surplus using the probabilities induced by B's strategy and distribution of types. That is, A compares $(\beta_X + \beta_{XY})s_{XA}$

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[26] Observe that this equivalence is a consequence of our assumption that there are only two networks. Suppose, for example, that there were three networks, X, Y, and Z, and that only X imposed exclusivity. Then a user might choose to belong to both Y and Z. This possibility raises issues similar to those addressed in the literature on network compatibility, in which some sets of networks may be compatible with each other while others are not. See, for example, Katz and Shapiro (1985) and Crémer et al. (2000).

[27] Also observe that B's strategy is the same as it would be if B chose the routing. The reason is that, in both cases, the transaction would be routed over B's less preferred network only when that was the sole available means of completing the transaction.

with $(\beta_Y + \beta_{XY})s_{YA}$. Figure 6 illustrates. The slope of the ray $\overrightarrow{O'U}$ is given by

$$\frac{\beta_X + \beta_{XY}}{\beta_Y + \beta_{XY}} \equiv \mu \,. \tag{5}$$

This pair of strategies constitutes the unique equilibrium in the connection-continuation game:

Proposition 4.

(i) Suppose either that (a) one or both networks require exclusivity from both sides of the market; or (b) one network requires exclusivity of A and the other requires exclusivity of B. Then the continuation game is equivalent to the game when both networks stipulate network routing and its equilibrium is described by Proposition 2.

(ii) Suppose that one or both networks requires exclusivity solely from A and neither network requires exclusivity from B. Then there exists a unique equilibrium of the connection-continuation game, which has the following properties:

   (a) B joins any network for which $s_{zB} > 0$; and joins no network for which $s_{zB} \leq 0$; and

   (b) A joins network X if $s_{XA} > \max\{0, \frac{1}{\mu}s_{YA}\}$; joins network Y if $s_{YA} > \max\{0, \mu s_{XA}\}$; and joins neither network otherwise (*i.e.,* if $s_{hA} \leq 0$); where μ is defined by expression (5) above.

Because B can be on both networks in Part (ii), there is greater trade than there would be under full exclusivity at a given set of prices.

4. Network pricing

The analysis in the previous section, particularly Proposition 4, Part (i), revealed that there are only five possible continuation games:

(a) Both networks give one side (A or B) the right to set the routing rule (see Proposition 1).

(b) One network gives A the right to set the routing rule and the other gives B that right.

(c) Both networks stipulate network routing (see Proposition 2).

(d) One network stipulates network routing and the other chooses one-side-chooses routing (see Proposition 3).

(e) One or both networks requires exclusivity of one side of the market and neither network requires exclusivity of the other side of the market (see Proposition 4, Part (ii)).

To solve for the equilibrium routing regime, we first must solve for the equilibrium of the pricing game taking the routing rules as given. We focus on pure-strategy equilibria. Recall that we did not consider game (b) above because it is unclear how the conflicting routing rules would be reconciled. Rather than solve for equilibrium profits for game (b) in the present section, we will consider three possibilities when we address routing-rule choices in the next section.

Although the setup of the model is straightforward, determining the equilibria of the pricing games is made difficult by the fact that the equilibria of the continuation games depend on the distribution functions, which have heretofore been arbitrary. Even if functional forms are assumed for the distribution functions, calculation of analytic, closed-form equilibrium demands in the continuation games is difficult. Hence, in what follows, we have employed Mathematica to calculate the pricing-game equilibria for specific distributions.[28]

We now assume that each user's gross consumption benefits are uniformly distributed on the unit square and the per-transaction cost lies between 0 and 2. Table 1 reports the equilibrium profits for various values of the marginal cost, c. For $c > 1$, Mathematica found only one pure-strategy equilibrium for each routing regime.

In an A-chooses routing regime, there is a symmetric Nash equilibrium of the pricing game (*i.e.*, $p_{XA} = p_{YA} \equiv p_A$ and $p_{XB} = p_{YB} \equiv p_B$). As shown in Table 2, $p_A > p_B$, although the difference in the two prices decreases as the transaction cost, c, increases. Intuitively, not having the routing choice makes B's network membership decision more price sensitive *ceteris paribus*; hence competition for B is fiercer, which leads B to be charged less in equilibrium.

When X is the only network to stipulate network routing, there is an asymmetric Nash equilibrium of the pricing game in which the networks set different prices, but each network sets the same price to both sides of the market (*i.e.*, $p_{XA} = p_{XB} \equiv p_X$ and $p_{YA} = p_{YB} \equiv p_Y$, but $p_X \neq p_Y$). For the games in which the transaction cost is low (*i.e.*, $c < .35$), $p_X > p_Y$. But for games with

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[28] The Mathematica programs used here and below can be downloaded from: `http://faculty.haas.berkeley.edu/hermalin/`. We calculated prices and profits for more values of c than shown in Tables 1 and 2. The additional results were omitted for the sake of brevity and are consistent with those reported here.

high transaction costs (*i.e.,* $c \geq .35$), $p_X < p_Y$. Regardless of transaction costs, the network *without* a network-routing requirement earns greater expected profits than does the network with the network-routing requirement. As Corollary 1 suggests, X carries less traffic in expectation than does Y, which translates into smaller expected profits for X.

The game in which both networks stipulate network routing does not have a pure-strategy equilibrium in the pricing game when transaction costs are low (*i.e.,* $c < 1$). The reason is that, when prices are low and similar, the connection-continuation game has multiple equilibria. For instance, if $p_{zk} = 1/4$ for all z and k, then the connection-continuation game has three equilibria: (1) $\tan(\theta_A) = \tan(\theta_B) = 2/3$; (2) $\tan(\theta_A) = \tan(\theta_B) = 1$; and (3) $\tan(\theta_A) = \tan(\theta_B) = 3/2$. In terms of Figure 3, they correspond, respectively, to equilibria that favor Y (*i.e.,* $\overrightarrow{O'U}$ closer to horizontal); are neutral (*i.e.,* $\overrightarrow{O'U}$ has slope 1); and favor X (*i.e.,* $\overrightarrow{O'U}$ closer to vertical). Moreover, the middle equilibrium (equal market shares) is unstable. Consequently, small changes in price can lead to large changes in market share. This tension puts pressures on both networks to undercut on price. However, were prices too low, a network would rationally "stop competing" and seek rents from its loyal consumers. But if a network were to exploit its loyal customers, the other network's best response would be to raise prices, starting the "cycle" over.

For high enough transaction costs (*i.e.,* $c \geq 1$), a symmetric pure-strategy equilibrium exists for the pricing game when both networks stipulate network routing. Both networks charge the same price to both sides of the market (*i.e.,* $p_{zk} \equiv p$ for all z and k). When prices are high enough, there is a unique pure-strategy equilibrium of the kind described in Proposition 2. The pricing game then becomes a well-behaved game between differentiated duopolists. Because of exclusivity, competition is fiercer between the networks than in the other routing regimes. This and the lower volume of trade result in much lower profits when both networks stipulate network routing than in the other continuation games.

Finally, the one-side exclusivity game results in a symmetric equilibrium: $p_{XA} = p_{YA} \equiv p_A$ and $p_{XB} = p_{YB} = p_B$. Moreover, p_A and p_B tend to be nearly equal.

5. The choice of routing regime

Using Table 1, and assuming a payoff for the case of conflicting routing rules, we can solve for the choice of routing regime when the distributions are uniform and $c \geq 1$. Figure 7 presents the routing-regime game in normal form. From Table 1, we have $\Pi_A > \max\{\Pi_E, \Pi_{NO}\}$ and

$\Pi_{AO} > \Pi_E > \Pi_N$.

Above, we did not analyze the pricing game in which one network chooses issuer routing and the other chooses merchant routing because it was unclear how the conflicting routing rules would be reconciled. Here, we consider three alternatives. One is that reconciliation would entail very significant transaction costs, possibly including litigation costs. Under this assumption, Π_D (expected profit when the networks impose incompatible routing rules) would be the lowest payoff. Alternatively, conflicting assignments of formal authority could result in *de facto* authority going to the party that actually implements the physical routing.[29] Under this assumption, the payoffs when one network chooses issuer routing and the other chooses merchant routing are identical to the payoffs when both networks choose merchant routing.[30] Thirdly, the conflicting routing rules could, as in the network-routing regime, induce each user to sign exclusively with one network to avoid the adverse consequences of conflicting routing rules. Under this alternative, the game would be equivalent to network routing. In summary, under any of these three assumptions, $\Pi_A \geq \Pi_D$.

Inspection of Figure 7 establishes the following result.

Proposition 5. Suppose that each user's gross consumption benefits are distributed uniformly on the unit square and the transaction cost, c, exceeds 1. Then the pure-strategy equilibria of the routing-rule game are:

(i) Both networks delegate routing to a common side of the market, either A or B.

(ii) Both networks require exclusivity of a common side of the market, but not of the other side.

The networks Pareto prefer an equilibrium in which one side is delegated the authority to choose routing to an equilibrium with one-sided exclusivity.[31]

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[29] Something similar occurs in the PIN debit industry: many merchants route transactions over their preferred networks when there is issuer routing but the issuer is recorded as having specified multiple networks as its first choice.

[30] In the statement of the next result, we treat these outcomes as equivalent and refer only to the outcome in which both networks delegate authority to the same side of the market. We are unaware of any circumstances in which debit networks have offered conflicting routing regimes.

[31] Although the uniform-distribution version of our model predicts that networks should adopt issuer routing (or, possibly, merchant routing), some debit networks actually use network routing. At least in the United States, network routing may be a holdover from the evolution of automated teller machine networks—for which network routing was prevalent—into point-of-sale debit networks. Moreover, in recent years, an increasing number of networks have implemented issuer routing.

As indicated above, both trade inefficiency and routing inefficiency can arise under either a one-side-chooses or one-sided-exclusivity routing regime. We now compare the resulting levels of total surplus under the two possible types of equilibria in Proposition 5 with each other and with the first best under the assumption that a_X, a_Y, b_X, and b_Y are independently and uniformly distributed on $[0, 1]$. Table 3 reports the results based on formulas derived in the Appendix. Expected welfare is greater in a one-side-chooses equilibrium than in a one-side-exclusivity equilibrium. Hence, the equilibrium preferred by the networks (see Proposition 5) is also the expected-welfare-maximizing equilibrium.

One can also examine welfare in cases where the choice of routing regime is restricted either by technological constraints or by regulation that sets the routing regime but does not constrain the networks' pricing decisions. Hence, the full ranking of welfare outcomes is of interest. Calculations show that, in our example, one-side-chooses is the regime that maximizes welfare, a single network's stipulating network routing is second, one-side exclusivity is third, and both networks' stipulating network routing is the regime that results in the lowest welfare level.

6. Additional cases

We next consider two extensions and one detailed case of our baseline model.

The deciding party pays

It is of some practical interest to consider the effects of a rule requiring that, if one side of the market gets to choose the network, then the other side of the market faces a price of zero. This rule, for instance, has been applied to mobile telephony. Specifically, federal regulators in the United States do not allow calling-party-pays billing when the receiver is a mobile user. In large part, the rationale for this prohibition is that the called party is the one who has made the choice among wireless carriers.[32] As has been well established by the literature on pricing in two-sided markets, it generally is not efficient to set the price paid by one side of the market to 0.[33] Moreover, a requirement that only the party with routing control be the one to pay for the service can induce

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[32] Observe, however, that, if the calling party is familiar with the called party's telephone numbers, then one could just as well prohibit called-party-pays billing on the grounds that the calling party chooses the carrier (routing) by deciding to dial the wireless number instead of the wireline one.

[33] See, for example, Jeon et al. (2004), Kim and Lim (2001), and Hermalin and Katz (2004). Doyle and Smith (1998) focus on the issue with particular regard to mobile telephony.

networks to choose a different routing regime than they would under a policy of *laissez-faire*.

The potential adverse profit and welfare effects of a chooser-pays rule are readily seen by considering the following limiting case. Suppose regulation requires that, if network z implements an A-chooses routing rule, then it must set $p_{zB} = 0$. Observe that, if c exceeds the maximal value of A's willingness to pay, then the profits associated with letting A choose the network are zero because there is no trade. A regime under which the costs of a transaction can be shared between the two parties, however, may allow profitable trade to occur. Specifically, consider our case in which user types are uniformly distributed on the unit square. As c goes to one, the profits associated with either issuer or merchant routing go to zero, but other routing regimes remain profitable.

Straightforward computations show that, for all $c \in (1 - \delta, 2)$, for some $\delta > 0$, $\Pi_A < \Pi_{NO}$. Moreover, for all $c \in (1, 2)$, $\Pi_{AO} < \Pi_E$.

Proposition 6. Suppose that each user's gross consumption benefits are distributed uniformly on the unit square and the transaction cost, c, is in $(1, 2)$. Then the pure-strategy equilibria of the routing-rule game with a chooser-pays regulatory requirement are:

(i) One network chooses network routing and the other network chooses either A exclusivity or B exclusivity.

(ii) Both networks require exclusivity of a common side of the market, but not of the other side.

These equilibria all have the same connection-continuation game and give rise to identical outcomes in terms of equilibrium prices, transactions quantities, profit, and welfare.

Coupled with Proposition 6, the rankings in Table 3 imply the following:[34]

Corollary 3. Chooser-pays regulation results in lower equilibrium profits and welfare relative to the networks' Pareto-preferred equilibrium absent a chooser-pays requirement.

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[34] In applying Proposition 6 and the results of Table 3, we are assuming that the calling party would know which network was being used to complete the call and what price was being charged to the calling party. At least some US policy makers would require telecommunications carriers to use automated voice prompts to provide this information to callers as a condition for being able to implement any form of calling-party-pays pricing. We also ignore the effects of inter-carrier payments (*e.g.,* termination charges) when the calling and called party are on different, interconnected networks.

A Hotelling special case

Many analyses in the two-sided markets literature have employed Hotelling models of product differentiation (*e.g.,* Armstrong, 1998; Laffont et al., 1998a,b; Rochet and Tirole, 2003).[35] A Hotelling model can be considered a special case of our model. Specifically, let the gross consumption benefits be $(a, 1-a)$ and $(b, 1-b)$ for A and B, respectively, where $a \sim \mathsf{U}[0,1]$ and $b \sim \mathsf{U}[0,1]$. In terms of the spatial metaphor, there are unit transportation costs in a linear city in which network X has address 1, network Y has address 0, and users on both sides of the market are uniformly distributed across the city.

In what follows, it is useful to observe that, by Lemma 1, if $\min\{p_{Xk}, p_{Yk}\} \geq 1/2$, then user k will never elect to be on both networks.

Suppose that either A has the choice of routing or B is the only side required to be exclusively on one network. The transaction volume on network X is

$$D_X = \alpha_X\big(\beta_X + \beta_{XY}\big) + \alpha_{XY}\big(\beta_X + \lambda_X\beta_{XY}\big)\,.$$

Because a is distributely uniformly, $\lambda_X = \lambda_Y = 1/2$. Substituting for α_X and α_{XY},

$$D_X(\mathbf{p}) = (1 - p_{XA})\beta_X(\mathbf{p}) + \left(\frac{1}{2}(1 - p_{XA} - p_{YA}) + p_{YA}\right)\beta_{XY}(\mathbf{p})\,. \tag{6}$$

where $\mathbf{p} \equiv (p_{XA}, p_{XB}, p_{YA}, p_{YB})$.

Consider the case in which B is required to be exclusive (so $\beta_{XY} \equiv 0$). Our focus is on symmetric equilibria of the pricing game. Observe that, because $p_{XA} = p_{YA} \equiv p_A$,

$$\alpha_X + \alpha_{XY} = \alpha_Y + \alpha_{XY}\,.^{36}$$

When user B has preferences $(b, 1-b)$, it joins network X if and only if

$$\big(b - p_{XB}\big)\big(\alpha_X + \alpha_{XY}\big) \geq \max\big\{0, \big(\alpha_Y + \alpha_{XY}\big)\big(1 - b - p_{YB}\big)\big\}$$

or, simplifying,

$$b - p_{XB} \geq \max\{0, 1 - b - p_{YB}\}\,.$$

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[35] Unlike the analysis here, these models do not allow for endogenous routing. There are other differences as well. For instance, Laffont et al. (1998a,b) allow for two-part tariffs, whereas we consider only simple pricing. In addition, in their models of telecommunication networks, Armstrong (1998) and Laffont et al. (1998a,b) consider a situation in which each party conducts multiple transactions (*e.g.,* makes multiple phone calls).

[36] Recall, by Proposition 4(ii)—with the roles of A and B reversed—that A will join any network that offers it surplus, so its decision is unaffected by the prices charged to B.

Hence,

$$\beta_X(\mathbf{p}) = \begin{cases} 1 - p_{XB} \text{ if } p_{XB} + p_{YB} \geq 1 \\ \frac{1}{2}(p_{YB} + 1 - p_{XB}) \text{ if } p_{XB} + p_{YB} < 1 \end{cases} .$$

We first show that there cannot be a symmetric equilibrium in which both $p_B < 1/2$ and $p_A < 1/2$. Suppose to the contrary and consider network X's profits if it deviates from the candidate symmetric equilibrium by raising p_B by ε:

$$\Pi_X = (p_A + p_B + \varepsilon - c) D_X(p_A, p_B + \varepsilon, p_A, p_B) \tag{7}$$

which, substituting for β_X, equals

$$= (p_A + \varepsilon + p_B - c)(1 - p_A)\frac{1 - \varepsilon}{2} .$$

Because the networks are in equilibrium, it must be that $\partial \Pi_X / \partial \varepsilon_{|\varepsilon=0} = 0$. But

$$\frac{\partial \Pi_X}{\partial \varepsilon}_{|\varepsilon=0} = \frac{1}{2}(1 - p_A)\big(1 - (p_A + p_B - c)\big) > 0$$

if, as assumed, $p_A + p_B < 1$. By contradiction, we have established that, if a symmetric equilibrium exists, $p_k \geq 1/2$ for users on at least one side of the market.

Straightforward but tedious calculations demonstrate that $p_B = 1/2$ and $p_A = 1/4 + c/2$ is a symmetric equilibrium for $c \leq 1/2$. Specifically, these calculations demonstrate that, if $p_{YA} = 1/4 + c/2$ and $p_{YB} = 1/2$, then: (a) for any p_{XA}, network X would find it optimal to set $p_{XB} = 1/2$; and (b) $p_{XA} = 1/4 + c/2$ is optimal when $p_{XB} = 1/2$. It can also be shown that, if $c > 1/2$, then $p_A = p_B = (1 + c)/3$ is a symmetric equilibrium.

A similar analysis is possible for the A-chooses routing regime. The price to B can never be less than 1/2 in a symmetric equilibrium. Moreover, the equilibrium prices are the same: $p_B = 1/2$ and $p_A = 1/4 + c/2$ if $c \leq 1/2$; and $p_A = p_B = (1 + c)/3$ if $c > 1/2$. Finally, because B is never on both networks, the probabilities of trade are the same as in the B-exclusive case. Hence, profits and welfare are the same under the A-chooses and B-exclusive routing regimes.

Additional continuation games are analyzed in the Appendix. Summarizing this analysis:

Proposition 7. Suppose that user preferences have been generated by the Hotelling model (*i.e.,* $(a_X, a_Y) = (a, 1 - a)$, $(b_X, b_Y) = (b, 1 - b)$, where a and $b \sim \mathsf{U}[0, 1]$). If

- both networks implement k-chooses routing; or

- at least one network requires k', $k' \neq k$, to be exclusive and neither network requires k to be exclusive; or
- one network adopts network routing and the other adopts either k-chooses or k'-chooses routing;

then the following is the unique pure-strategy, symmetric equilibrium:

(i) if $c \leq 1/2$, then the equilibrium prices are $p_{Xk} = p_{Yk} = 1/4 + c/2$ and $p_{Xk'} = p_{Yk'} = 1/2$, for $k = A, B$;

(ii) if $c > 1/2$, then the equilibrium prices are $p_{XA} = p_{YA} = p_{XB} = p_{YB} = (1 + c)/3$.

Equilibrium profits and welfare are the same across the routing regimes.

The intuition for why identical outcomes hold across three different routing regimes (in contrast to the analysis in Section 5) is the now familiar idea that membership decisions can trump formal authority. As shown above, the networks always set prices greater than or equal to 1/2 for at least one side of the market, say B. Given such prices, no type of B can have positive surplus levels from both networks at once. Therefore, A's choice of network and, thus, the networks' pricing to A have no effect on B's choice of network. Moreover, given that B makes an exclusive network choice, A has no reason not to join all networks that yield it positive surplus, regardless of the routing rules; B's choice of network faces A with an all-or-nothing choice with regard to which network will handle the transaction if one takes place. Thus, when a network changes its price to A, there is no effect on the other network's sales. In this regard, the two networks act as monopolists under all three routing regimes when setting their prices to A.

If the networks require exclusivity of both sides, then it can be shown that the equilibrium prices are

$$p_{XA} = p_{YA} = p_{XB} = p_{YB} = \begin{cases} 1/2 & \text{if } c \leq 1/2 \\ (1+c)/3 & \text{if } c > 1/2 \end{cases} . \tag{8}$$

Because, as noted previously, once one side is exclusive, a network need not care whether members of the other side join the rival network (only whether they join it), it follows that the networks must be better off with the equilibrium pricing in Proposition 7 when $c \leq 1/2$ than with the prices in (8). That is, consistent with the results in Section 5, double-sided exclusivity is not the optimal routing regime for the networks (at least when cost is low).

When cost is high enough in a Hotelling model (*i.e.,* $c > 1/2$), Proposition 7 and expression (8) reveal that the routing regime doesn't matter. Once cost is high enough, it is never in a network's interest to price low enough to induce a user to join it when the user intrinsically prefers the other network (*e.g.,* for high c, network X will never find it profitable to induce user A to join X if $a_Y > a_X$). Manifestly, if no one is ever on both networks, then routing regime is irrelevant.

The congruence of prices and profits in the Hotelling version of our model across routing regimes (the three regimes in Proposition 7 and all four regimes if $c > 1/2$) contrasts with the results when types are uniformly distributed on the unit square (see Tables 1 and 2). This suggests that analyses of Hotelling models of two-sided markets should be viewed in perspective; the high degree of differentiation in such models can lead to extreme outcomes (*e.g.,* here, it results in one side's always being exclusive).

Rent dissipation in the absence of product differentiation

Our analysis has heretofore been restricted to the case of symmetric user preferences with product differentiation. We now examine equilibrium when users do not perceive intrinsic differences between the two networks. Specifically, we ask whether there exist pure-strategy equilibria in which networks earn positive profits.

The answer is "no" when there is no product differentiation on either side of the market and at least one side joins any network that offers it positive surplus (*i.e.,* one-side-chooses routing or one-side exclusivity). To see why, suppose, to the contrary, that p^e_{XA}, p^e_{XB}, p^e_{YA}, and p^e_{YB} are equilibrium prices and that at least one of the networks earns positive profits. Let A be the side that is willing to join both networks (*i.e.,* A has the routing choice or B is the only side that must be exclusive). Moreover, label the networks so that X's profits are at least as large as Y's. Now, suppose that Y were to deviate from the candidate equilibrium by charging $p^d_{YA} = p^e_{XA} - \varepsilon$ and $p^d_{YB} = p^e_{XB} - \varepsilon$, where ε is an arbitrarily small positive number. Then any A on network X will also be on Y and user B can, thus, rationally choose to be exclusively on Y. In equilibrium, all transactions go over network Y. It is readily shown that, for sufficiently small choices of ε, the deviation would raise network Y's profits. Therefore, any prices that yield positive profits cannot constitute a pure strategy equilibrium when there is no intrinsic differentiation of the two networks.

If one network stipulates network routing, while the other does not, then this simple undercutting argument still applies, but is somewhat more involved. Suppose, first that X, the network earning weakly greater profits, is the one that stipulated network routing. If Y undercuts as above, then, neither side would join X exclusively. From expression (A5), that means that the dividing ray between "join Y only" and "join both" (see Figure 4) has slope one. Because $p_Y < p_X$, that ray lies below the 45° line, and everyone who joins a network joins Y only. It follows that Y's profits are greater from this deviation. Suppose, instead, that X has not stipulated network routing and Y, which has, undercuts. Then both A and B should join both networks, and—because network routing stipulates that all traffic go on Y—this would be a profitable deviation for Y.

When both networks impose network routing, simple undercutting arguments are insufficient because one must account for how A and B form beliefs about who is on which network following out-of-equilibrium pricing by one of the networks (a point also made by Caillaud and Jullien, 2001, among others). On the other hand, if, as seems reasonable in this context, A and B believe that they should join the network that charges a lower price to *both* sides, then the same undercutting argument again rules out pure-strategy equilibria in which one or both networks earn positive expected profits.

When both networks stipulate network routing in a setting without differentiation, there exists an equilibrium in which both networks charge the same prices, p_A and $p_B = c - p_A$, but all traffic is on just one of the networks, say X. Indeed, except for the knife-edge case in which each network attracts exactly half of each side, the only pure-strategy equilibria must exhibit this tipping.[37]

It is also interesting to ask what happens when users on one side of the market consider the networks to be differentiated, but users on the other side do not. Suppose, for example, that A's type is uniformly distributed on the unit square, while B's type is uniformly distributed on the forty-five degree line from $(0, 0)$ to $(1, 1)$. Further suppose that the per-transaction cost lies between 0 and 2. A reasonable hypothesis might be that network price competition to attract B would dissipate any profits that might be earned as the result of the differentiation perceived by A. This hypothesis need not hold, however, because the networks endogenously differentiate themselves from B's perspective by differentially attracting the various types of A.

Under a B-chooses regime, for example, numerical calculations show that the networks charge equal equilibrium prices to the two sides.[38] That is, even though B is indifferent between the two

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[37] Hermalin and Katz (2004) consider how the cost c should be optimally split between p_A and p_B in situations such as this.

[38] We assume that B chooses the routing by tossing a fair coin when $p_{XB} = p_{YB}$.

networks and B is the side that nominally chooses the network, competition is just as strong to attract A as B. Moreover, the price is not driven to cost, so that firms earn positive equilibrium profits. Product differentiation on one side of the market is enough to create differentiation on both sides because, even though B does not distinguish different underlying network characteristics, the two networks do offer B access to different sets of user types on the other side of the market. Hence, a small reduction in p_{zB} will not lead to a discontinuous jump in sales for network z because high-value types of B will remain on both networks in order to be able to trade with types of A that have joined only one network.

In an A-chooses regime, user A pays a higher equilibrium transactions price than does B.[39] As in the B-chooses regime, the sum of the prices charged to the two sides of the market exceeds costs, and the networks earn positive equilibrium profits.

7. Conclusion

We have examined the choice of routing rules for a set of situations in which two networks compete for business. The principal motivating example is PIN debit networks, but other networks, including payment, retail, and communications networks, raise similar issues.

The central insight from analysis of the connection-continuation game is that membership decisions can override formal rules and lead to counterintuitive equilibrium outcomes. Thus, transactions tend to be routed over B's preferred network when A is given the formal authority to choose the routing. Similarly, for some distributions of user types, a network that imposes network routing in an otherwise symmetric setting will have a lower market share than its rival. Intuitively, a user who cannot choose the routing has greater incentives to join solely its preferred network than does a user that can choose the routing.

Our main result for the overall game establishes conditions under which competing networks should adopt routing rules that give one side of the market control of the routing choice (Proposition 5). Intuitively, such a routing regime gives one side incentives to join both networks, which lessens the all-or-nothing competition that would exist with network routing. Moreover, because many people join both networks, the volume of trade is greater (*i.e.,* the likelihood of a trade inefficiency is reduced). This equilibrium is also welfare maximizing relative to the other routing

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[39] For other routing rules, no pure-strategy equilibria exist.

regime, exclusivity, that can be sustained as an equilibrium of the routing-choice game.

Clearly work remains to be done. There are several profitable extensions to consider. One is networks that are asymmetrically positioned in terms of costs, consumer preferences, or installed bases. Intuitively, such cases might be more likely to give rise to equilibria in which the “leading” network imposes an exclusivity or network routing requirement in order to capitalize on its superior position.

Second, it would be interesting to consider situations in which networks use more sophisticated forms of pricing, such as a combination of membership fees and per-transactions charges. It is readily seen that—holding users’ network membership decisions fixed—allowing non-uniform pricing schemes would matter only when applied to a party with formal routing authority. Under issuer routing, for example, a merchant has no discretion once it has made its network membership choices. Thus, any two price schedules that give rise to the same expected payment are equivalent from the merchant’s perspective. Issuer behavior, however, could be affected by the mix of fixed and variable fees. Moreover, the pricing structure could affect all users’ network membership decisions (*e.g.,* the use of fixed fees would reduce a user’s incentives to join multiple networks).

Third, and related to the last point, one could explore a richer set of contracts or mechanisms for the networks to offer. As noted previously, we have focussed on the set of contracts most applicable to the payment-card industry. While simple extensions, for instance random-routing rules, would be straightforward, defining the overall set of feasible contracts is difficult. For instance, the operable rules and prices could be made dependent on the choices of both sides of the transaction (*e.g.,* user A faces one tariff and routing rule from network X if user B has selected a given option offered by X, but A faces a different tariff and routing rule if B has selected another option). Moreover, each network could make its terms dependent on the terms offered by the other network.[40] Presumably, at some point, the transaction costs imposed by complex rules limits the degree of complexity in the menus offered.

Lastly, it could be useful to characterize mixed-strategy equilibria for those continuation games in which pure-strategy equilibria don’t exist.

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[40] For a general analysis of the implications of interdependent contracts, see Katz (in press).

Appendix

Proof of Proposition 2

Let $\Theta_k(\cdot)$ be party k's best response function. Consider $\Theta_A(\cdot)$. B's strategy, θ_B, defines the regions join-X-only and join-Y-only and, thus, the probabilities β_X and β_Y. From above,

$$\Theta_A(\theta_B) = \arctan\left(\frac{\beta_X(\theta_B)}{\beta_Y(\theta_B)}\right) . \tag{A1}$$

Because the underlying distribution is continuous, $\beta_X(\cdot)$ and $\beta_Y(\cdot)$ are continuous, as is their ratio. It follows that $\Theta_A(\cdot)$ is continuous. It is also readily shown to be increasing. By assumption (3) and Lemma 1, $\beta_X(\cdot)$ and $\beta_Y(\cdot)$ are bounded away from zero for all $\theta_B \in [0°, 90°]$. Hence,

$$\Theta_A(0°) > 0° \text{ and } \Theta_A(90°) < 90° . \tag{A2}$$

Using expression (A2) and the corresponding analysis for B, we know the best-response curves will resemble those shown in Figure 8, at least with respect to their end points. These end points and the functions' continuity guarantee that the functions cross; hence, an equilibrium exists.

Proof of Proposition 3

From assumption (3),

$$\alpha_X > 0\,,\ \alpha_Y > 0\,,\ \beta_X > 0\,,\ \text{and } \beta_Y > 0\,. \tag{A3}$$

As before, party k joins neither network if $s_{hk} \leq 0$ and joins only network h if $s_{hk} > 0 \geq s_{\ell k}$. The only case remaining, therefore, is $s_{\ell k} > 0$. Consider A's decision.[41] When $s_{\ell A} > 0$, the payoffs for A are

$$\begin{aligned} \pi_X^A &= s_{XA}(\beta_X + \beta_{XY}) \quad (X \text{ only})\,, \\ \pi_Y^A &= s_{YA}(\beta_Y + \beta_{XY}) \quad (Y \text{ only})\,, \text{ and} \\ \pi_{XY}^A &= s_{XA}(\beta_X + \beta_{XY}) + s_{YA}\beta_Y \quad (\text{both}) \end{aligned}$$

If $s_{XA} \geq s_{YA} > 0$, then, in the light of (A3), A's unique best response is to join both networks. Intuitively, A joins not only its preferred network, X, but also Y because a transaction will go over Y only if B is not on X. Observe, because $\mathcal{I}_A$ has full support, the region $s_{XA} \geq s_{YA} > 0$

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[41] The analysis for B is symmetric.

has positive probability; hence, the probability that A joins both, α_{XY}, must also be positive. An analogous argument ensures that $\beta_{XY} > 0$.

If $s_{XA} < s_{YA}$, then joining network X only is strictly dominated. Observe that we have established that A joins solely network X if and only if $s_{XA} > 0 \geq s_{YA}$. The question remaining is under what conditions should A join Y only or join both when $s_{XA} < s_{YA}$? That decision depends on whether

$$0 \gtrless \pi^A_{XY} - \pi^A_Y$$

which is equivalent to

$$s_{YA} \gtrless s_{XA} \frac{\beta_X + \beta_{XY}}{\beta_{XY}} \,. \tag{A4}$$

Figure 4 illustrates A's strategy. The fraction in expression (A4) is the slope of the ray $\overrightarrow{O'U}$ that divides the join-Y-only region from the join-both region. The angle θ is, thus, the arctan of that fraction. Observe that θ is greater than forty-five degrees for any $\beta_X > 0$. Types in the region between the forty-five degree ray and the θ ray would prefer that the transaction take place over network Y, and joining X risks having the transaction routed over that network even though A and B both are on Y as well. However, the benefit to these A-types of joining network X is that it allows them to transact with B-types that join only X.

Let $\Omega_k(\cdot)$ be party k's best-response function. Consider $\Omega_A(\cdot)$ (the analysis for B is symmetric). B's strategy θ_B defines the join-both region and, thus, the probability β_{XY}. From (A4),

$$\Omega_A(\theta_B) = \arctan\left(\frac{\beta_X + \beta_{XY}(\theta_B)}{\beta_{XY}(\theta_B)}\right) . \tag{A5}$$

Because the underlying distributions are continuous, $\beta_{XY}(\theta_B)$ is continuous, and, thus, so too is the argument of arctan in (A5). Hence, $\Omega_A(\cdot)$ is continuous. It is readily shown to be *decreasing* (unlike $\Theta_A(\cdot)$ or $\Theta_B(\cdot)$). As the above analysis demonstrated (see also Figure 4), $\theta_B \in [45^\circ, 90^\circ]$. Because $\beta_{XY} > 0$,

$$\Omega_A\big([45^\circ, 90^\circ]\big) \subset [45^\circ, 90^\circ) \,.$$

Hence, $\Omega_A(\cdot)$ and $\Omega_B(\cdot)$ will resemble those shown in Figure 9—at least with respect to their end points. That and their continuity guarantees that they cross; hence, an equilibrium exists.

Welfare calculations

Define $g_z = a_z + b_z$ as total gross consumption benefits if trade occurs on network z. Because a_z and b_z are independently distributed uniformly on $[0, 1]$, g_z has the following density and cumulative distribution functions, respectively:

$$\psi(g) = \begin{cases} g\,, \text{ if } 0 \leq g \leq 1 \\ 2 - g\,, \text{ if } 1 < g \leq 2 \end{cases} \quad \text{and} \quad \Psi(g) = \begin{cases} g^2/2\,, \text{ if } 0 \leq g \leq 1 \\ 2g - g^2/2 - 1\,, \text{ if } 1 < g \leq 2 \end{cases} .$$

Expected welfare under first-best routing is

$$\mathbb{E}W^{FB} = \int_0^2 \int_0^2 \max\big\{0, g_X - c, g_Y - c\big\} \psi(g_X)\psi(g_Y) dg_X dg_Y = 2\int_c^2 (g - c)\Psi(g)\psi(g)dg\,.$$

Tedious calculations demonstrate that

$$\mathbb{E}W^{FB} = \begin{cases} \frac{1}{60}(74 - 60c + 3c^5)\,, \text{ if } 0 \leq c \leq 1 \\ \frac{1}{60}(2 - c)^3(8 + 12c - 3c^2)\,, \text{ if } 1 < c \leq 2 \end{cases} .$$

Expected welfare under A-chooses routing is

$$\begin{aligned} \mathbb{E}W^A = {} & 2\alpha_z(\beta_z + \beta_{XY})(\mathbb{E}\{a_z|\text{only on } z\} + \mathbb{E}\{b_z|\text{able to trade on } z\} - c) \\ & + 2\alpha_{XY}\lambda_z(\beta_z + \beta_{XY})(\mathbb{E}\{a_z|\text{on both, prefers } z\} + \mathbb{E}\{b_z|\text{able to trade on } z\} - c) \\ & + 2\alpha_{XY}(1 - \lambda_z)\beta_z(\mathbb{E}\{a_z|\text{on both, doesn't prefer } z\} + \mathbb{E}\{b_z|\text{only on } z\} - c)\,, \end{aligned}$$

where the factor of 2 reflects that trade is equally likely on either network in the symmetric equilibrium of the pricing game.

Expected welfare under A-exclusivity routing is

$$\mathbb{E}W^E = 2\tilde{\alpha}_z(\tilde{\beta}_z + \tilde{\beta}_{XY})(\mathbb{E}\{a_z|\text{only on } z\} + \mathbb{E}\{b_z|\text{able to trade on } z\} - c)\,,$$

where, again, the factor of 2 reflects that trade is equally likely on either network in the symmetric equilibrium of the pricing game and the tildes are a reminder that the probabilities are different than in a one-side-chooses regime.

Remainder of proof of Proposition 7

Consider the pricing game when X has stipulated network routing and Y permits either issuer or merchant routing. Because of a user's obligation under X's network routing stipulation, being assigned the routing choice by Y is worthless. Hence, A and B are effectively in symmetric positions.

If, however, $c \leq 1/2$, then this initial symmetry is broken in equilibrium; there are two asymmetric pure-strategy equilibria of the pricing game. In one, $p_A = 1/4 + c/2$ and $p_B = 1/2$; and, in the other, $p_A = 1/2$ and $p_B = 1/4 + c/2$. If $c > 1/2$, then symmetry is restored: $p_A = p_B = (1 + c)/3$. Observe, that the equilibria of this pricing game are the same as in the two previously considered pricing games.

As in the previous games, one side, say B, is always pushed to be exclusive; that is, $p_{XB} = p_{YB} \geq 1/2$. Hence, from expression (A5), $\Omega_A = 90°$ and, thus, from Figure 4, the probability that A is willing to trade on z is $1 - p_{zA}$. It is readily shown that $p_{zA} = 1/4 + c/2$ is a best response for both X and Y if $c \leq 1/2$. If $p_A = 1/4 + c/2$, $c \leq 1/2$, and $p_{z'B} = 1/2$, $z' \neq z$, then B's demand for z is just $1 - p_{zB}$ if $p_{zB} \geq 1/2$. It is straightforward to prove that $p_{zB} > 1/2$ then yields lower expected profits for z than $p_{zB} = 1/2$. Thus, neither network should deviate upward from $p_B = 1/2$. If Y drops its price by ε from $p_{YB} = 1/2$, then, of the ε B types that Y will induce to join its network, a significant fraction will remain on X as well. Moreover, the small increase in β_{XY} will induce only a small fraction of A's types to switch from belonging to both to belonging to Y exclusively. It can be shown that the total gain in expected sales for Y is too small to compensate for the drop in p_{YB}; that is, Y doesn't wish to deviate downward. If X drops its price to B by ε from $1/2$, then it gains fewer than ε B types (some types who would now enjoy positive surplus trading over X prefer to remain solely on Y because s_{YB} is sufficiently greater than s_{XB}). It also loses some types of A that were on both networks, because they respond to the increase in β_{XY} by quitting network X. Hence, as with Y, the limited gain in sales does not compensate for the drop in price. Network X therefore doesn't wish to deviate downward from $p_{XB} = 1/2$ either. For $c > 1/2$, neither network would find it in its interest to price so low that some types wish to join both networks; that is, the networks are essentially monopolists to their ends of the linear city and $p_A = p_B = (1 + c)/3$ are readily shown to be the profit-maximizing monopoly prices.

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TABLE 1

COMPARISON OF EQUILIBRIUM PROFITS

	A routing	Only X uses network routing		Both network route	One side exclusive
c	profit $\equiv \Pi_A$	profit$_X \equiv \Pi_{NO}$	profit$_Y \equiv \Pi_{AO}$	profit $\equiv \Pi_N$	profit $\equiv \Pi_E$
0	.200	.172	.222	No Pure-Strategy Equilibrium	.170
.1	.180	.160	.195		.153
.2	.160	.145	.169		.135
.3	.140	.129	.146		.119
.4	.121	.113	.124		.103
.5	.103	.097	.106		.088
.6	.086	.082	.087		.074
.7	.070	.068	.071		.061
.8	.057	.055	.057		.049
.9	.045	.043	.044		.039
1.0	$.341 \times 10^{-1}$	$.334 \times 10^{-1}$	$.340 \times 10^{-1}$	$.196 \times 10^{-1}$	$.301 \times 10^{-1}$
1.1	$.252 \times 10^{-1}$	$.248 \times 10^{-1}$	$.251 \times 10^{-1}$	$.164 \times 10^{-1}$	$.225 \times 10^{-1}$
1.2	$.180 \times 10^{-1}$	$.177 \times 10^{-1}$	$.179 \times 10^{-1}$	$.127 \times 10^{-1}$	$.162 \times 10^{-1}$
1.3	$.122 \times 10^{-1}$	$.121 \times 10^{-1}$	$.121 \times 10^{-1}$	$.918 \times 10^{-2}$	$.111 \times 10^{-1}$
1.4	$.777 \times 10^{-2}$	$.771 \times 10^{-2}$	$.773 \times 10^{-2}$	$.617 \times 10^{-2}$	$.714 \times 10^{-2}$
1.5	$.454 \times 10^{-2}$	$.451 \times 10^{-2}$	$.452 \times 10^{-2}$	$.378 \times 10^{-2}$	$.422 \times 10^{-2}$
1.6	$.234 \times 10^{-2}$	$.233 \times 10^{-2}$	$.233 \times 10^{-2}$	$.203 \times 10^{-2}$	$.221 \times 10^{-2}$
1.7	$.993 \times 10^{-3}$	$.990 \times 10^{-3}$	$.991 \times 10^{-3}$	$.893 \times 10^{-3}$	$.948 \times 10^{-3}$
1.8	$.295 \times 10^{-3}$	$.295 \times 10^{-3}$	$.295 \times 10^{-3}$	$.276 \times 10^{-3}$	$.286 \times 10^{-3}$
1.9	$.370 \times 10^{-4}$	$.370 \times 10^{-4}$	$.370 \times 10^{-4}$	$.358 \times 10^{-4}$	$.364 \times 10^{-4}$

TABLE 2

COMPARISON OF EQUILIBRIUM PRICES

	A routing		Only X uses network routing		Both network route	One side exclusive	
c	p_{zA}	p_{zB}	p_{Xk}	p_{Yk}	p_{zk}	p_{zA}	p_{zB}
0	.314	.262	.285	.280	No Pure-Strategy Equilibrium	.236	.236
.1	.353	.309	.327	.324		280	.280
.2	.389	.354	.367	.366		.324	.324
.3	.425	.397	.407	.407		.366	.366
.4	.460	.438	.445	.446		.408	.408
.5	.494	.477	.482	.484		.449	.449
.6	.529	.516	.519	.521		.490	.490
.7	.563	.553	.555	.558		.530	.530
.8	.597	.590	.591	.593		.569	.569
.9	.631	.626	.627	.629		.608	.608
1.0	.665	.662	.662	.663	.594	.646	.645
1.1	.699	.696	.696	.698	.647	.684	.683
1.2	.732	.731	.731	.732	.695	.721	.720
1.3	.766	.765	.765	.766	.739	.757	.756
1.4	.800	.800	.799	.800	.781	.793	.793
1.5	.833	.833	.833	.833	.821	.829	.828
1.6	.867	.866	.866	.867	.859	.864	.863
1.7	.900	.900	.900	.900	.898	.898	.898
1.8	.933	.933	.933	.933	.932	.933	.932
1.9	.967	.967	.967	.967	.966	.967	.967

TABLE 3

COMPARISON OF EXPECTED WELFARE

c	Expected Welfare		
	First best	A routing	One side exclusive
1.0	.2833	.1401	.1360
1.1	.2135	.1032	.1002
1.2	.1543	$.7318 \times 10^{-1}$	$.7105 \times 10^{-1}$
1.3	.1059	$.4944 \times 10^{-1}$	$.4805 \times 10^{-1}$
1.4	$.6811 \times 10^{-1}$	$.3136 \times 10^{-1}$	$.3053 \times 10^{-1}$
1.5	$.4010 \times 10^{-1}$	$.1826 \times 10^{-1}$	$.1782 \times 10^{-1}$
1.6	$.2082 \times 10^{-1}$	$.9396 \times 10^{-2}$	$.9201 \times 10^{-2}$
1.7	$.8879 \times 10^{-2}$	$.3980 \times 10^{-2}$	$.3913 \times 10^{-2}$
1.8	$.2651 \times 10^{-2}$	$.1182 \times 10^{-2}$	$.1168 \times 10^{-2}$
1.9	$.3328 \times 10^{-3}$	$.1481 \times 10^{-3}$	$.1464 \times 10^{-3}$

FIGURE 1

A'S EQUILIBRIUM STRATEGY AS A FUNCTION OF TYPE UNDER AN A-CHOOSES ROUTING REGIME. THE DOTTED RAY HAS SLOPE 1.

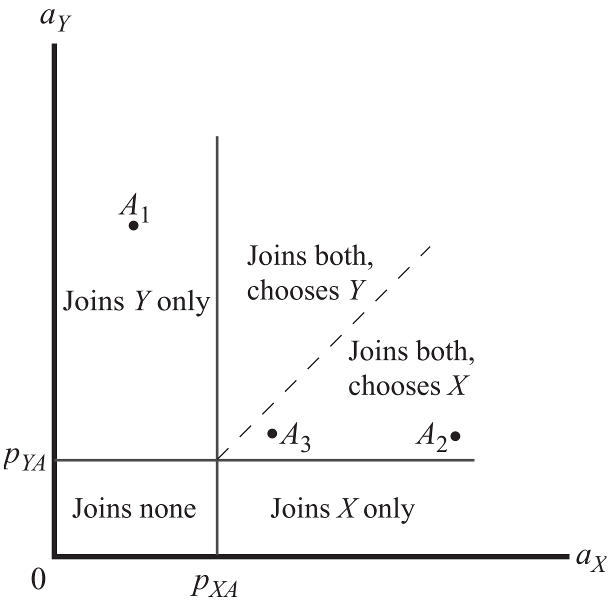

FIGURE 2

B'S EQUILIBRIUM STRATEGY AS A FUNCTION OF TYPE UNDER AN A-CHOOSES ROUTING REGIME. THE DOTTED RAY HAS SLOPE 1.

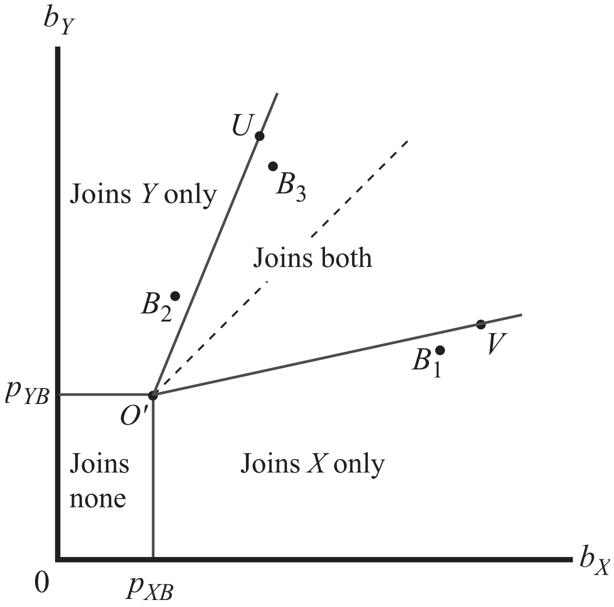

FIGURE 3

B'S EQUILIBRIUM STRATEGY AS A FUNCTION OF TYPE WHEN BOTH NETWORKS ADOPT NETWORK ROUTING.

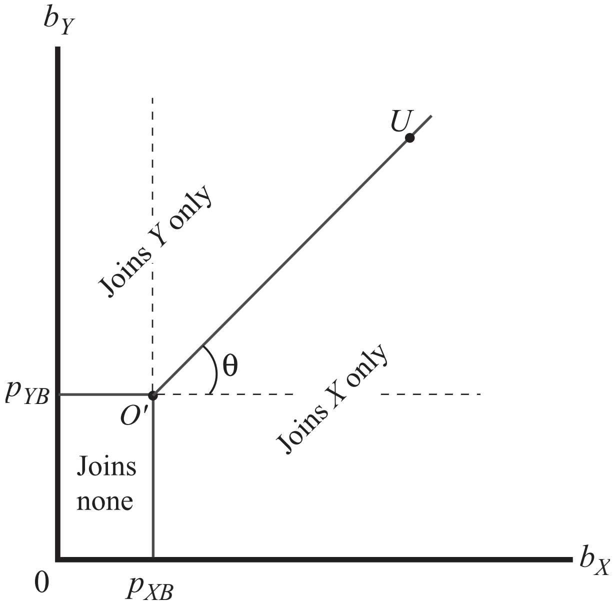

FIGURE 4

A'S EQUILIBRIUM STRATEGY AS A FUNCTION OF TYPE WHEN ONLY NETWORK X STIPULATES NETWORK ROUTING.

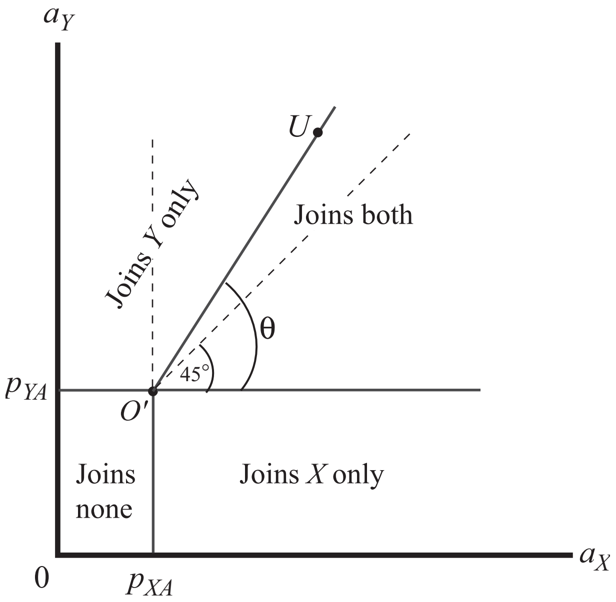

FIGURE 5

B'S EQUILIBRIUM STRATEGY AS A FUNCTION OF TYPE WHEN BOTH NETWORKS REQUIRE EXCLUSIVITY OF A.

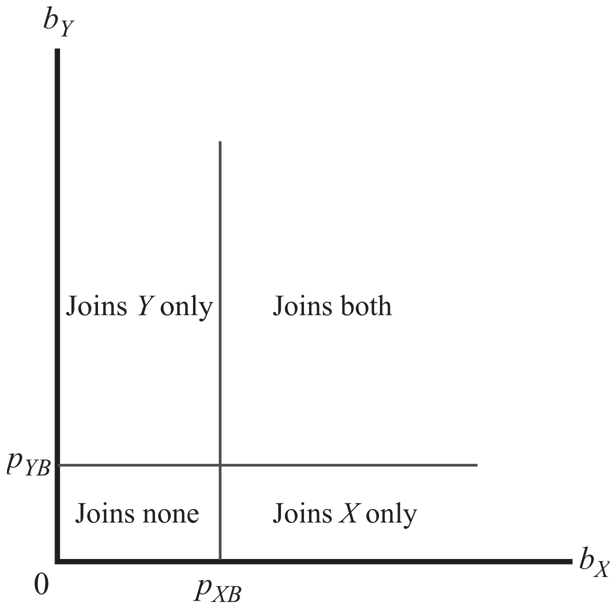

FIGURE 6

A'S EQUILIBRIUM STRATEGY AS A FUNCTION OF TYPE WHEN BOTH NETWORKS REQUIRE EXCLUSIVITY OF A. THE SLOPE OF RAY $\overrightarrow{O'U}$ IS GIVEN BY EXPRESSION (5).

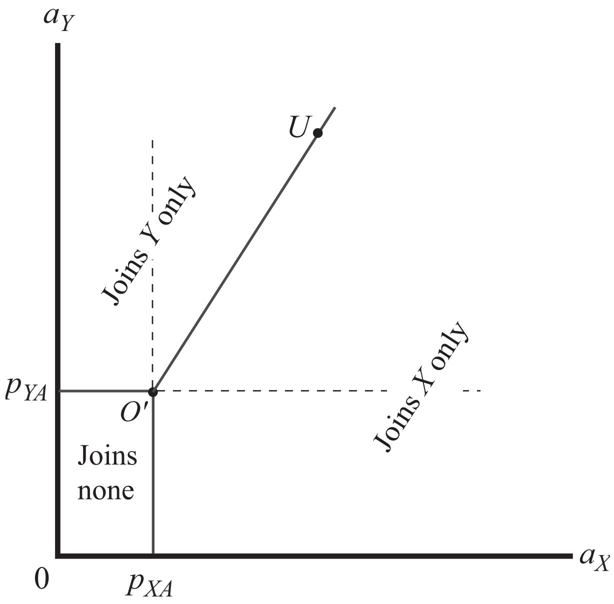

FIGURE 7

ROUTING-REGIME GAME

		Network X				
		A routing	B routing	network routing	A exclusive	B exclusive
Network Y	A routing	Π_A Π_A	Π_D Π_D	Π_{NO} Π_{AO}	Π_E Π_E	Π_E Π_E
	B routing	Π_D Π_D	Π_A Π_A	Π_{NO} Π_{AO}	Π_E Π_E	Π_E Π_E
	network routing	Π_{AO} Π_{NO}	Π_{AO} Π_{NO}	Π_N Π_N	Π_E Π_E	Π_E Π_E
	A exclusive	Π_E Π_E	Π_E Π_E	Π_E Π_E	Π_E Π_E	Π_N Π_N
	B exclusive	Π_E Π_E	Π_E Π_E	Π_E Π_E	Π_N Π_N	Π_E Π_E

Where

Π_A = expected profit when both networks have A routing (or both have B routing)[a]
Π_{AO} = expected profit for network with A (B) routing when other network has network routing
Π_{NO} = expected profit for network with network routing when other network has A (B) routing
Π_N = expected profit when both networks have network routing[b]
Π_E = expected profit under one-sided exclusivity[c]
Π_D = expected profit when networks impose incompatible routing rules

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[a] The assumption of a uniform distribution on the unit square ensures that the continuation game with A routing yields the same profits as the continuation game with B routing. Were the two sides to have different distributions, this would not hold generally.

[b] Alternatively, one or both networks require exclusivity of both sides of the market; or one network requires exclusivity from A, while the other requires exclusivity from B. See Proposition 4.

[c] Specifically, one network (at least) requires exclusivity of one side and neither network requires exclusivity of the other side.

FIGURE 8

BEST-RESPONSE FUNCTIONS IN θ WHEN BOTH NETWORKS STIPULATE NETWORK ROUTING

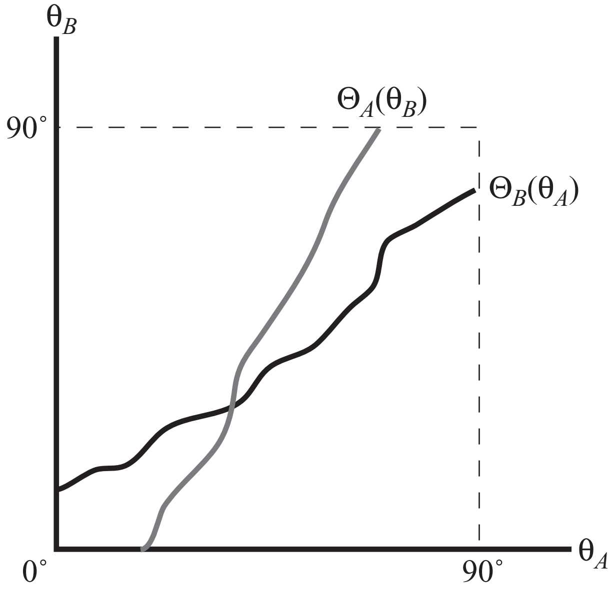

FIGURE 9

BEST-RESPONSE FUNCTION IN θ WHEN X ONLY STIPULATES NETWORK ROUTING