Appendix A

Proofs

A.1 Proof of Proposition 52

It is clear that there are no situations where a positive measure ε of independent buyers or sellers have incentive to deviate and to join the cartel on their respective side of the market. Indeed, outsiders obtain a higher payoff than insiders provided that the cartel is active. Hence the only relevant deviations consist in situations in which a positive measure ε of cartel members wish to defect from the cartel.

Consider first market outcomes with symmetric trade. These outcomes can arise for all levels of market frictions provided that the fraction of independent traders are such that $\alpha \geq \underline{\alpha}$ and $\rho \geq \underline{\rho}$. In particular, assume that the fractions of independent buyers and sellers are such that

$$\max\{\beta_1, \sigma_1\} = \sigma_1 \leq \min\{\beta_2, s\} = \min\{\beta_2, \sigma_2, s\}$$

whereby equilibrium strategies are such that $(\beta, \sigma) = (q, q)$, with

$$\sigma_1^{\alpha} = \frac{2\alpha(2-\gamma)}{\gamma(1+\alpha(3-2\gamma))} \leq q \leq \min\{\beta_2, s\}.$$

Suppose further that, at a given market outcome, a strictly positive measure ε of the members of buyers' cartel leave the cartel. When such a defection occurs, the best reply function of buyers' cartel shifts towards the right, due to an increase in the fraction of independent buyers (the latter changes from α to $\alpha+\varepsilon$ as a consequence of the defection). If the equilibrium measure of active traders q is such that

$$\sigma_1^{\alpha+\varepsilon} = \frac{2(\alpha+\varepsilon)(2-\gamma)}{\gamma(1+(\alpha+\varepsilon)(3-2\gamma))} \leq q \leq \min\{\beta_2, s\};$$

then we claim that leaving the cartel is beneficial. Indeed, after the defection, the buyers' cartel continues to set its measure of active traders equal to $\beta^{\alpha+\varepsilon,\rho}(q) = q$, which yields per capita payoffs

$$\pi_B^L(q,q) = \pi_B^S(q,q) = \frac{\gamma(2-\gamma)}{2}$$

to outsiders (and to defecting cartel members). Prior to the defection, the individual payoff to cartel members is

$$\frac{B^{\alpha,\rho}(q,q)}{(1-\alpha)} = \frac{(q-\alpha)\gamma(2-\gamma)}{2(1-\alpha)};$$

and it is immediate to check that $\frac{B^{\alpha,\rho}(q,q)}{(1-\alpha)} < \pi_B^L(q,q)$. However, if q is such that

$$\sigma_1^{\alpha} = \frac{2\alpha(2-\gamma)}{\gamma(1+\alpha(3-2\gamma))} \le q < \frac{2(\alpha+\varepsilon)(2-\gamma)}{\gamma(1+(\alpha+\varepsilon)(3-2\gamma))} = \sigma_1^{\alpha+\varepsilon};$$

then the buyers' cartel breaks down completely as a consequence of the defection, and it plays $\beta^{\alpha+\varepsilon,\rho}(q) = 1$. In this situation, defecting buyers would receive a payoff equal to

$$\pi_B^L(1,q) = \gamma q\frac{(4-3\gamma)-\gamma q(3-2\gamma)}{4(1-\gamma q)}$$

each, and a defection would not be profitable if $\frac{B^{\alpha,\rho}(1,q)}{(1-\alpha)} \ge \pi_B^L(1,q)$, or else if $\sigma_1 \le q < 1$, which is precisely the case at hand. Conversely, it remains profitable for members of sellers' cartel to leave their cartel, and consequently a defection of ε members does not induce sellers' cartel to modify the chosen measure q of active sellers, being $\beta_1 \le \sigma_1$.

In general, when $\alpha \ge \underline{\alpha}$ and $\rho \ge \underline{\rho}$, both cartels are stable if and only if

$$\beta = \beta_1 = \frac{2\rho s(2-\gamma)}{\gamma(1+\rho(3-2\gamma))} = \frac{2\alpha(2-\gamma)}{\gamma(1+\alpha(3-2\gamma))} = \sigma_1 = \sigma;$$

which implies

$$\alpha = \frac{\rho s}{1-\rho(3-2\gamma)(1-\gamma)}:$$

Notice that, in order for both cartels to be active (i.e. in order for $\beta = \sigma < s$ to be true), it must be that $\alpha < \alpha_1$ and $\rho < \rho_1$, where both $0 < \rho_1 < 1$ and $0 < \alpha_1 < 1$ hold. A symmetric stable cartel configuration thus exists when $\underline{\alpha} \le \alpha \le \alpha_1$ and $\underline{\rho} \le \rho \le \rho_1$.

Secondly, consider market outcomes with asymmetric trade. Recall that these outcomes, where at most one cartel is active, are attained only when market frictions are not high.

Suppose that the strategy pair $\left(\widehat{\beta}(s), s\right)$ is played. In this situation, condition (3.7) fails and the necessary and sufficient conditions for $\left(\widehat{\beta}(s), s\right)$ to be an equilibrium is that $\max\{\sigma_2, \sigma_3\} \le s$, whereby $\widehat{\beta}(s) \le s$, and $\widehat{\beta}(s) < \min\{\beta_1, \beta_3\}$. Take s as the quantity offered by the sellers and consider a defection from the buyers' cartel.

Suppose, for the time being, that $\max\{\sigma_2, \sigma_3\} = \sigma_2$. After the deviation, the measure of independent buyers becomes $\alpha + \varepsilon$ and the cartel's best reply function shifts slightly towards the right. Such a defection has three possible consequences, depending on the magnitude of $\alpha + \varepsilon$. (i) The buyers' cartel continues to respond to the total quantity s offered by sellers demanding $\beta(s) = \widehat{\beta}^{\alpha+\varepsilon,\rho}(s)$, where

$$\widehat{\beta}^{\alpha+\varepsilon,\rho}(s) = \frac{s(5-2\gamma)-\sqrt{s(1-\gamma)(5-2\gamma)(s-(\alpha+\varepsilon)\gamma)}}{\gamma(5-2\gamma)};$$

and the equilibrium of the quantity-setting game is $\left(\widehat{\beta}^{\alpha+\varepsilon,\rho}(s), s\right)$. This occurs when $\alpha+\varepsilon<\alpha_2$, or equivalently when $\sigma_2^{\alpha+\varepsilon}<s$, and when $\widehat{\beta}^{\alpha+\varepsilon,\rho}(s)<\min\{\beta_1,\beta_3\}\leq s$. We claim that, when no cartel is active on the supply side, it is profitable for a measure $\varepsilon>0$ of members of the buyers' cartel to defect. Observe that the per capita utility of outsiders after the defection is equal to

$$\pi_B^S\left(\widehat{\beta}^{\alpha+\varepsilon,\rho}(s), s\right)=\gamma\frac{(5-2\gamma)(s-\gamma(\alpha+\varepsilon))-\sqrt{(s(1-\gamma)(5-2\gamma)(s-\gamma(\alpha+\varepsilon)))}}{4(s-\gamma(\alpha+\varepsilon))}, \tag{A.1}$$

whereas the per capita utility that cartel members receive prior to the defection is

$$\frac{B\left(\widehat{\beta}^{\alpha,\rho}(s),s\right)}{1-\alpha}=\frac{((s-\alpha\gamma)(5-2\gamma)+s(1-\gamma))-2\sqrt{s(1-\gamma)(5-2\gamma)(s-\alpha\gamma)}}{4(1-\alpha)}. \tag{A.2}$$

Furthermore note that the inequality $\pi_B^S\left(\widehat{\beta}^{\alpha,\rho}(s), s\right)>\frac{B\left(\widehat{\beta}^{\alpha,\rho}(s),s\right)}{1-\alpha}$ always holds and that the expression for $\pi_B^S\left(\widehat{\beta}^{\alpha+\varepsilon,\rho}(s), s\right)$ is decreasing in ε. Thus, for ε small enough, expression (A.1) is strictly greater than (A.2). (ii) After the defection, the buyers' cartel demands $\widehat{\beta}^{\alpha+\varepsilon,\rho}(s)$ but no equilibrium of the quantity-setting game exists. This is the case when $\min\{\beta_1,\beta_3\}<s$ and $\min\{\beta_1,\beta_3\}\leq\widehat{\beta}^{\alpha+\varepsilon,\rho}(s)<s$. This situation could then be discarded. (iii) The buyers' cartel sets the measure of active traders $\beta(s)=s$ and the equilibrium of the game $G^{\alpha+\varepsilon,\rho}$ is (s,s). Then it must be that $\alpha+\varepsilon\geq\alpha_2$, or equivalently that $\sigma_2^{\alpha+\varepsilon}\geq s$, and that $\min\{\beta_1,\beta_3\}>s$. When this defection occurs, outsiders have individual payoff equal to

$$\pi_B^L(s,s)=\pi_B^S(s,s)=\tfrac{1}{2}\gamma(2-\gamma);$$

cartel members have individual payoff given by (A.2) before the defection, and $\frac{B\left(\widehat{\beta}^{\alpha,\rho}(s),s\right)}{1-a}>\pi_B^L(s,s)$. Therefore, if the measures of independent buyers and sellers are such that $\alpha=\alpha_2-\varepsilon$ and $\rho>\max\{\rho_1,\rho_3\}$ respectively, the profile $\left(\alpha,\rho,\widehat{\beta}(s),s\right)$ is ε-stable.

When instead $\max\{\sigma_2,\sigma_3\}=\sigma_3$ and a defection from buyers' cartel occurs, the following cases have to be considered. (i) The buyers' cartel continues to respond to s setting $\beta(s)=\widehat{\beta}^{\alpha+\varepsilon,\rho}(s)$, and the outcome of the quantity-setting game is still $\left(\widehat{\beta}^{\alpha+\varepsilon,\rho}(s), s\right)$ after the defection. If $\sigma_3^{\alpha+\varepsilon}<s$, which implies $\widehat{\beta}^{\alpha+\varepsilon,\rho}(s)<s$, and $\widehat{\beta}^{\alpha+\varepsilon,\rho}(s)<\min\{\beta_1,\beta_3\}$, then the deviation is profitable. (ii) The buyers' cartel plays $\widehat{\beta}^{\alpha+\varepsilon,\rho}(s)$, but no Nash equilibrium exists for $\widehat{\beta}^{\alpha+\varepsilon,\rho}(s)\geq\min\{\beta_1,\beta_3\}$ or $\widehat{\beta}^{\alpha+\varepsilon,\rho}(s)>s$. (iii) When $\sigma_3^{\alpha+\varepsilon}\geq s$, or equivalently $\alpha+\varepsilon\geq\alpha_3$, the defection from the cartel triggers the response $\bar{\beta}^{\alpha+\varepsilon,\rho}(s)=1$, in which case the equilibrium outcome is $(1,s)$ and the deviating members are not better off. Then the profile $\left(\alpha,\rho,\widehat{\beta}(s),s\right)$ is an ε-stable market outcome for $\alpha=\alpha_3$ and $\rho>\max\{\rho_1,\rho_3\}$.

Finally, consider market outcomes of the form $(\alpha,\rho,1,\widehat{s}(1))$. In order for such profile to be an ε-stable market outcome, it must be the case that the strategy pair $(1,\widehat{s}(1))$ be a Nash equilibrium of the quantity-setting game $G^{\alpha,\rho}$. Recall that $\widehat{s}(1)<s$ if and only if

$$\rho<\frac{s\gamma(5-2\gamma)(2-s\gamma)-(4-\gamma)}{(1-\gamma)s\gamma}=\tilde{\rho}.$$

Therefore, profile $(\alpha;\rho_2-\varepsilon;1;b(1))$; where $\alpha\geq\alpha_1$; is ε-stable only if the additional condition $\rho_2-\varepsilon<\sigma$ is satisfied, which is the case if and only if $s>s_\varepsilon$; where s_ε solves $\rho_2-\varepsilon=\sigma$ and is such that

$$s_\varepsilon\equiv\frac{(4-\gamma)+\gamma^2(5-2\gamma)+\varepsilon\gamma(1-\gamma)-\sqrt{(1-\gamma)\left(\gamma^2(1-\gamma)\varepsilon^2+2\gamma((5-2\gamma)\gamma^2+(4-\gamma))\varepsilon+(1-\gamma)(4+3\gamma-2\gamma^2)^2\right)}}{2(5-2\gamma)\gamma^2};$$

with $s_\varepsilon<1$ being true for all $\varepsilon>0$. Finally, the profile $(\alpha;\rho_3;1;b(1))$ represents an ε-stable market outcome only if $\rho_3<\sigma$ and $\alpha>\max\{\alpha_1;\alpha_3\}$.

A.2 Proof of Theorem 76

Consider first case (i); where $b_L-s_H\geq 0$. Then the Sorting, the One-Sided Pooling and the Pooling QEI might all exist and the middleman's profits corresponding to these three quasi-equilibria must be compared. In particular, the payoff associated to the Sorting QEI is π_M^S in expression (4.41), the benefits that the intermediary obtains at the One-Sided Pooling QEI are either π_M^{OSP} in (4.45) or $\underline{\pi}_M^{OSP}$ in (4.47), and finally the profits corresponding to the Pooling QEI are given by π_M^P in (4.49).

Suppose that $\gamma\leq\gamma_1$; in which case no One-Sided Pooling Equilibrium exists and the only candidates for a SEI reduce to the Sorting or the Pooling QEI. Now, one has that

$$\pi_M^S>\pi_M^P\iff b_L<\frac{s_H(1+\theta)+2\gamma\theta(s_H-s_L)}{(1+\theta)}\equiv b_L^{S\succ P};\tag{A.3}$$

where $s_H<b_L^{S\succ P}<b_H$. Observe that when condition (A.3) is satisfied, then also (4.42) holds. Then it is more profitable for the middleman to serve only high surplus agents rather than serving all potential traders when the bid and ask prices posted in the former case are such that $P_b<s_H$ and $P_a>b_L$. Conversely, if serving only the high surplus agent implies setting too narrow a bid-ask spread, namely $(P_a-P_b)<(b_L-s_L)$; then it is surely more profitable for the middleman to serve the whole market and let low surplus agents be just indifferent between trading or not.

When $\gamma_1<\gamma<\gamma_0$ and $s_H\leq b_L<b_L^{OSP}$; then a OSP quasi-equilibrium also exists. The middleman's payoff in this case is $\underline{\pi}_M^{OSP}$ which is such that

$$\underline{\pi}_M^{OSP}<\pi_M^P\iff b_L>\frac{(1+\theta)(1+\gamma)(s_H-s_L)+(1+(1+\theta)(1-\gamma))s_L}{(1+(1+\theta)(1-\gamma))}\equiv\underline{b}_L^{P\succ OSP}>s_H.$$

Moreover the inequality $\underline{\pi}_M^{OSP}<\pi_M^S$ always holds for $\gamma_1<\gamma\leq\frac{1}{2}$; otherwise for $\frac{1}{2}<\gamma<\gamma_0$ it is satisfied if and only if

$$b_L>\frac{(1-\gamma(1+\theta))s_H+(2\gamma-1)(s_H-s_L)}{(1-\gamma(1+\theta))}\quad\underline{b}_L^{S\succ OSP}>s_H;$$

where $b_L^{OSP}>\max\left\{\underline{b}_L^{P\succ OSP};\underline{b}_L^{S\succ OSP}\right\}$ is true whenever $\gamma_1<\gamma<\gamma_0$. Further observe that $b_L^{OSP}>b_L^{S\succ P}$ if and only if

$$\gamma>\frac{-\left(1+\theta+\theta^2\right)+\sqrt{(7\theta^2+4\theta^3+4\theta+\theta^4+1)}}{2\theta(1+\theta)}\equiv\gamma_2;$$

where $\gamma_1 < \gamma_2 < \frac{1}{2}$ and that the chain of inequalities $b_L^{S\wedge P} > \underline{b}_L^{P\wedge OSP} > \underline{b}_L^{S\wedge OSP}$ holds if and only if

$$\gamma < \frac{-1 + \sqrt{(1+2\theta^3+4\theta^2+2\theta)}}{2\theta(1+\theta)} \equiv \gamma_3 ;$$

where $\frac{1}{2} < \gamma_3 < \gamma_0$. Therefore if $\gamma_1 < \gamma \le \frac{1}{2}$ then the OSP quai-equilibrium is always dominated in terms of the benefits accruing to the middleman, which are maximal at a Sorting QEI if $b_L < b_L^{S\wedge P}$ and otherwise it is maximal at a Pooling QEI.

If instead $\gamma \ge \gamma_0$, then the middleman receives payoff π_M^{OSP} at a OSP quasi-equilibrium, where $\pi_M^{OSP} > \pi_M^S$ always holds and where

$$\pi_M^{OSP} > \pi_M^P \iff s_H < b_L < \frac{(2+\theta)s_H - \gamma(1+\theta)s_L}{((2+\theta) - \gamma(1+\theta))} \equiv b_L^{OSP\wedge P} .$$

Examine now case (ii) in which $b_L < s_H$. In this event the pooling quasi-equilibrium does not exists, and the One-Sided Pooling and the Sorting QEI only hold under certain conditions. OSP quasi-equilibria always exist for $\gamma > \gamma_1$. In particular, $\underline{\underline{\pi}}_M^{OSP}$ as given by (4.48) is the relevant payoff for $\gamma \ge \gamma_0$ or $\gamma < \gamma_0$ and $b_L \le \underline{b}_L^{OSP}$, whereas $\underline{\pi}_M^{OSP}$ is relevant when $b_L > \underline{b}_L^{OSP}$ and $\gamma_1 < \gamma < \gamma_0$. Sorting quasi-equilibria yield payoffs $\underline{\pi}_M^S$, whose expression is (4.43), and exist for any γ and $b_L > b_L^S$.

Note that $b_L^S > \underline{b}_L^{OSP}$ if and only if $\gamma < \frac{1-\theta}{(1+\theta)^2} \equiv \gamma_4$, where $\gamma_4 < \gamma_0$ always holds and where $\gamma_4 > \gamma_1$ if and only if $\theta < \frac{1}{3}$. Suppose that $\gamma \le \min\{\gamma_1, \gamma_4\}$, then for $\underline{b}_L^{OSP} < b_L \le b_L^S$ no equilibrium with intermediation exists. For $b_L \le \underline{b}_L^{OSP}$, the unique SEI is the one corresponding to the OSP quasi-equilibrium yielding benefits $\underline{\pi}_M^{OSP}$, and for $b_L > b_L^S$ the unique SEI corresponds to the Sorting quasi-equilibrium. Conversely, for $\gamma > \min\{\gamma_1, \gamma_4\}$ a equilibrium with intermediation always exists. Note that $\underline{\underline{\pi}}_M^{OSP} > \underline{\pi}_M^S$ always holds and $\underline{\pi}_M^{OSP} > \underline{\pi}_M^S$ is true if and only if

$$\underline{\pi}_M^{OSP} > \underline{\pi}_M^S \iff b_L < 2\gamma(s_H - s_L) + s_L \equiv \underline{b}_L^{OSP\wedge S} ;$$

where $\underline{b}_L^{OSP\wedge S} > \underline{b}_L^{OSP}$ always holds and $\underline{b}_L^{OSP\wedge S} > b_L^S$ is true whenever $\gamma > \min\{\gamma_1, \gamma_4\}$. Hence the One-Sided Pooling quasi-equilibrium is always dominating for $b_L < \underline{b}_L^{OSP\wedge S}$ and the Sorting quasi-equilibrium dominates only if $b_L \ge \underline{b}_L^{OSP\wedge S}$ and $\gamma < \gamma_0$.

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