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PRICING OF SETTLEMENT LINK SERVICES AND MERGERS OF CENTRAL SECURITIES DEPOSITORIES

by Jens Tapking

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Abstract

This paper tries to contribute to the discussion on the role of securities settlement infrastructures for financial integration in Europe. It presents a model that can explain a well-known stylized fact of securities settlement, the surprisingly high fees charged by central securities depositories (CSDs) for settlement through links between CSDs. As the model turns out to provide a robust explanation for this stylized fact, it is then used to analyzes an important policy question, the welfare effects of mergers of CSDs.

Keywords: Securities settlement, link settlement fees, central securities depositories.

JEL Classifications: G21, G15, L13.

Non-technical summary

Most developed countries have established a central securities depository (CSD) as central institution for the depository and settlement of securities. In many countries, the CSD is operated as a private company and may as such have profit maximization as main business goal.

Fees charged by CSDs for the settlement of securities transactions between members of the same CSD are relatively low. However, when buyer and seller are members of two different CSDs (typically located in different countries) and the transaction is settled through a link between the two CSDs, then the trading parties often pay substantial settlement fees. To reduce settlement fees, banks may even try to avoid trading with foreign banks so that the high fees for settlement across CSDs may to some extent hamper financial integration. Cross-border consolidation of CSDs within Europe has been proposed as a possible remedy.

CSDs argue that the high fees for settlement across CSDs simply reflect the underlying operational costs. Doubts may however be raised about this explanation as modern information technology might allow for cross-border settlement at reasonable costs.

The purpose of this theoretical paper is twofold.

Firstly, it provides an alternative explanation of the relatively high fees for settlement through CSD links. This explanation refers to the strategic interaction between two profit maximizing CSDs when they set their settlement fees independently. It does not refer to underlying costs for operating CSD links. It is assumed that banks take settlement fees into account when they negotiate over-the-counter with each other on securities prices. Consider for example a bank that wishes to sell securities and assume that its CSD charges higher fees for link settlement. The bank will demand a relatively low price for the securities when it negotiates with a bank that is member of the same CSD. And it will demand a relatively high price when it negotiates with a bank that is member of a different CSD in order to recover its additional settlement costs. This implies that the fee charged by a CSD for cross-border transactions is partly borne by banks participating in the other CSD. CSDs therefore have incentives to charge relatively high fees for settlement through CSD links and at the same time to lower the fees for settlement within the CSD as a compensation for their own members.

Secondly, the paper analyses the welfare effects of a merger of two CSDs that are initially linked with each other. A full technological merger of the two CSDs implies that the link can be abolished and all member banks are members of the same single CSD. Although we assume that bank cannot freely choose one of the CSDs but either have to use the CSD located in their own country or leave the market altogether (i.e. although there is no direct competition between the CSDs for members), we find that the two CSDs still interact due to the link in a way that drives down settlement fees at given operational costs as long as the CSDs are run independently. As a consequence, a merger of the two CSDs reduces welfare as long as it does not reduce operational costs. Operational

costs can however be trimmed down through a merger as the merger allows to abolish the link. A merger therefore has a second, a cost reduction effect that is positive for welfare. We find that in the present model, the overall effect of a merger of the two CSDs on welfare is ambiguous and depends on the model parameters. It follows that strong policy conclusions should not be made on the basis of this paper.

1 Introduction

With the globalization of financial markets, more and more securities transactions involve trading parties located in different countries. Settlement, that is the transfer of the securities from the seller to the buyer and the transfer of the funds from the buyer to the seller, can in such a case require complicated and costly steps, in particular if the buyer and the seller do not use the same settlement service provider. The high costs of settlement across countries have been identified as a major obstacle in the process of financial integration in particular within Europe and has triggered a lively debate.[1]

This paper provides an explanation why an arguably relatively simple way to settle cross-border securities transactions, namely through links between different national central securities depositories (CSDs), appears to be particularly costly for investors. In this context, the paper also tries to shed some light on the pros and cons of an intensively discussed remedy for this phenomenon at least in Europe, the cross-border mergers of CSDs.[2]

1.1 Securities settlement

As indicated above, the transfer of securities from the seller to the buyer and the transfer of the related funds from the buyer to the seller is referred to as securities settlement. Today, securities and funds are typically transferred electronically through account entries rather than physically. Funds are transferred through payment systems, often operated by national central banks. To facilitate the transfer of securities, many countries have established a CSD. A CSD can be thought of as a central store house where securities are stored in paper form or increasingly often electronically as computer entry. If an issuer wants to issue securities in a given country, he usually deposits the entire issue with the national CSD of that country. Investors who own securities need to have a (direct or indirect) securities account relation with the CSD where the securities issue is stored.

The transfer of securities can be explained by means of Figure 1. We assume that there are two countries A and B with a national CSD in each country. There are four investor institutions (banks or brokers) A, B, C and D. Arrows indicate securities accounts so that A and B have securities accounts with CSD A while C and D have securities accounts with CSD B. The CSDs have securities accounts with each other, so-called link accounts.

In the simplest case, the buyer and the seller have their securities accounts directly with the CSD at which the issue is deposited. Suppose for example that A sells to B securities deposited in CSD A. The securities transfer then only involves debiting the securities from the seller's securities account and crediting them to the buyer's account.[3] Settlement is simple also when A sells to B

[1] See for example Giovannini Group (2001, 2003).

[2] See for example Bourse Consult (2005).

[3] If buyer and seller also have cash acounts with the same institution, typically the national central bank, then the transfer of funds involves debiting the buyer's cash account with the

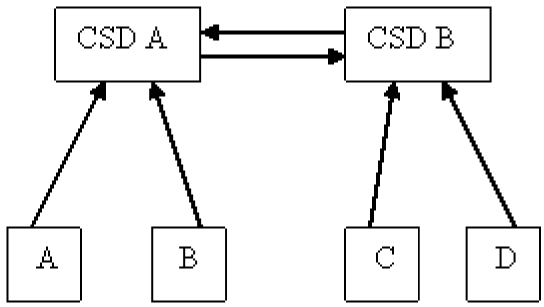

Figure 1: Links between CSDs.

securities deposited in CSD B. Again, the country B securities only need to be debited from A's account with CSD A and credited to B's account with CSD A.

If however A sells to C or vice versa, then a link account comes into play. Suppose that A sells to (buys from) C securities deposited in CSD A. The securities now need to be debited from A's account with CSD A (C's account with CSD B), then credited to (debited from) CSD B's account with CSD A and finally credited to C's account with CSD B (A's account with CSD A). Similarly, suppose that A buys from C securities deposited in CSD B. The securities now need to be debited from C's account with CSD B, then credited to CSD A's account with CSD B and finally credited to A's account with CSD A.

As an alternative to settlement through links between CSDs, investor institutions often use local custodians as intermediaries to settle across borders. Assume that C has a securities account with B so that C could use B as local custodian for country A securities. If A now sells to C securities deposited in CSD A, then the securities could be transferred by debiting them from A's account with CSD A, crediting them to B's account with CSD A and finally crediting them to C's account with B.

One may find that settlement through links between CSDs might be more efficient than settlement through a local custodian. As C needs to have an account relation with CSD B in any case to settle country B securities, it seems to be reasonable that C also uses this account to settle transactions in country A securities instead of opening an account with B for them. However, there are strong indications that links are hardly used to settle across borders.[4] And one reason for this observation might be the surprisingly high prices CSDs charge for settlement through links.

central bank and crediting the seller's cash account with the central bank.

[4] See for example Giovannini Group (2001), page 10.

1.2 Settlement prices - stylized facts

It is worth having a closer look at the structure of the various settlement prices charged by (European) CSDs to their participants.[5] We distinguish four prices:

- The price for internal transfers of domestic securities. In Figure 1, this would be for example the price that A and B (alike) have to pay to CSD A for a transfer of country A securities from A to B.
- The price for internal transfer of foreign securities. In Figure 1, this would be the price that A and B have to pay to CSD A for a transfer of country B securities from A to B.
- The price for a transfer of domestic securities through a link. In Figure 1, this would be the price that A has to pay to CSD A for a transfer of country A securities from A to C or vice versa.
- The price for a transfer of foreign securities through a link. In Figure 1, this would be the price that A has to pay to CSD A for a transfer of country B securities from A to C or vice versa.

National CSDs typically charge the same price for both types of internal transfers. They also charge the same price for both types of link transfers. The prices for link transfers are however much higher than those for internal transfers.[6]

There is an intensive debate in Europe about why prices for link settlement are so much higher than those for internal settlement. It may not be a surprise that the CSDs argue that their price schedules simply reflect the underlying (operating) costs of settlement. However, not everyone believes that in times of modern information technology, the underlying costs for link settlements are many times higher than those for internal settlement.

When elaborating on possible strategic (as opposed to cost-based) reasons for this price structure, one may also take into consideration another price, charged by one CSD to the other:

- The price charge by the CSD at which the securities are deposited (the so-called issuer CSD) to the linked CSD (the so-called investor CSD) for a link transfer. In Figure 1, this would be the price that CSD B has to pay to CSD A for a transfer of country A securities from A to C or vice versa.

[5] The fee schedules of the national CSDs of Germany, France and the Netherlands have been studied in this respect.

[6] The price structure is in some cases highly complex as the average price often depends on the number of transfers per month. Nevertheless, for the European Union, Nera (2004) for example estimates that for an equity transaction settled internally within a CSD, the price is in the range of EUR 0.35 to EUR 0.80 ($0.42 to $0.96), while a cross-border settlement through a CSD link can cost up to EUR 35 ($42).

Indeed, one may argue that the issuer CSD may try to charge excessively high prices to the investor CSD in order to prevent settlement business from moving out of the issuer CSD. This could force the investor CSD to charge high prices for transfers of foreign securities through a link. There is not much known about the prices charged by issuer CSDs to investor CSDs for link transfers as they are typically a matter of negotiations. However within the European Union, an investor CSD could certainly complain with the European Commission as the relevant competition authority, if an issuer CSD charges excessively high prices to it.[7] Moreover, many CSDs maintain bilateral links, i.e. both CSDs have a link with the other as in Figure 1. As the prices charged by one CSD to the other are typically a matter of bilateral negotiations, it appears to be likely that these prices are not excessive in these cases.

1.3 Towards an explanation for the structure of settlement prices

In this paper, we suggest a model with an alternative explanation for the high link settlement prices. The structure of the model is basically the one depicted in Figure 1. There are two national CSDs A and B. There are two (large) groups of investor institutions, we call them for simplicity banks. Country A banks can leave the market or participate in CSD A. Similarly, country B banks can leave the market or participate in CSD B. Thus, banks cannot participate in the foreign CSD.

The two national CSDs A and B are assumed to maximize profits and set prices for internal and link settlement accordingly.[8] Banks that decide not to leave the market are randomly matched with one another to trade. The probability for, say, a country A bank of being matched with a country B bank is endogenous in our model. The more country B banks decided not to leave the market and the more country A banks decided to leave the market, the higher is the probability of being matched with a country B bank.

When two banks are matched, they start to negotiate on securities prices whereby they take into account also the settlement prices. Suppose for example that CSD A charges a higher price for link settlement than for internal settlement. Suppose now that some country A bank wishes to sell, say, country A securities. This bank now would try to get a higher price for the securities when negotiating with a country B bank than in negotiations with another country A bank in order to get compensation for the relatively high settlement prices in case of trading with a bank located in country B. That means that the link

[7] Note for example that in June 2004, the European Commission found that Clearstream Banking AG, the national German CSD, "infringed competition rules by refusing to supply cross-border securities clearing and settlement services and by applying discriminatory prices" to the international CSD Euroclear Bank.

[8] In reality, CSDs are typically private entities. Only a few (usually small) CSDs are still operated by central banks or other public entities. CSDs that are private entities are often subsidiaries of listed companies and the for-profit assumption might appear reasonable. Other CSDs argue to be user-owned and user-oriented rather than for-profit.

settlement price charged by, for example, CSD A is indirectly borne partly by banks that do not participate in CSD A, but in CSD B.[9]

Suppose for simplicity that for participants of CSD A, the probability of being matched with another participant of CSD A is $\frac{1}{2}$, and of being matched with a participant of CSD B is $\frac{1}{2}$.[10] This implies that when CSD A increases the prices for link settlement and decreases those for internal settlement by the same amount, then participants of CSD A get better off although they still pay the same expected settlement prices as before. This is because they can externalize parts of the price for link settlement to their trading partners in CSD B in the negotiations for securities prices. Thus, with this strategy, CSD A can attract more participants and raise profits. The same holds for CSD B. In equilibrium, both CSDs will charge the highest possible link settlement prices and use the revenues from link settlement to cross-subsidize the price for internal settlement.

We discuss a basic and an extended model. In the basic model, we assume that banks cannot influence the probability of being matched with participants of the other CSD. When we later on extend the model, we assume that banks can make an effort to make it more likely to be matched with a participant of the same CSD. In the extended model, which is relatively complex so that we can only solve it numerically, we still find that the link settlement prices in equilibrium are relatively high, although somewhat lower than in the basic model.

1.4 Welfare considerations

As our model can well explain the stylized facts of settlement prices, we feel confident enough to use our model to analyze an important policy question, the welfare effects of (cross-border) mergers of national CSDs. In particular internationally active market participants have called for consolidation of European CSDs through mergers as a way to trim down the costs of cross-border settlement. Indeed, several mergers have taken place already in Europe recently.[11] However, some players also argue that mergers of CSDs could reduce competition in the settlement industry and could therefore also have adverse effects on market efficiency.[12]

[9] It is apparent that we assume that securities are traded over-the-counter rather than on an exchange as securities prices are determined in direct negotiations between the buyer and the seller. This assumption is reasonable as trades executed on an exchange are typically settled within a single CSD without using links. Transfers from the seller to the buyer through a link between CSDs typically result from over-the-counter trades. For a discussion of the use of links for on-exchange trades, see Tapking and Yang (2006).

[10] As mentioned above, these probabilities will be endogenous in our model.

[11] The national CSDs of Belgium, France, the Netherlands and the UK have been merged (together with the international CSD Euroclear Bank) to form Euroclear Group. Clearstream International comprises the German national CSD and the international CSD Clearstream Banking Luxembourg. The national CSDs of Sweden and Finland have been merged to form Nordic CSD.

[12] See Giovannini Group (2003), in particular Section 3.

In our model, we assume that the two CSDs do not compete for banks as country A banks can only participate in CSD A, but not in CSD B. And country B banks can only participate in CSD B. Nevertheless, there is strong strategic interaction between the two CSDs. If, say, CSD A decreases its settlement prices, then more country A banks will participate in it. This implies in our model that the probability for country B banks to be matched with a country A bank increases. As the prices for link settlement are high, this could make country B banks leave the market so that CSD B would need to lower its own prices. Thus, there is indirect price pressure as long as the two CSDs set prices independently: if one CSD lowers its prices, then the other CSD will follow.

In our basic model, we find that a merger of the two CSDs reduces welfare as long as the merger does not reduce any operating costs. The reason is of course the indirect price pressure just mentioned as this price pressure will be removed after a merger. However, if the two CSDs are not only legally merged, but also technically so that they use one account system and do not need to operate links anymore, then the merger is beneficial from a welfare perspective due to lower operating costs.

However, this only holds in our basic model. In the extended model, even a full technical merger of the two CSDs can reduce welfare, if the operating costs for settlement through links are higher than those for internal settlement. In this case, banks should, from a welfare perspective, make an effort to avoid settlement through links and are indeed encouraged to do so by the very high equilibrium prices for link settlement. The positive welfare effect of a technical merger of the CSDs, i.e. of the removal of the link and the related costs, now does not offset anymore the positive effect of the indirect price pressure in case that the CSDs do not merge.

Thus, our welfare results derived from the basic model are not robust so that a strong policy conclusion cannot be drawn from our model.

1.5 Academic literature

Motivated by the ongoing policy discussion on the European financial market infrastructure, there is an increasing body of academic literature on the securities settlement industry, mainly focused on questions related to competition between and consolidation of different service providers.

Kauko (2003) might be the paper that is closest related to ours. The paper tries to explain why links between CSDs are set up, but are often hardly used. It argues that a CSD could allow other CSDs to open links with it in order to commit itself to relatively low prices. Without links, the CSD can lock in its participants and then charge excessively high fees. In anticipation of such a strategy, potential participants could be deterred from using the CSD. If other CSDs maintain links to it, then its participants could leave the CSD and settle elsewhere if the CSD starts charging excessive prices. The CSD will therefore charge only modest prices so that potential participants are not deterred. The links will nevertheless not be used. The paper however does not provide an explanation of the relatively high prices for link settlement.

Tapking and Yang (2006) discuss the welfare effects of mergers of different national CSDs (horizontal mergers) that are linked with each other and compare them with those of mergers of a CSD with a stock exchange (vertical mergers). They find that in their model, both types of mergers are welfare improving, but horizontal mergers are even better than vertical mergers. As in the present paper, the positive effect of horizontal mergers is partly a consequence of the lower operating cost when a link between CSDs can be closed after a full technical merger of two CSDs.

With a view to the potentially negative competition effects of mergers of CSDs, Serifsoy and Weiss (2005) argue that the best model for Europe would be a single, but contestable CSD. Schmiedel and Schönenberger (2005) summarize the main trends and points of discussion in the industry in Europe. The empirical papers by Schmiedel, Malkamaki and Tarkka (2002) and by Van Cayseele (2005) find significant economies of scale in securities settlement, suggesting that mergers of CSDs should generally reduce operating costs of settlement. Other less related papers on consolidation in the settlement industry are the theoretical papers by Koeppl and Monnet (2004), Holthausen and Tapking (2006) and Rochet (2005).

1.6 Structure of the paper

The assumptions of our basic model are introduced in Section 2. The Sections 3 and 4 present the equilibrium before and after a merger of the CSDs in our basic model. The welfare results of the basic model are discussed in Section 5. Finally, the extended model is introduced and analyzed in Section 6.

2 The model

There are two countries A and B. There are two profit maximizing CSDs: CSD A is located in country A and CSD B is located in country B. In each country, there is a continuum $[0, \frac{1}{2}]$ of banks. The banks are the potential participants (i.e. securities account holders) in the CSDs. However, we assume that banks located in country A can participate only in CSD A and banks located in country B can only participate in CSD B.

There are two types of securities. Securities of type A have been issued in CSD A and securities of type B have been issued in CSD B. The two CSDs are linked with each other so that securities issued in one CSD can also be held and settled in the other CSD. The bilateral link consists of (i) a securities account of CSD B with CSD A to transfer A securities from CSD A to CSD B and back and (ii) a securities account of CSD A with CSD B to transfer B securities from CSD B to CSD A and back.

Two types of settlement can occur: (1) Securities may need to be transferred from one participant in CSD k ($k = A, B$) to another participant in the same CSD k (internal settlement in CSD k); In this case, CSD k debits the account of the delivering participant and credits the account of the receiving participant.

(2) Securities may need to be transferred from a participant in CSD k to a participant in CSD l ($l = A, B$, $l \neq k$); (a) If country k securities are being transferred, then CSD k debits them from the account of the delivering participant and credits them to CSD l's account with CSD k, while CSD l credits them to the receiving participant. (b) If l securities are being transferred, then CSD k debits them from the account of the delivering participant while CSD l debits them from CSD k's account with CSD l and credits them to the account of the receiving participant in CSD l.

Decisions are taken by the different players in several steps. First, the two CSDs negotiate on the prices r_A and r_B. Here, r_k is the price that CSD l (the investor CSD) has to pay to CSD k (the issuer CSD) whenever CSD k debits or credits CSD l's account. As our model is completely symmetric with respect to the two CSDs, we assume that the CSDs always agree on $r_A = r_B = r$ for some (non-negative) number r. This assumption will later on ensure that r_A and r_B drop out when the CSDs maximize profits so that we do not need to determine r_A and r_B in equilibrium.

Second, CSD A sets the prices p_{AA}, p_{BA}, q_{AA} and q_{BA} while CSD B simultaneously set the prices p_{AB}, p_{BB}, q_{AB} and q_{BB}. Here, p_{Ak} (p_{Bk}) is the price that a participant in CSD k has to pay whenever his account with CSD k is debited or credited to transfer A (B) securities from his account to another participant in CSD k or from another participant in CSD k to his account (internal settlement within CSD k). And q_{Ak} (p_{Bk}) is the price that he has to pay whenever his account with CSD k is debited or credited to transfer A (B) securities from his account to a participant in CSD l or from a participant in CSD l to his account (external settlement across the two CSDs).

When a CSD debits or credits accounts, it incurs operating costs. Costs functions of the CSDs are linear. The costs that CSD k incurs when it debits or when it credits an account to transfer k securities (i.e. domestic securities) from one participant with CSD k to another participant with CSD k (internal settlement) are c_{DI}. The costs that CSD k incurs when it debits or when it credits an account to transfer l securities (i.e. foreign securities) from one participant with CSD k to another participant with CSD k (internal settlement) are c_{FI}. The costs that it incurs when it debits or when it credits an account to transfer k securities across the CSDs (external settlement) are c_{DE}. And its costs when it debits or when it credits an account to transfer l securities across the CSDs are c_{FE}. The overall costs of settling a transaction across CSDs are thus $c_{FE} + 2c_{DE}$. The overall costs of settling a transaction internally in one CSD are $2c_{DI}$ in case of a domestic securities and $2c_{FI}$ in case of a foreign securities. We assume that $c_{FE} + 2c_{DE} \geq 2c_{DI} = 2c_{FI}$ as this assumption appears empirically reasonable.

Third, each bank located in country k has to decide if it would like to participate in CSD k (i.e. to open a securities account with CSD k) or to opt out. For any country k bank $i \in [0, \frac{1}{2}]$, participating in CSD k costs $t \cdot i$. Here, t is an exogenous parameter. Denote a the number of banks that go to CSD A and b the number of banks that go to CSD B. The number of country A (B) banks that opt out is then $\frac{1}{2} - a$ ($\frac{1}{2} - b$).

Forth, half of all those banks that have not opted out receives one unit of A securities each and does not benefit from holding A securities (potential sellers of A securities). The other half of these banks does not receive A securities, but would have benefits v from holding A securities (potential buyers of A securities). Similarly, one half of all those banks that have not opted out receives one unit of B securities each and does not benefit from holding them (potential sellers), while the other half of banks does not receive B securities, but would have benefits v from holding B securities (potential buyers). Potential buyers and sellers of both types of securities are selected randomly.

Finally, each potential seller of A securities is matched with a potential buyer of A securities to trade. And each potential seller of B securities is matched with a potential buyer of B securities. Thus, each bank that has not opted out is matched twice, once to trade A securities and once to trade B securities. If two country A banks are matched to trade k securities, then they agree on a price s_{aa}^k such that

$$s_{aa}^k - p_{kA} = v - s_{aa}^k - p_{kA}$$

so that $s_{aa}^k = \frac{1}{2}v$ and both reach a utility of $\frac{1}{2}v - p_{kA}$. If $\frac{1}{2}v - p_{kA} < 0$, then they do not trade. Similarly, if two country B banks are matched to trade k securities, then they agree on a price s_{bb}^k such that

$$s_{bb}^k - p_{kB} = v - s_{bb}^k - p_{kB}$$

so that $s_{bb}^k = \frac{1}{2}v$ and both reach a utility of $\frac{1}{2}v - p_{kB}$. If $\frac{1}{2}v - p_{kB} < 0$, then they do not trade. Thus, when they set prices, the CSDs will have to ensure that $p_{kA}, p_{kB} \leq \frac{1}{2}v$. Note that this implies that we have to assume $c_{DI}, c_{FI} \leq \frac{1}{2}v$. Otherwise, trade would not be possible.

If a country A and a country B bank are matched to trade k securities and the country A bank is the seller, then they agree on a price s_{ab}^k such that

$$s_{ab}^k - \gamma q_{kA} = v - s_{ab}^k - \gamma q_{kB}$$

so that $s_{ab}^k = \frac{1}{2}(v + \gamma q_{kA} - \gamma q_{kB})$. The parameter γ will turn out to be crucial in our model. It is therefore important to understand its economic interpretation. If $\gamma = 1$, then each bank takes fully into account its settlement costs when it negotiates with the other bank. If $\gamma = 0$, then the banks ignore settlement costs when they negotiate. From the trade, the country A bank reaches a utility of $\frac{1}{2}[v - (2-\gamma)q_{kA} - \gamma q_{kB}]$ and the country B bank of $\frac{1}{2}[v - \gamma q_{kA} - (2-\gamma)q_{kB}]$. If $v - (2-\gamma)q_{kA} - \gamma q_{kB} < 0$ or $v - \gamma q_{kA} - (2-\gamma)q_{kB} < 0$, then they do not trade.

Finally, if a country A and a country B bank are matched to trade k securities and the country A bank is the buyer, then they agree on a price s_{ba}^k such that

$$s_{ba}^k - \gamma q_{kB} = v - s_{ba}^k - \gamma q_{kA}$$

so that $s_{ba}^k = \frac{1}{2}(v - \gamma q_{kA} + \gamma q_{kB})$. The country A bank reaches a utility of $\frac{1}{2}[v - (2-\gamma)q_{kA} - \gamma q_{kB}]$ and the country B bank of $\frac{1}{2}[v - \gamma q_{kA} - (2-\gamma)q_{kB}]$.

If $v-(2-\gamma)q_{kA}-\gamma q_{kB}<0$ or $v-\gamma q_{kA}-(2-\gamma)q_{kB}<0$, then they do not trade.

The probability that a given country A bank is matched with a country B bank to trade k securities is

$$\alpha\frac{b}{a+b}$$

Here, α is an exogenous parameter. If $\alpha=1$, then the probability only depends on the proportion of a and b banks and $a=b$ implies that a country A bank is equally likely matched with a country A bank and with a country B bank. If $\alpha<1$, then the probability for a country A bank of being matched with another country A bank is relatively high. For conceptional reasons, we at least need to assume that $\alpha\leq 1$ because otherwise, the probability $\alpha\frac{b}{a+b}$ could exceed 1 for sufficiently small values of a. Indeed, we assume throughout the paper that $\alpha<1$ as this assumption appears empirically reasonable.

A country A bank's expected benefit from trading k securities is thus given by

$$\begin{aligned} u_A^k &= \alpha\frac{b}{a+b}\frac{1}{2}[v-(2-\gamma)q_{kA}-\gamma q_{kB}] \\ &\quad +[1-\alpha\frac{b}{a+b}](\frac{1}{2}v-p_{kA}) \end{aligned}$$

Similarly, a country B bank's probability of being matched with a country A bank to trade k securities is

$$\alpha\frac{a}{a+b}$$

and its expected benefit from trading k securities is thus given by

$$\begin{aligned} u_B^k &= \alpha\frac{a}{a+b}\frac{1}{2}[v-(2-\gamma)q_{kB}-\gamma q_{kA}] \\ &\quad +[1-\alpha\frac{a}{a+b}](\frac{1}{2}v-p_{kB}) \end{aligned}$$

Define $p_A=p_{AA}+p_{BA}$, $q_A=q_{AA}+q_{BA}$, $p_B=p_{AB}+p_{BB}$, $q_B=q_{AB}+q_{BB}$. Country A bank i's utility if it decides to participate in CSD A is

$$u_{A,i}=u_A-ti$$

with

$$u_A\equiv u_A^A+u_A^B=v-p_A+\alpha\frac{b}{a+b}[p_A-\frac{1}{2}(2-\gamma)q_A-\frac{1}{2}\gamma q_B]$$

Country B bank i's utility if it decides to participate in CSD B is

$$u_{B,i}=u_B-ti$$

with

$$u_B\equiv u_B^A+u_B^B=v-p_B+\alpha\frac{a}{a+b}[p_B-\frac{1}{2}\gamma q_A-\frac{1}{2}(2-\gamma)q_B]$$

Finally, if a bank opts out, it gets a benefit of 0.

The variables a and b are accordingly given by

$$a = \frac{1}{t}u_A,\ b = \frac{1}{t}u_B \tag{1}$$

as long as for given prices, this system of equations has a solution $a, b \in [0, \frac{1}{2}]$. Although it typically has two solutions, numerical evaluations on the computer show that at most one of them fulfils $a, b \in [0, \frac{1}{2}]$. If for a given combination of prices, the system 1 does not have a solution with $a, b \in [0, \frac{1}{2}]$, then corner solutions occur.

Figure 2 describes cases with and without such corner solutions. We assume $\alpha = \gamma = t = v = q_A = q_B = \frac{1}{2}$, $p_B = \frac{1}{5}$. As long as we have an interior solution, we find that a decreases and b increases when p_A is increasing. Why does b increase when p_A is increasing? As a is decreasing in p_A, the probability of a country B bank to be matched with a country A bank, i.e. the probability that the country B bank has to pay q_A, goes down when p_A increases. As we assume in the example that q_B is very high ($q_B = v$), more country B banks are ready to participate in CSD B when p_A is increasing.

Note that corner solutions with $a = 0$ or with $b = 0$ cannot occur as $u_{A,0} = u_A \geq 0$ as long as prices p_A, q_A, p_B and q_B must not exceed v. Corner solutions with $a = \frac{1}{2}$ or with $b = \frac{1}{2}$ occur if domestic prices are low and/or foreign prices are high, provided that t is sufficiently small. To avoid corner solutions with $a = \frac{1}{2}$ or with $b = \frac{1}{2}$, we assume from now on that $t \geq 2v$ as this implies that country A (B) bank $i = \frac{1}{2}$ will not participate in CSD A (B) even if $p_A = q_A = p_B = q_B = 0$.

Let $c = c_{FE} + 2c_{DE} - c_{DI} - c_{FI}$ and $c_I = c_{DI} + c_{FI}$. Note that $c \geq 0$ as we assume $c_{FE} + 2c_{DE} \geq 2c_{DI} = 2c_{FI}$. Moreover, $c_I \leq v$ as we assume $c_{DI} = c_{FI} \leq \frac{1}{2}v$. The profits of the two CSDs are given by

$$\begin{aligned}
\pi_A &= \alpha\frac{ab}{a+b}(q_{AA} + r_A - 2c_{DE}) \\
&\quad + [a - \alpha\frac{ab}{a+b}](p_{AA} - c_{DI}) \\
&\quad + \alpha\frac{ab}{a+b}(q_{BA} - r_B - c_{FE}) \\
&\quad + [a - \alpha\frac{ab}{a+b}](p_{BA} - c_{FI}) \\
&= \alpha\frac{ab}{a+b}(q_A - p_A - c) + a(p_A - c_I)
\end{aligned}$$

and similarly

$$\pi_B = \alpha\frac{ab}{a+b}(q_B - p_B - c) + b(p_B - c_I)$$

where we made use of our assumption that $r_A = r_B$.

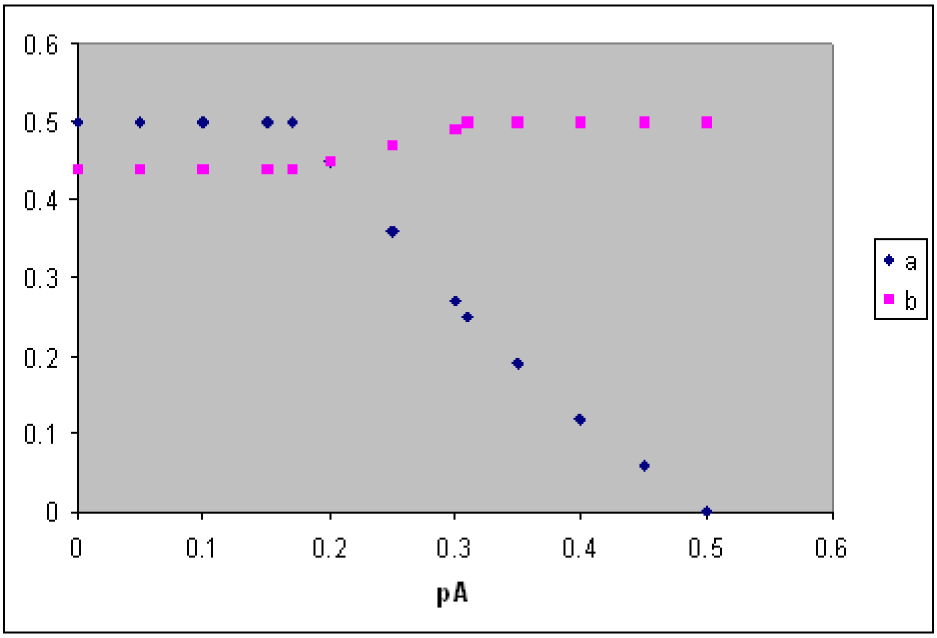

Figure 2: Demand parameters a and b as they vary with p_A for $\alpha = \gamma = t = v = q_A = q_B = \frac{1}{2}$, $p_B = \frac{1}{5}$. For $p_A \in [0.17; 0.31]$, we have $a = \frac{1}{t}u_A$ and $b = \frac{1}{t}u_B$. For $p_A < 0.17$, we get $a = \frac{1}{2}$ and $b = \frac{1}{t}u_B (= 0.44)$. For $p_A > 0.31$, we get $a = \frac{1}{t}u_A$ and $b = \frac{1}{2}$.

3 Complete separation of CSDs

In this section, we assume that the two CSDs set their prices independently. We only consider symmetric equilibria, i.e. equilibria in which we have $p_{Ak} = p_{Bk}$ and $q_{Ak} = q_{Bk}$ for $k = A, B$, $p_A = p_B$ and $q_A = q_B$. In the appendix, we prove the following:

Proposition 1 *Let $\gamma > 0$. Let $v \geq c_I + \frac{\alpha(3-2\alpha)}{4-3\alpha}c$.*[13] *If there is a symmetric equilibrium, then it is given by*

$$\begin{aligned} p_A &= p_B = \frac{1-\alpha}{2-\alpha}v + \frac{\alpha(1-\alpha)}{(2-\alpha)(4-3\alpha)}c + \frac{1}{2-\alpha}c_I \\ q_A &= q_B = v \\ a &= b = \frac{1}{2t}[v - c_I - \frac{\alpha(1-\alpha)}{4-3\alpha}c] \equiv a_{CS} \end{aligned}$$

We are not able to provide a full proof that the prices of proposition 1 indeed constitute an equilibrium. However, we evaluate numerically on the computer a wide range of parameter constellations and find that for all these parameter constellations, the above prices are also sufficient for an equilibrium. We are therefore sufficiently confident that proposition 1 describes a unique symmetric equilibrium.[14][15]

Our analysis gives a simple explanation of why the prices of external settlement through a link between CSDs are so high. As long as $\gamma > 0$, participants of, for instance, CSD A can partially shift the burden of high external settlement prices charged by CSD A to their trading partners who participate in CSD B. Thus, a participant in CSD A suffers less, if his expected settlement price to be paid to CSD A increase due to a higher price q_A instead of due to a higher price p_A. Or in other words, if CSD A increases q_A and at the same time decreases p_A in a way that leaves the expected settlement price its participants have to

[13] This is needed to ensure that profits π_A and π_B do not get negative for the prices of proposition 1.

[14] Note that there are parameter constellations such that the prices given in Proposition 1 are the only prices that satisfy our sufficient conditions for a symmetric equilibrium, but do not constitute an equilibrium. We have excluded such parameter constellations by our assumption that $t \geq 2v$. An example would be $\alpha = \frac{9}{10}$, $t = v = \gamma = c = \frac{1}{2}$, $c_I = 0$. The prices according to Proposition 1 would be $p_A = p_B = \frac{1}{13}$, $q_A = q_B = \frac{1}{2}$ which would give $\pi_A = 0.0197$. If now CSD A increases p_A until $p_A = \frac{1}{13} + \frac{1}{71}$, then π_A decreases until it is at $\pi_A = 0.0193$, and $b = \frac{1}{2}$ now. If CSD A now further increases p_A, then π_A starts to increase (b remains at $b = \frac{1}{2}$, a decreases). At $p_A = \frac{1}{10}$, we get $\pi_A = 0.02$. Thus, the prices of Proposition 1 do not constitute an equilibrium.

[15] It should be noted that substantially different results would occur if we did not assume $\alpha < 1$ and $c \geq 0$. It is easy to show that we would get a symmetric equilibrium given by

$$\begin{aligned} p_A &= p_B = c_I \\ q_A &= q_B = \frac{\frac{4}{3}v - \frac{4}{3}c_I + \alpha c_I + \frac{1}{3}\alpha c}{\alpha} \end{aligned}$$

if $\alpha c \leq (v - c_I)(3\alpha - 4)$, implying that $q_A = q_B < v$. However, this condition is apparently not compatible with our assumption $\alpha < 1$ and $c \geq 0$.

pay to it unchanged, then all its participants get better off. Accordingly, CSD A has clear incentives to set $q_A = v$ and to choose a relatively low price p_A. Note that the equilibrium prices do not depend on γ as long as $\gamma > 0$. The above effect holds even if γ is very small.

For $\gamma = 0$, there is a range of symmetric equilibria. As this range of equilibria is difficult to describe, we do not give a full description here. But we note that the price combination of proposition 1 is still an equilibrium when $\gamma = 0$. At the same time, it can be shown that

$$\begin{aligned} p_A &= p_B = q_A = q_B = \frac{1}{2}[v + \frac{1}{4}\alpha c + c_I] \\ a &= b = \frac{1}{2t}[v - c_I - \frac{1}{4}\alpha c] \end{aligned}$$

is also an equilibrium. As $\gamma = 0$, the CSDs do not have incentives anymore to choose a very high price for external settlement.[16]

4 Integration of CSDs

We now assume that the two CSDs are merged so that they are operated by the same company. We distinguish two steps in the merger process. In a first step, the two CSDs are brought under the same corporate roof, but are technically operated on different platforms. We refer to this as a (purely) legal merger of the CSDs. In a second step, the two CSDs are also technically merged, i.e. they are operated on the same technical platform. That means that all trades are now settled internally, even trades between a country A bank and a country B bank. In our model, a technical merger of the CSDs implies that $c = 0$ and that $p_A = p_B = q_A = q_B$.

Ultimately, every merger of CSDs will result in a technical merger as the operator of the merged CSDs will aim at minimizing operating costs. Nevertheless, analyzing a legal merger as an intermediate step towards an eventually technical merger is important to fully understand the economics behind our formal results. It allows us to separate a competition effect from a cost effect of the merger. A purely legal merger has a competition effect as it changes the strategic interaction between the CSDs from a competitive to a cooperative interaction. A technical merger that follows the legal merger then has a cost reduction effect. To strengthen the economic intuition, we assume that after a legal merger, the operator of the CSDs has to choose already $p_A = p_B$ and

[16] Indeed, there is for a range of p_B-q_B combination respectively a multiplicity of best responses (p_A, q_A) of CSD A (that all satisfy $a = b$ and that all lead to the same values a and b). For example, $p_A = q_A = \frac{1}{2}[v + \frac{1}{4}\alpha c + c_I]$ is a best response on $p_B = q_B = \frac{1}{2}[v + \frac{1}{4}\alpha c + c_I]$ as well as

$$p_A = \frac{(1-\alpha)v + \frac{1}{4}\alpha c + c_I}{2-\alpha}, \; q_A = v$$

Note that $p_B = q_B = \frac{1}{2}[v + \frac{1}{4}\alpha c + c_I]$ is however not a best response on ($p_A = \frac{(1-\alpha)v+\frac{1}{4}\alpha c+c_I}{2-\alpha}$, $q_A = v$).

$q_A = q_B$. A change from complete separation to a legal merger of the CSDs however does not change the parameter c. We get the following

Proposition 2 *Let $v \geq c_I + \frac{1}{2}\alpha c$. If the two CSDs are legally merged and the operator of the CSDs has to choose $p_A = p_B$ and $q_A = q_B$, then we get in equilibrium*

$$\begin{aligned} \alpha q_A + (2-\alpha) p_A &= v + c_I + \frac{1}{2}\alpha c \\ a &= b = \frac{1}{2t}[v - c_I - \frac{1}{2}\alpha c] \equiv a_{LI} \end{aligned}$$

and $0 \leq p_B = p_A \leq v$, $0 \leq q_B = q_A \leq v$.

Note that a and b under a legal merger are lower than under complete separation of CSDs (provided that $c > 0$). This is very easy to verify. Why is this so? As discussed, the CSDs have under complete separation strong incentives to set prices for external settlement equal to v. For given $q_A = q_B = v$, the two CSDs play a Bertrand game to choose the prices p_A and p_B. If CSD B lowers p_B, than b goes up and the probability for a country A bank to be matched with a country B bank increases, i.e. a decreases. To offset this effect, CSD A would decrease p_A. Or to put it differently, the best response function $p_A^*(p_B)$ of CSD A on a price p_B has a positive slope. Thus, there exist (indirect) competitive pressures that drive down the prices for internal settlement, if the two CSDs are separated. If the two CSDs are merged, these pressures do not exist anymore.

Now we move on to a situation in which the two CSDs are technically merged and get

Corollary 3 *Let $v \geq c_I$. If the two CSDs are technically merged, then we get in equilibrium*

$$\begin{aligned} p_A &= p_B = q_A = q_B = \frac{1}{2}(v + c_I) \\ a &= b = \frac{1}{2t}[v - c_I] \equiv a_{TI} \end{aligned}$$

Note that a and b are now greater than under complete separation. Thus, we find that $a_{TI} > a_{CS} > a_{LI}$. The competition effect of a merger increases prices and lowers demands a and b. The cost reduction effect lowers prices and increases demands. And the cost reduction effect is apparently stronger than the competition effect.

5 Welfare

Overall economic welfare is defined by

$$\begin{aligned} W &= \pi_A + \pi_B + \int_{i=0}^{a} u_{A,i} di + \int_{i=0}^{b} u_{B,i} di \\ &= \pi_A + \pi_B + \frac{1}{2}t(a^2 + b^2) \end{aligned}$$

In a symmetric equilibrium, we apparently get

$$\begin{aligned} W &= 2\pi_A + ta^2 \\ &= 2va - ta^2 - 2a(\frac{1}{2}\alpha c + c_I) \equiv W(a, c) \end{aligned}$$

In the appendix, we prove

Proposition 4 *Let $v \geq c_I + \frac{\alpha(3-2\alpha)}{4-3\alpha}c$. We get $W(a_{TI}, 0) \geq W(a_{CS}, c) \geq W(a_{LI}, c)$.*

Thus, the economic welfare is highest after a full technical merger of the two CSDs, and lowest after a purely legal merger. This of course does not come as a surprise given the results of the previous two sections. As the two CSDs have market power, any measure that results in lower settlement prices and higher demand should increase welfare. And we have seen that a purely legal merger of the CSDs reduces indirect competitive pressure and leads therefore to higher prices. A full technical merger however reduces prices more than the legal merger increased them and increases demand more than the legal merger reduced demand.

6 Extension: banks can influence matching probabilities

We now discuss an extension of our model. Up until now, we have assumed that the banks take the probability of being matched with a bank located in the other country as given. We now assume that every bank can make an effort to install facilities which make it more or less likely to be matched with a bank located in the same country. Let e_A (e_B) be the effort that each country A (B) bank (except bank i) undertakes. The country A bank i's probability of being matched with a country B bank to trade k securities, $k \in \{A, B\}$, is assumed to be

$$\alpha \frac{b}{a+b} - \beta e_i - (1-\beta)e_A - e_B$$

where e_i denotes country A bank i's effort. Its expected benefit from trading k securities is thus given by

$$\begin{aligned} u_A^k &= [\alpha \frac{b}{a+b} - \beta e_i - (1-\beta)e_A - e_B]\frac{1}{2}[v - (2-\gamma)q_{kA} - \gamma q_{kB}] \\ &\quad + [1 - (\alpha \frac{b}{a+b} - \beta e_i - (1-\beta)e_A - e_B)](\frac{1}{2}v - p_{kA}) \\ &= \frac{1}{2}v - p_{kA} + [\alpha \frac{b}{a+b} - \beta e_i - (1-\beta)e_A - e_B][p_{kA} - \frac{1}{2}(2-\gamma)q_{kA} - \frac{1}{2}\gamma q_{kB}] \end{aligned}$$

Bank i's effort costs are $d\cdot(e_i)^2$. Its expected utility from trading both securities, taking into account its effort costs is thus

$$\begin{aligned} u_A &= u_A^A + u_A^B - d\cdot(e_i)^2 \\ &= v - p_A + [\alpha\frac{b}{a+b} - \beta e_i - (1-\beta)e_A - e_B][p_A - \frac{1}{2}(2-\gamma)q_A - \frac{1}{2}\gamma q_B] - d\cdot(e_i)^2 \end{aligned}$$

Maximization with respect to e_i immediately gives

$$e_i = \frac{\beta}{2d}[\frac{1}{2}(2-\gamma)q_A + \frac{1}{2}\gamma q_B - p_A]$$

As this optimal effort level e_i does not depend on those of the other banks (e_a and e_b), we have in equilibrium

$$e_A = \frac{\beta}{2d}[\frac{1}{2}(2-\gamma)q_A + \frac{1}{2}\gamma q_B - p_A]$$

Similarly, we find for country B banks

$$e_B = \frac{\beta}{2d}(\frac{1}{2}(2-\gamma)q_B + \frac{1}{2}\gamma q_A - p_B)$$

We thus get

$$\alpha\frac{b}{a+b} - \frac{\beta}{2d}(q_A + q_B - p_A - p_B)$$

as the probability for a country A bank of being matched with a country B bank to trade security k for $k = A, B$, and

$$\alpha\frac{a}{a+b} - \frac{\beta}{2d}(q_A + q_B - p_A - p_B)$$

as the probability for a country B bank of being matched with a country A bank. Accordingly,

$$u_A = v - p_A + [\alpha\frac{b}{a+b} - \frac{\beta}{2d}(q_A + q_B - p_A - p_B)][p_A - \frac{1}{2}(2-\gamma)q_A - \frac{1}{2}\gamma q_B] - d\cdot(e_A)^2$$

and

$$u_B = v - p_B + [\alpha\frac{a}{a+b} - \frac{\beta}{2d}(q_A + q_B - p_A - p_B)][p_B - \frac{1}{2}(2-\gamma)q_B - \frac{1}{2}\gamma q_A] - d\cdot(e_B)^2$$

Finally, country A bank i's utility if it decides to participate in CSD A is

$$u_{A,i} = u_A - ti$$

while country B bank i would get utility

$$u_{B,i} = u_B - ti$$

if it participates in CSD B. If a bank opts out, it gets a benefit of 0. As before, it follows that

$$a = \frac{1}{t}u_A,\ b = \frac{1}{t}u_B$$

The profits of the two CSDs are given by

$$\begin{aligned}
\pi_A &= [\alpha\frac{ab}{a+b} - \frac{\beta a}{2d}(q_A + q_B - p_A - p_B)](q_{AA} + r_A - 2c_{DE}) \\
&\quad +[a - (\alpha\frac{ba}{a+b} - \frac{\beta a}{2d}(q_A + q_B - p_A - p_B))](p_{AA} - c_{DI}) \\
&\quad +[\alpha\frac{ab}{a+b} - \frac{\beta a}{2d}(q_A + q_B - p_A - p_B)](q_{BA} - r_B - c_{FE}) \\
&\quad +[a - (\alpha\frac{ba}{a+b} - \frac{\beta a}{2d}(q_A + q_B - p_A - p_B))](p_{BA} - c_{FI}) \\
&= [\alpha\frac{ab}{a+b} - \frac{\beta a}{2d}(q_A + q_B - p_A - p_B)](q_A - p_A - c) + a(p_A - c_I)
\end{aligned}$$

and similarly

$$\pi_B = [\alpha\frac{ab}{a+b} - \frac{\beta b}{2d}(q_A + q_B - p_A - p_B)](q_B - p_B - c) + b(p_B - c_I)$$

where we assumed that $r_A = r_B$.

In the appendix, we describe a set of conditions that are necessary for a symmetric equilibrium. We solve these conditions numerically for various parameter constellations. We also calculate for all these cases the respective equilibrium welfare as defined in Section 5. We use a heuristic approach to verify that for the respective parameter constellations, the prices that fulfil our necessary conditions indeed constitute an equilibrium.

Our extended model is unfortunately too complicated to be solved analytically. We therefore apply numerical technics to evaluate our model. Our procedure is described in the Appendix. We now discuss first parameter constellations with $c = 0$ and then turn to those with $c > 0$.

In Figure **??**, we present the equilibrium prices and welfare as a function of β, where we assume $\alpha = \frac{1}{2}$, $c = 0$, $c_I = \frac{1}{4}$, $t = 2$, $\gamma = v = d = 1$. We see that p_A increases with β, while q_A remains first at $q_A = 1$ and then starts to decrease. The reason is simple: As β increases, it is getting cheaper for the banks to avoid settlement through the links. To keep their profits at a high level, the CSDs increase the price for internal settlement. Moreover, they narrow the gap between the prices for internal settlement and for link settlement to reduce the incentives for banks to avoid link settlement. We also observe that less banks participate in the CSDs (a decreases) and that profits go down (π_A decreases) as β increases. This is interesting as it is getting cheaper for the banks to avoid the expensive settlement across the CSDs when β goes up so that one would expect more banks to participate. However, under the given parameters, the impact of the on average higher settlement prices appears to be stronger. Finally, we observe that welfare is decreasing as β increases. This is plausible as we assume

β	pA	qA	a	πA	W
0	0.5	1	0.1875	0.0703	0.2109
0.1	0.5297	1	0.1871	0.0702	0.2105
0.2	0.5539	1	0.1861	0.0699	0.2092
0.3	0.5741	1	0.1849	0.0695	0.2074
0.4	0.5916	1	0.1832	0.0691	0.2052
0.5	0.6068	1	0.1813	0.0685	0.2027
0.55	0.6104	0.9734	0.1807	0.0684	0.2021
0.6	0.612	0.9381	0.1804	0.0685	0.202
0.7	0.615	0.8835	0.1798	0.0686	0.2018
0.8	0.6178	0.8435	0.1792	0.0687	0.2016
0.9	0.6205	0.8132	0.1786	0.0688	0.2015
1	0.6229	0.7896	0.1781	0.0689	0.2013

$c = 0$. Thus, from a welfare perspective, the banks should not make a costly effort to avoid settlement across the CSDs.

The picture looks different for $c > 0$ as we show in Figure 3, where we assume $\alpha = \frac{1}{2}$, $c = \frac{1}{8}$, $c_I = \frac{1}{4}$, $t = 2$, $\gamma = v = d = 1$. Again, p_A increases with β, while q_A remains first at $q_A = 1$ and then starts to decrease. If β increases beyond $\frac{7}{10}$, then we get corner solutions with link settlement probabilities of 0 which we ignore for simplicity. We now see that a is increasing in β for low values of β and then starts to decrease. The profit π_A is increasing in β. Most importantly, welfare W is also increasing in β for low values of β. It is immediate to check that in case of technical integration of the two CSDs, welfare would be at $W = 0.1992$. Thus, we see that for $\beta \geq \frac{1}{10}$, we get higher welfare levels in case of complete separation.

Why can welfare now increase when β increases and $c > 0$? As $c > 0$, banks should make an effort to avoid settlement through the links. And they do so the greater β is. That means that the cost reduction effect of a technical merger, which only refers to the operating costs for the links, is getting less important when β increases as the links are used less and less anyway.

To summarize, we find that in our extended model, the prices for link settlement are still higher than those for internal settlement, although the gap between the prices is smaller than in the basic model. In this respect, the extended model does not provide major new insights. However, in our basic model, a technical merger of the CSD was always welfare improving in comparison to completely separated CSDs. This is not the case in our extended model so that the analysis of the extended model shows that the welfare results obtained from our basic model are not robust.

β	pA	qA	a	πA	W
0	0.5083	1	0.1844	0.0645	0.1971
0.1	0.5327	1	0.1859	0.0655	0.2
0.2	0.5528	1	0.1867	0.0662	0.2021
0.3	0.567	1	0.1869	0.0667	0.2033
0.4	0.5849	1	0.1867	0.0671	0.2038
0.5	0.5981	1	0.1861	0.0673	0.2038
0.6	0.61	1	0.1851	0.0674	0.2033
0.7	0.6158	0.9719	0.1842	0.0674	0.2027

Figure 3: Equilibrium prices and welfare for $\alpha = \frac{1}{2}$, $c = \frac{1}{8}$, $c_I = \frac{1}{4}$, $t = 2$, $\gamma = v = d = 1$. This implies that the welfare in case of a technical integration of the two CSDs is $W = 0.1992$.

7 Conclusions and discussion

We presented a model that explains why fees for settlement through CSD links are much higher than those for settlement within a CSD. Our explanation is very much based on the assumption that securities traders take settlement fees into account when they negotiate with each other on securities prices.

One may argue that although the fees for settlement across CSDs are much higher than those for settlement within a CSD, settlement fees are generally so small compared to values of typical transactions that traders simply ignore them when they negotiate on securities prices. However, in this context two points should be noted: (1) Our result holds even if γ is very small, but positive. Thus, traders need to take settlement fees only to a very small extent into account to get the results of our model. (2) For the traders, not the value of transactions matters, but the (expected) benefit of transactions - and the benefit might be much smaller than the value.

As our model appears to be powerful as an explanation for an important stylized fact of securities settlement, we use it to analyze welfare effects of mergers of CSDs. We find however, that the welfare effects depend on the model specification so that we do not obtain any robust results. Thus, a clear policy recommendation cannot be drawn from our model.

8 Appendix

Proof of Proposition 1:

Differentiation gives

$$\frac{d\pi_A}{dq_A} = \alpha\frac{ab}{a+b} + \frac{\alpha}{(a+b)^2}(b^2\frac{da}{dq_A} + a^2\frac{db}{dq_A})(q_A - p_A - c) + (p_A - c_I)\frac{da}{dq_A} \quad (2)$$

$$\frac{d\pi_A}{dp_A} = a - \alpha\frac{ab}{a+b} + \frac{\alpha}{(a+b)^2}(b^2\frac{da}{dp_A} + a^2\frac{db}{dp_A})(q_A - p_A - c) + (p_A - c_I)\frac{da}{dp_A} \quad (3)$$

The market shares a and b are given by

$$t \cdot a = v - p_A + \alpha\frac{b}{a+b}[p_A - \frac{1}{2}(2-\gamma)q_A - \frac{1}{2}\gamma q_B] \quad (4)$$

$$t \cdot b = v - p_B + \alpha\frac{a}{a+b}[p_B - \frac{1}{2}\gamma q_A - \frac{1}{2}(2-\gamma)q_B] \quad (5)$$

Total differentiation gives

$$\begin{aligned} t \cdot da &= -dp_A - \alpha\frac{b}{(a+b)^2}[p_A - \frac{1}{2}(2-\gamma)q_A - \frac{1}{2}\gamma q_B]da \\ &+\alpha\frac{a}{(a+b)^2}[p_A - \frac{1}{2}(2-\gamma)q_A - \frac{1}{2}\gamma q_B]db \\ &+\alpha\frac{b}{a+b}dp_A - \alpha\frac{b}{a+b}\frac{1}{2}(2-\gamma)dq_A \end{aligned}$$

and

$$\begin{aligned} t \cdot db &= -\alpha\frac{a}{(a+b)^2}[p_B - \frac{1}{2}(2-\gamma)q_B - \frac{1}{2}\gamma q_A]db \\ &+\alpha\frac{b}{(a+b)^2}[p_B - \frac{1}{2}(2-\gamma)q_B - \frac{1}{2}\gamma q_A]da \\ &-\alpha\frac{a}{a+b}\frac{1}{2}\gamma dq_A \end{aligned}$$

Rearranging gives

$$\frac{da}{dq_A} = -\frac{\alpha\frac{b}{a+b}\frac{1}{2}(2-\gamma)y_b + \alpha\frac{a}{a+b}\frac{1}{2}\gamma x_b}{x_a y_b - x_b y_a} \quad (6)$$

$$\frac{db}{dq_A} = -\frac{\alpha\frac{b}{a+b}\frac{1}{2}(2-\gamma)y_a + \alpha\frac{a}{a+b}\frac{1}{2}\gamma x_a}{x_a y_b - x_b y_a} \quad (7)$$

$$\frac{da}{dp_A} = -\frac{(1-\alpha\frac{b}{a+b})y_b}{x_a y_b - x_b y_a} \quad (8)$$

$$\frac{db}{dp_A} = -\frac{(1-\alpha\frac{b}{a+b})y_a}{x_a y_b - x_b y_a} \quad (9)$$

with

$$x_a = t + \alpha\frac{b}{(a+b)^2}[p_A - \frac{1}{2}(2-\gamma)q_A - \frac{1}{2}\gamma q_B] \quad (10)$$

$$x_b = \alpha\frac{a}{(a+b)^2}[p_A - \frac{1}{2}(2-\gamma)q_A - \frac{1}{2}\gamma q_B] \quad (11)$$

$$y_b = t + \alpha \frac{a}{(a+b)^2}[p_B - \frac{1}{2}(2-\gamma)q_B - \frac{1}{2}\gamma q_A] \quad (12)$$

$$y_a = \alpha \frac{b}{(a+b)^2}[p_B - \frac{1}{2}(2-\gamma)q_B - \frac{1}{2}\gamma q_A] \quad (13)$$

For $p_A = p_B$ and $q_A = q_B$, we get

$$a = b = \frac{1}{t}[v - p_A + \frac{1}{2}\alpha(p_A - q_A)]$$

$$x_a = y_b = x_b + t = y_a + t = t + \frac{\alpha}{4a}(p_A - q_A)$$

$$\begin{aligned}
\frac{da}{dp_A} &= -\frac{(1-\frac{1}{2}\alpha)x_a}{2tx_a - t^2} \\
\frac{db}{dp_A} &= -\frac{(1-\frac{1}{2}\alpha)(x_a - t)}{2tx_a - t^2} \\
\frac{da}{dq_A} &= -\frac{\alpha\frac{1}{4}(2-\gamma)x_a + \alpha\frac{1}{4}\gamma(x_a - t)}{2tx_a - t^2} = -\frac{\alpha\frac{1}{2}x_a - \alpha\frac{1}{4}\gamma t}{2tx_a - t^2} \\
\frac{db}{dq_A} &= -\frac{\alpha\frac{1}{4}(2-\gamma)(x_a - t) + \alpha\frac{1}{4}\gamma x_a}{2tx_a - t^2} = -\frac{\alpha\frac{1}{4}\gamma t + \alpha\frac{1}{2}(x_a - t)}{2tx_a - t^2}
\end{aligned}$$

$$\begin{aligned}
\frac{d\pi_A}{dq_A} &= \alpha a\frac{1}{2} + \alpha\frac{1}{4}(q_A - p_A - c)(\frac{da}{dq_A} + \frac{db}{dq_A}) + (p_A - c_I)\frac{da}{dq_A} \\
&= \frac{\alpha}{2t}[v - p_A + \frac{1}{2}\alpha(p_A - q_A) - \frac{1}{4}\alpha(q_A - p_A - c)] \\
&\quad -(p_A - c_I)\frac{\alpha}{4t}\frac{(2-\gamma)(v - p_A) + \frac{1}{2}(3-\gamma)\alpha(p_A - q_A)}{v - p_A + \alpha(p_A - q_A)} \equiv U
\end{aligned}$$

$$\begin{aligned}
\frac{d\pi_A}{dp_A} &= a(1 - \alpha\frac{1}{2}) + \alpha\frac{1}{4}(q_A - p_A - c)(\frac{da}{dp_A} + \frac{db}{dp_A}) + (p_A - c_I)\frac{da}{dp_A} \\
&= (1 - \alpha\frac{1}{2})\frac{1}{t}[v - p_A + \frac{1}{2}\alpha(p_A - q_A) - \frac{1}{4}\alpha(q_A - p_A - c)] \\
&\quad -(p_A - c_I)(1 - \frac{1}{2}\alpha)\frac{1}{4t}\frac{4(v - p_A) + 3\alpha(p_A - q_A)}{v - p_A + \alpha(p_A - q_A)} \equiv V
\end{aligned}$$

Recall that CSD A and CSD B have to ensure that $v-(2-\gamma)q_{kA}-\gamma q_{kB} \geq 0$ and $v - \gamma q_{kA} - (2-\gamma)q_{kB} \geq 0$ so that

$$q_{kA} \leq f(q_{kB}) \equiv \begin{cases} \min\{\frac{v-\gamma q_{kB}}{(2-\gamma)}, \frac{v-(2-\gamma)q_{kB}}{\gamma}\}, & \text{if } \gamma > 0 \\ \frac{1}{2}v, & \text{if } \gamma = 0 \end{cases}$$

Assume that CSD B plays $p_{AB} = p_{BB}$ and $q_{AB} = q_{BB}$. It is easy to see that we now get $f(q_{kB}) = \frac{1}{2}g(q_B)$ for $k = A, B$ with

$$g(q_B) = \begin{cases} \min\{\frac{2v-\gamma q_B}{(2-\gamma)}, \frac{2v-(2-\gamma)q_B}{\gamma}\}, & \text{if } \gamma > 0 \\ v, & \text{if } \gamma = 0 \end{cases}$$

CSD A's best response requires that it maximizes π_A with respect to p_A and q_A subject to $0 \leq p_A \leq v$ and $0 \leq q_A \leq g(q_B)$. Define the Lagrange function

$$L_A = \pi_A + \lambda_p p_A + \lambda_q q_A + \mu_p[v - p_A] + \mu_q[g(q_B) - q_A] \tag{14}$$

The Kuhn-Tucker conditions for L_A are then necessary conditions for (p_A, q_A) being a best response of CSD A on (p_B, q_B) (given that $p_{AB} = p_{BB}$ and $q_{AB} = q_{BB}$). Finally, the Kuhn-Tucker conditions for L_A together with $p_A = p_B$, $q_A = q_B$ form necessary conditions for a symmetric equilibrium. Thus, the necessary conditions for a symmetric equilibrium are

$$\begin{aligned} V + \lambda_p - \mu_p &= 0 \\ U + \lambda_q - \mu_q &= 0 \\ \lambda_p, \lambda_q, \mu_p, \mu_q &\geq 0 \\ 0 &\leq p_A \leq v, 0 \leq q_A \leq g(q_A) \\ \lambda_p \cdot p_A &= \lambda_q \cdot q_A = \mu_p[v - p_A] = \mu_q[g(q_A) - q_A] = 0 \end{aligned}$$

We first look at the constraint $q_A \leq g(q_A)$. Assume that $g(q_A) = \frac{2v-\gamma q_A}{(2-\gamma)}$. We apparently get in this case $q_A \leq g(q_A) \Leftrightarrow q_A \leq v$. Now assume that $g(q_A) = \frac{2v-(2-\gamma)q_B}{\gamma}$. Again we get $q_A \leq g(q_A) \Leftrightarrow q_A \leq v$. Thus we in general have $q_A < g(q_A) \Leftrightarrow q_A < v$ and $q_A = g(q_A) \Leftrightarrow q_A = v$.

We now have to discuss the following nine cases, where we will occasionally make use of the relation

$$U = \frac{\alpha}{2t}[\frac{tV}{(1-\frac{1}{2}\alpha)} + (p_A - c_I)\frac{1}{2}\gamma\frac{v - p_A + \frac{1}{2}\alpha(p_A - q_A)}{v - p_A + \alpha(p_A - q_A)} \tag{15}$$

(A) $\lambda_p = \lambda_q = \mu_p = \mu_q = 0$, i.e. $U = V = 0$. It is easy to see that $U = V = 0$ requires $p_A = c_I$ and thus

$$v - p_A + \frac{1}{2}\alpha(p_A - q_A) - \frac{1}{4}\alpha(q_A - p_A - c) = 0$$

so that we get

$$q_A = \frac{\frac{4}{3}v - \frac{4}{3}c_I + \alpha c_I + \frac{1}{3}\alpha c}{\alpha}$$

To ensure $q_A \leq g(q_A)$, we need

$$\begin{aligned} \frac{\frac{4}{3}v - \frac{4}{3}c_I + \alpha c_I + \frac{1}{3}\alpha c}{\alpha} &\leq v \\ &\Leftrightarrow \\ \alpha c &\leq (v - c_I)(3\alpha - 4) \end{aligned}$$

This condition is not compatible with our assumptions $\alpha \leq 1$, $v \geq c_I$ and $c \geq 0$ so that we get a contradiction.

(B) $\lambda_p = \lambda_q = \mu_p = [g(q_A) - q_A] = 0$, i.e. $V = 0$, $U = \mu_q$ and $q_A = v$. From $V = 0$, we easily get

$$p_A = \frac{1-\alpha}{2-\alpha}v + \frac{\alpha(1-\alpha)}{(2-\alpha)(4-3\alpha)}c + \frac{1}{2-\alpha}c_I$$

With equation 15, $V = 0$, $U = \mu_q$ and $q_A = v$, this gives

$$\mu_q = \frac{\alpha}{2t}(p_A - c_I)\frac{1}{2}\gamma\frac{2-\alpha}{2-2\alpha} = \frac{\alpha\gamma}{8t}[v - c_I + \frac{\alpha}{4-3\alpha}c]$$

As we need to ensure $\mu_q \geq 0$, we find $\alpha c \geq (v - c_I)(3\alpha - 4)$. This condition is always fulfilled as $c_I \leq v$, $\alpha \leq 1$ and $c \geq 0$. Next, we need $p_A \leq v$, i.e. $v - c_I \geq \frac{\alpha(1-\alpha)}{4-3\alpha}c$. As $1 - \alpha < 3 - 2\alpha$, this is fulfilled if the condition given in the proposition is fulfilled. Finally, we need $a \leq \frac{1}{2}$. It is easy to show that this requires $\frac{\alpha(1-\alpha)}{4-3\alpha}c \geq v - c_I - t$. This is always the case as we assume that $t \geq 2v$. Thus we know that

$$\begin{aligned} p_A &= \frac{1-\alpha}{2-\alpha}v + \frac{\alpha(1-\alpha)}{(2-\alpha)(4-3\alpha)}c + \frac{1}{2-\alpha}c_I \\ q_A &= v \end{aligned}$$

fulfils the necessary conditions, if the condition given in the proposition is fulfilled.

(C) $\lambda_p = \lambda_q = v - p_A = \mu_q = 0$, i.e. $U = 0$, $V = \mu_p$ and $p_A = v$. With equation 15, $U = 0$, $V = \mu_p$ and $p_A = v$, we get

$$\mu_p = -\frac{\gamma}{8t}(2-\alpha)(v - c_I) < 0$$

so that we get a contradiction as we need $\mu_p \geq 0$.

(D) $\lambda_p = q_A = \mu_p = \mu_q = 0$, i.e. $V = 0$, $U = -\lambda_q$ and $q_A = 0$. With equation 15, $V = 0$, $U = -\lambda_q$ and $q_A = 0$ we get

$$-\lambda_q = \frac{\alpha\gamma}{4t}(p_A - c_I)\frac{v - p_A + \frac{1}{2}\alpha p_A}{v - p_A + \alpha p_A}$$

To ensure that $\lambda_q \geq 0$, we apparently need $p_A \leq c_I$. However, this would lead to $\pi_A < 0$ as $q_A = 0$. It is clear that this cannot be an equilibrium.

(E) $p_A = \lambda_q = \mu_p = \mu_q = 0$, i.e. $U = 0$, $V = -\lambda_p$ and $p_A = 0$. With equation 15, $U = 0$, $V = -\lambda_p$ and $p_A = 0$ we get

$$\frac{t}{1 - \frac{1}{2}\alpha}\lambda_p = -c_I\frac{1}{2}\gamma\frac{v - \frac{1}{2}\alpha q_A}{v - \alpha q_A}$$

Apparently, we get $\lambda_p < 0$ as $\alpha \leq 1$ and $q_A \leq v$.

(F) $p_A = \lambda_q = \mu_p = v - q_A = 0$, i.e. $V = -\lambda_p$ and $U = \mu_q$. We easily get

$$V = (1 - \frac{1}{2}\alpha)\frac{1}{t}[(1 - \frac{3}{4}\alpha)v + \frac{1}{4}\alpha c + \frac{1}{4}c_I\frac{(4-3\alpha)}{1-\alpha}] > 0$$

So that $\lambda_p < 0$ which is a contradiction.

(G) $p_A = q_A = \mu_p = \mu_q = 0$. This apparently cannot be an equilibrium.

(H) $\lambda_p = \lambda_q = v - p_A = q(q_A) - q_A = 0$, i.e. $q_A = p_A = v$. This apparently cannot be an equilibrium.

(I) $\lambda_p = q_A = v - p_A = \mu_q = 0$, i.e. $q_A = 0$, $p_A = v$, $U = -\ \lambda_q$ and $V = \mu_p$. We get

$$\begin{aligned} U &= \frac{\alpha}{2t}[\frac{3}{4}\alpha v + \frac{1}{4}\alpha c - (v - c_I)\frac{1}{4}(3-\gamma)] \leq 0 \\ V &= (1 - \frac{1}{2}\alpha)\frac{1}{t}[\frac{3}{4}\alpha v + \frac{1}{4}\alpha c - (v - c_I)\frac{3}{4}] \geq 0 \end{aligned}$$

This together is impossible as $(3 - \gamma) < 3$.

Thus, we now know that only the prices given in Proposition 1 fulfil the necessary conditions for a symmetric equilibrium.

■

Numerical analysis to verify that Proposition 1 is indeed an equilibrium:

We now know that only the prices given in Proposition 1 fulfil the necessary conditions for a symmetric equilibrium. However, to show that Proposition 1 indeed describes an equilibrium, we have to show that CSD A's strategy is indeed a best response on CSD B's strategy. Unfortunately, it is extremely cumbersome to provide a general proof. We therefore employ numerical methods and computer evaluations. Any best response on some strategy (p_B, q_B) has to fulfil the Kuhn-Tucker conditions

$$\begin{aligned} \frac{dL_A}{dq_A} &= \frac{d\pi_A}{dq_A} + \lambda_q - \mu_q = 0, \ \frac{dL_A}{dp_A} = \frac{d\pi_A}{dp_A} + \lambda_p - \mu_p = 0 \\ 0 &\leq p_A \leq v, 0 \leq q_A \leq g(q_B),\ \lambda_p, \lambda_q, \mu_p, \mu_q \geq 0 \\ \lambda_p \cdot p_A &= \lambda_q \cdot q_A = \mu_p[v - p_A] = \mu_q[g(q_B) - q_A] = 0 \end{aligned}$$

on the lagrange function 14 as necessary conditions, where the equations 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 and 13 for the variables $\frac{d\pi_A}{dq_A}$, $\frac{d\pi_A}{dp_A}$, a, b, $\frac{da}{dq_A}$, $\frac{db}{dq_A}$, $\frac{da}{dp_A}$, $\frac{db}{dp_A}$, x_a, x_b, y_a and y_b have to hold. We test 100 randomly selected parameter constellations with $\alpha, \gamma, v, t, c, c_I \in \{0, \frac{1}{10}, \frac{2}{10}, ..., \frac{9}{10}, 1\}$ that fulfil our assumptions $\gamma, t, v > 0$, $\alpha < 1$, $v \geq c_I$, $c \geq 0$, $t \geq 2v$ and $v - c_I \geq \frac{\alpha(3-2\alpha)}{4-3\alpha}c$ and respectively assume that p_B and q_B are given as in Proposition 1. We respectively determine all combinations (p_A, q_A) that fulfil the above Kuhn-Tucker conditions. We find that for all of these parameter constellations, the prices p_A and q_A as given in Proposition 1 (and only these prices) constitute a best response of CSD A on p_B and q_B as given in Proposition 1.

■

Proof of Proposition 2:

For $p_A = p_B$ and $q_A = q_B$, we immediately get

$$\pi_A + \pi_B = 2[\alpha \frac{a}{2}(q_A - p_A - c) + a(p_A - c_I)]$$

and

$$\begin{aligned} a &= \frac{1}{t}[v - p_A + \frac{1}{2}\alpha(p_A - q_A)] \\ &= \frac{1}{t}[v - \frac{1}{2}(\alpha q_A + (2-\alpha)p_A)] \end{aligned}$$

so that

$$\begin{aligned} \pi_A + \pi_B &= [\alpha(q_A - p_A - c) + 2p_A - 2c_I]\frac{1}{t}[v - \frac{1}{2}(\alpha q_A + (2-\alpha)p_A)] \\ &= \frac{1}{t}[\alpha q_A + (2-\alpha)p_A - \alpha c - 2c_I][v - \frac{1}{2}(\alpha q_A + (2-\alpha)p_A)] \end{aligned}$$

Maximizing with respect to $\alpha q_A + (2-\alpha)p_A$ immediately gives as maximizer

$$\alpha q_A + (2-\alpha)p_A = v + c_I + \frac{1}{2}\alpha c$$

so that

$$a = \frac{1}{2t}[v - c_I - \frac{1}{2}\alpha c]$$

■

Proof of Proposition 4:

Note that $W(a, c)$ is a concave function in a with a maximum in

$$a = a_{opt} \equiv \frac{1}{2t}[2v - \alpha c - 2c_I]$$

It is easy to see that $a_{opt} > a_{CS}$ (as $v \geq c_I + \frac{\alpha(3-2\alpha)}{4-3\alpha}c$). Since $a_{CS} > a_{LI}$, we can conclude that $W(a_{CS}, c) > W(a_{LI}, c)$.

We now compare $W(a_{CS}, c)$ and $W(a_{TI}, 0)$. We get

$$W(a_{TI}, 0) = \frac{1}{2t}(v - c_I)(\frac{3}{2}v - \frac{3}{2}c_I)$$

and

$$W(a_{CS}, c) = \frac{1}{2t}(v - c_I - \frac{1-\alpha}{4-3\alpha}\alpha c)[\frac{3}{2}v - \frac{3}{2}c_I - (1 - \frac{1}{2}\frac{1-\alpha}{4-3\alpha})\alpha c]$$

As $\frac{1}{2t}(v - c_I - \frac{1-\alpha}{4-3\alpha}\alpha c) = a_{CS} \geq 0$ and $1 - \frac{1}{2}\frac{1-\alpha}{4-3\alpha} > 0$, it is apparent that $W(a_{TI}, 0) > W(a_{CS}, c)$.

■

Extension of the model: necessary conditions for a symmetric equilibrium:

Differentiation of the profit function π_A gives

$$\begin{aligned}\frac{d\pi_A}{dq_A} &= \alpha\frac{ab}{a+b} - \frac{\beta a}{2d}(2q_A + q_B - 2p_A - p_B - c) \\ &+\alpha(q_A - p_A - c)[\frac{b^2}{(a+b)^2}\frac{da}{dq_A} + \frac{a^2}{(a+b)^2}\frac{db}{dq_A}] \\ &+[p_A - c_I - \frac{\beta}{2d}(q_A + q_B - p_A - p_B)(q_A - p_A - c)]\frac{da}{dq_A}\end{aligned} \tag{16}$$

$$\begin{aligned}\frac{d\pi_A}{dp_A} &= a - \alpha\frac{ab}{a+b} + \frac{\beta a}{2d}(2q_A + q_B - 2p_A - p_B - c) \\ &+\alpha(q_A - p_A - c)[\frac{b^2}{(a+b)^2}\frac{da}{dp_A} + \frac{a^2}{(a+b)^2}\frac{db}{dp_A}] \\ &+[p_A - c_I - \frac{\beta}{2d}(q_A + q_B - p_A - p_B)(q_A - p_A - c)]\frac{da}{dp_A}\end{aligned} \tag{17}$$

The market shares a and b are given by

$$\begin{aligned}t \cdot a &= v - p_A + [\alpha\frac{b}{a+b} - \frac{\beta}{2d}(q_A + q_B - p_A - p_B)][p_A \\ &-\frac{1}{2}(2-\gamma)q_A - \frac{1}{2}\gamma q_B] - d \cdot (e_A)^2\end{aligned} \tag{18}$$

$$\begin{aligned}t \cdot b &= v - p_B + [\alpha\frac{a}{a+b} - \frac{\beta}{2d}(q_A + q_B - p_A - p_B)][p_B \\ &-\frac{1}{2}(2-\gamma)q_B - \frac{1}{2}\gamma q_A] - d \cdot (e_B)^2\end{aligned} \tag{19}$$

with

$$e_A = \frac{\beta}{2d}(\frac{1}{2}(2-\gamma)q_A + \frac{1}{2}\gamma q_B - p_A) \tag{20}$$

$$e_B = \frac{\beta}{2d}(\frac{1}{2}(2-\gamma)q_B + \frac{1}{2}\gamma q_A - p_B) \tag{21}$$

Total differentiation gives

$$\begin{aligned}t \cdot da &= -dp_A - \alpha\frac{b}{(a+b)^2}[p_A - \frac{1}{2}(2-\gamma)q_A - \frac{1}{2}\gamma q_B]da \\ &+\alpha\frac{a}{(a+b)^2}[p_A - \frac{1}{2}(2-\gamma)q_A - \frac{1}{2}\gamma q_B]db \\ &+\alpha\frac{b}{a+b}dp_A - \alpha\frac{b}{a+b}\frac{1}{2}(2-\gamma)dq_A \\ &+\frac{\beta}{2d}[p_A - \frac{1}{2}(2-\gamma)q_A - \frac{1}{2}\gamma q_B - q_A - q_B + p_A + p_B]dp_A \\ &-\frac{\beta}{2d}[p_A - (2-\gamma)q_A - q_B + \frac{1}{2}(2-\gamma)p_A + \frac{1}{2}(2-\gamma)p_B]dq_A \\ &+\beta e_A dp_A - \frac{1}{2}(2-\gamma)\beta e_A dq_A\end{aligned}$$

and

$$\begin{aligned}
t \cdot db &= -\alpha \frac{a}{(a+b)^2}[p_B - \frac{1}{2}(2-\gamma)q_B - \frac{1}{2}\gamma q_A]db \\
&+\alpha \frac{b}{(a+b)^2}[p_B - \frac{1}{2}(2-\gamma)q_B - \frac{1}{2}\gamma q_A]da \\
&-\alpha \frac{a}{a+b}\frac{1}{2}\gamma dq_A \\
&+\frac{\beta}{2d}[p_B - \frac{1}{2}(2-\gamma)q_B - \frac{1}{2}\gamma q_A]dp_A \\
&-\frac{\beta}{2d}[p_B - q_B - \gamma q_A + \frac{1}{2}\gamma p_A + \frac{1}{2}\gamma p_B]dq_A \\
&-\frac{1}{2}\gamma \beta e_B dq_A
\end{aligned}$$

Rearranging gives

$$\frac{da}{dq_A} = -\frac{X_q Y_b + X_b Y_q}{X_a Y_b - X_b Y_a} \tag{22}$$

$$\frac{db}{dq_A} = -\frac{X_q Y_a + X_a Y_q}{X_a Y_b - X_b Y_a} \tag{23}$$

$$\frac{da}{dp_A} = \frac{X_b Y_p + X_p Y_b}{X_a Y_b - X_b Y_a} \tag{24}$$

$$\frac{db}{dp_A} = \frac{X_p Y_a + X_a Y_p}{X_a Y_b - X_b Y_a} \tag{25}$$

with

$$X_a = t + \alpha \frac{b}{(a+b)^2}[p_A - \frac{1}{2}(2-\gamma)q_A - \frac{1}{2}\gamma q_B] \tag{26}$$

$$X_b = \alpha \frac{a}{(a+b)^2}[p_A - \frac{1}{2}(2-\gamma)q_A - \frac{1}{2}\gamma q_B] \tag{27}$$

$$\begin{aligned}
X_p &= \alpha \frac{b}{a+b} - 1 + \frac{\beta}{2d}[p_A - \frac{1}{2}(2-\gamma)q_A - \frac{1}{2}\gamma q_B \\
&-q_A - q_B + p_A + p_B] + \beta e_A
\end{aligned} \tag{28}$$

$$\begin{aligned}
X_q &= \alpha \frac{b}{a+b}\frac{1}{2}(2-\gamma) + \frac{\beta}{2d}[p_A - (2-\gamma)q_A - q_B + \frac{1}{2}(2-\gamma)p_A \\
&+\frac{1}{2}(2-\gamma)p_B] + \frac{1}{2}(2-\gamma)\beta e_A
\end{aligned} \tag{29}$$

$$Y_a = \alpha \frac{b}{(a+b)^2}[p_B - \frac{1}{2}(2-\gamma)q_B - \frac{1}{2}\gamma q_A] \tag{30}$$

$$Y_b = t + \alpha \frac{a}{(a+b)^2}[p_B - \frac{1}{2}(2-\gamma)q_B - \frac{1}{2}\gamma q_A] \tag{31}$$

$$Y_p = \frac{\beta}{2d}[p_B - \frac{1}{2}(2-\gamma)q_B - \frac{1}{2}\gamma q_A] \tag{32}$$

$$Y_q = \alpha \frac{a}{a+b}\frac{1}{2}\gamma + \frac{\beta}{2d}[p_B - \gamma q_A - q_B + \frac{1}{2}\gamma p_A + \frac{1}{2}\gamma p_B] + \frac{1}{2}\gamma \beta e_B \tag{33}$$

As before (see proof of Proposition 1), CSD A's best response requires that it maximizes π_A with respect to p_A and q_A subject to $0 \leq p_A \leq v$ and $0 \leq q_A \leq g(q_B)$, where

$$g(q_B) = \min\{\frac{2v - \gamma q_B}{(2-\gamma)}, \frac{2v - (2-\gamma)q_B}{\gamma}\}$$

Define the Lagrange function

$$L_A = \pi_A + \lambda_p p_A + \lambda_q q_A + \mu_p[v - p_A] + \mu_q[g(q_B) - q_A]$$

The Kuhn-Tucker conditions for L_A are then necessary conditions for (p_A, q_A) being a best response of CSD A on (p_B, q_B). Finally, the Kuhn-Tucker conditions for L_A together with

$$p_B = p_A \quad (34)$$

$$q_B = q_A \quad (35)$$

form necessary conditions for a symmetric equilibrium. As before, we find that $q_A \leq g(q_A) \Leftrightarrow q_A \leq v$. Thus, the necessary conditions for a symmetric equilibrium are

$$\begin{aligned} \frac{dL_A}{dq_A} &= \frac{d\pi_A}{dq_A} + \lambda_q - \mu_q = 0, \frac{dL_A}{dp_A} = \frac{d\pi_A}{dp_A} + \lambda_p - \mu_p = 0 \\ 0 &\leq p_A \leq v, 0 \leq q_A \leq v, \lambda_p, \lambda_q, \mu_p, \mu_q \geq 0 \\ \lambda_p \cdot p_A &= \lambda_q \cdot q_A = \mu_p[v - p_A] = \mu_q[v - q_A] = 0 \end{aligned}$$

where the equations 16 to 35 for the variables $\frac{d\pi_A}{dq_A}$, $\frac{d\pi_A}{dp_A}$, a, b, e_A, e_B, $\frac{da}{dq_A}$, $\frac{db}{dq_A}$, $\frac{da}{dp_A}$, $\frac{db}{dp_A}$, X_a, X_b, X_p, X_q, Y_a, Y_b, Y_p, Y_q, p_B and q_B have to hold. We solve these conditions for p_A, q_A, a for a number of parameter constellations $\alpha, \gamma, v, t, c, c_I, \beta, d$ that fulfil our assumptions $\gamma, t, v > 0$, $\alpha < 1$, $v \geq c_I$, $c \geq 0$, $t \geq 2v$ and $v - c_I \geq \frac{\alpha(3-2\alpha)}{4-3\alpha}c$ from the basic model. We also calculate for all these cases the respective equilibrium welfare $W = 2\pi_A + ta^2$ as defined in Section 5.

We use a heuristic approach to verify that for the respective parameter constellations, the prices that fulfil our necessary conditions indeed constitute an equilibrium. We simply test if CSD A could get better off with any prices p_A and q_A such that $p_A, q_A \in \{0, \frac{1}{10}, ..., v\}$. We find that this is not the case, indicating that our necessary conditions constitute an equilibrium.

■

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