

Global COE Hi-Stat Discussion Paper Series 062

---

**Research Unit for Statistical  
and Empirical Analysis in Social Sciences (Hi-Stat)**

**The Silk Road:  
Tax Competition among Nation States**

Kaz Miyagiwa

April 2009

**Hi-Stat**

Institute of Economic Research  
Hitotsubashi University  
2-1 Naka, Kunitatchi Tokyo, 186-8601 Japan  
<http://goe.ier.hit-u.ac.jp>

**The Silk Road:**  
**Tax competition among nation states**

Kaz Miyagiwa

Emory University and Osaka University

**Abstract**

All international trade involves the shipment of commodities from one nation to another. Many commodities, before reaching their final destinations, are transshipped through several nations, each having independent authorities to tax commodities in transit. However, we show that such “middle” nations may be unable to exercise monopoly power over commodities in transit and all the rents are captured by the country where the commodities are produced and the country where there are markets.

**JEL Classification Codes:** D4, F1, H2. L13

**Keywords:** international tax competition, international trade, economic geography, repeated game

*Correspondence:* Kaz Miyagiwa, Department of Economics, Emory University, Atlanta, GA 30322, U.S.A.; Telephone: (404) 727-6363, E-mail: [kmiyagi@emory.edu](mailto:kmiyagi@emory.edu)

## **1. Introduction**

The ancient civilizations of China and the Mediterranean were connected by the legendary Silk Road, the nearly 5, 000-mile-long trade route that meandered through many areas of influence, in which the independent nation states exacted tolls from traveling merchants. Analyzing a game-theoretic model of such trade routes, Karni and Chakrabarti (1997) found that the nation states collectively suffer from the double marginalization problem, so unification of them into one empire, such as achieved under the Mongols, leads to more trade and tax revenues. Gardner, Gaston and Masson (2002) reached similar conclusions in their theoretical analysis of cargo shipments down the medieval Rhine when local barons constructed castles along the river to exact tolls for the right of passage.

As these examples vividly illustrate, in market economies trade between producers and consumers of the products involve successive layers of intermediaries. Manufactures and farm produce are sold to wholesalers and then to retailers before reaching final consumers. Oil and natural gas are transported through pipelines across foreign countries, which demand user fees. Other examples include telephone calls involving local and long-distance or international telephone service providers, and vacation trips consisting of hub-to-hub flights by one carrier and local flights by another. In each of these cases, the double marginalization problem can arise when more than one intermediary have monopoly power over the commodities in transit. As is well known, however, the problem can be mitigated if two or more in a chain of monopolies are vertically integrated to coordinate prices. Furthermore, vertical integration is known to be socially desirable as the price is lowered and output increased.

As Feinberg and Kamien (2001) have pointed out, however, the double marginalization problem arises from the implicit assumption that prices and tolls charged by concatenated monopolies are pre-committed to before transactions take place. This indeed was the assumption made in the works of Karni and Chakrabarti (1997) and Gardner et al. (2002). Feinberg and Kamien (2001) have shown that, if trade occurs sequentially, the lack of commitment leads to the disappearance of the double marginalization problem; however, the economy will instead suffer from the holdup problem. To see this, consider a simple example from Feinberg and Kamien (2001). Suppose that a merchant travels the road to deliver his ware to the market. The road goes through two domains. Suppose that the merchant, having crossed the first domain, arrives at the second. Assume that the merchandise loses its value unless delivered to the market located at the end of the road. Then, if the lord of the second domain taxes the entire market value of the merchandise in exchange for the right of passage through its territory, then the merchant, whether he accedes to the demand or discontinues the journey, loses the value of his merchandise, and hence is indifferent between the two options. Therefore, if the tax is slightly lowered, the merchant will pay it and cross the second domain to deliver the merchandise to the market. This way, the lord of the second domain can collect nearly the entire value of the merchandise.

However, a forward-looking merchant may anticipate the taxing strategy of the second domain. Since he loses all his value, once having reached the second country, the merchant will not embark on a journey unless he can cross the first domain tax-free. The conclusion: when trade occurs the second domain captures the entire value of the merchandise (monopoly rent) while the first domain as well as the merchant earn zero

rent. Since only the second domain exercises monopoly power, there is no double marginalization problem. Furthermore, social welfare is greater than when the two domains commit to the taxes before the merchant embarks on a journey.

The above conclusion however hinges on the assumption that there are no trade costs. Should the merchant incur costs hauling his ware to the market, or should the first domain incur administrative costs, they will be unable to cover these costs and hence trade ceases.

In this paper we argue that the hold-up problem intimated in the Feinberg-Kamien analysis is a consequence of the assumption that the game is played only once. Although one can think of real-world examples in which games are played just once, many transactions are repeated. In this paper we analyze a model of infinitely repeated transactions, and find that trade thrives despite the presence of trade costs. Moreover, the equilibrium price is lower than when monopolists contract on prices in a one-period game, but higher than when all the monopolists are integrated into a single monopoly. Interestingly, an integration of subsets of monopolists does not lower the equilibrium price or increase joint profits unless both the first and the last monopolists are members of the integration.

The intuition underlying these results is as follows. In a repeated-game setting, the last monopoly can always act myopically, exacting the value of the commodity when the merchant arrives to his domain in the manner described in the one-period play. However, under the assumed trigger strategy the merchant will never embark on another journey in the future once he suffers financial losses so that the last monopoly's future profit becomes zero. The last monopoly instead can lower the tax enough to guarantee the

return of the merchants in the future periods. If this alternative strategy yields a greater discounted sum of revenues than the one-time monopoly rent, the last monopoly has an incentive to lower taxes, and trade occurs in the future. In this paper we investigate the nature of such an equilibrium outcome.

When there are more than two monopolies in a succession, we show that the entire value of the merchandise is shared between the first and the last monopoly. The reason for the failure of all the “middle” monopolists to capture any rent despite their monopoly positions over commodities in transit is as follows. What makes the last monopoly act myopically or patiently is the sum of taxes the merchants paid before getting there. If this sum is sufficiently high, the last monopoly has to set his tax significantly lower to ensure the return of the merchant, which makes acting myopically more attractive. We show that there is indeed a threshold level of sum of taxes collected by all the monopolies before the last. If the actual sum of taxes the merchant paid exceeds this threshold the last monopoly acts myopically, thereby ending future trade. Since no trade means no future revenues for all the monopolies, it is in the best interest of all the rest of the monopolists to keep this sum below or equal to the threshold to ensure future trade. But then the first monopolist capitalizes on a first-mover advantage, setting his tax equal to the threshold, which leaves no rent to the middle monopolists. Thus, the first and the last monopolists exact the entire value of the merchandise.

The remainder of the paper is organized in four sections. The next section revisits the Feinberg-Kamien model. Section 3 extends the model to cases of repeated interplays. Section 4 extends the model further to a case of multiple road segments. The final section concludes.

## 2. The one-period game

In this section we study the one-period game, which serves as the stage game of the dynamic model to be considered below. Merchants produce and sell their merchandise in the market. To reach the market the merchants must travel across two countries in a given order. Let  $x$  denote the number of merchants, a real number, to simplify the exposition. Choose units so that each merchant delivers one unit of merchandise to the market. Thus,  $x$  also denotes quantity of the product. Market (inverse) demand is given by  $p(x)$ , a differentiable function with respect to  $x > 0$ , with first and second derivatives denoted by  $p'(x) < 0$  and  $p''(x) \leq 0$ .

Consider the following four-stage game.

Stage 1: The first country announces a tax  $t_1 \geq 0$ .

Stage 2: Observing  $t_1$ , all the merchants simultaneously decide whether to cross the first country or not.

Stage 3: After the merchants have crossed the first, the second country posts a tax rate  $t_2 \geq 0$ .

Stage 4: Observing  $t_2$ , the merchants decide whether to cross the second country.

Each country's payoff per period is the net tax revenue it collects from the merchants (the difference between the total taxes collected and the total cost incurred), where country  $i$  incurs costs  $c_i$  ( $i = 1, 2$ ) per merchant crossing its territory ( $c_i \geq 0$ ). A merchant's payoff per period is the difference between the market price of the commodity (zero in case of non-delivery) and the sum of taxes he has paid. All the taxes become sunk after they are paid. We normalize each merchant's default payoff to zero, and adopt the tie-breaking

rule that a merchant sets out on a journey as long as he expects a non-negative payoff. Finally, we assume that  $p(0) > c_1 + c_2$ , so delivery of the commodity to the market is socially desirable.

We solve the game backwards. Let  $x_1$  be the number of merchants who, having crossed the first territory, arrive at the second. Then, observing  $t_2$ , each merchant reasons as follows. If he crosses the second country and expects  $x_2$  ( $\leq x_1$ ) other merchants to do the same, his payoff will be  $p(x_2) - t_2 - t_1$ . On the other hand, if he does not, his payoff will be  $-t_1$ , the first tax payment that is sunk. Therefore, a merchant goes forward if and only if

$$p(x_2) - t_2 - t_1 \geq -t_1$$

or

$$(1) \quad p(x_2) - t_2 \geq 0.$$

In the third stage of the game, country 2 chooses  $t_2$  to maximize the net tax revenue  $(t_2 - c_2)x_2$  subject to the constraint (1) and  $x_2 \leq x_1$ . Ignoring the second inequality for the moment, maximization of the Lagrangian

$$(t_2 - c_2)x_2 + \lambda[p(x_2) - t_2]$$

yields the optimality conditions

$$t_2 - c_2 + \lambda p'(x_2) = 0; \text{ and } x_2 - \lambda = 0,$$

where  $\lambda$  is the Lagrangian multiplier. The two equations above combine to yield

$$(2) \quad p(x_2) - c_2 + p'(x_2)x_2 = 0,$$



which is the standard first-order condition for a monopolist facing demand  $p(x)$  and constant marginal cost  $c_2$ . Given the assumption on  $p(x)$ , (2) has a unique solution, denoted by  $x_2^m$ . The (maximum) monopoly rent to country 2 equals

$$\pi_2^m \equiv [p(x_2^m) - c_2]x_2^m.$$

Substituting into the constraint equation from (1), we obtain country 2's optimal tax rate:

$$t_2^m = p(x_2^m).$$

Now return to the constraint  $x_2 \leq x_1$  that we have ignored. Suppose that  $x_2^m < x_1$ . Then, if all  $x_1$  merchants paid the tax  $t_2^m = p(x_2^m)$  and crossed the second country, the payoff to each merchant will be  $p(x_1) - p(x_2^m) - t_1$  which is less than  $-t_1$ . Therefore, not all merchants will cross the second country to reach the market. In equilibrium, the merchants have rational expectations so that exactly  $x_2^m$  merchants cross the second country while  $x_1 - x_2^m$  do not. However, each merchant, regardless of his or her choice, has the same payoff of  $-t_1$ .

Suppose alternatively that  $x_1 \leq x_2^m$ . Then, the left-hand side of (2) is strictly positive at  $x_1 < x_2^m$ . Therefore, the optimal tax is  $t_2 = p(x_1)$ , implying all the merchants  $x_1$  cross the second country, but again they all earn or suffer exactly the same loss,  $-t_1$ . To sum, country 2's optimal strategy is  $t_2 = p(x_1)$  if  $x_1 \leq x_2^m$  and  $t_2 = p(x_2^m)$  if  $x_1 > x_2^m$ .

Given country 2's optimal strategy, once they have crossed the first territory, the merchants earn the negative rent,  $-t_1$ , regardless of whether they cross the second or not.

Therefore, the merchants will embark on the journeys only if  $t_1 = 0$ . But country 1 is willing to charge  $t_1 = 0$  only if  $c_1 = 0$ . Thus:

**Proposition 1:** In a one-period game trade takes place only if  $c_1 = 0$ , in which case country 2 captures the monopoly rent while country 1 captures no rent through taxation.

### 3. Repeated interactions

Suppose that the players play the above game repeatedly an infinite number of periods. Each merchant makes one delivery per period. While no trade is still a possible equilibrium outcome under the conditions considered in the previous section, there is an alternative equilibrium outcome in which trade occurs. In this section we examine the properties of such an equilibrium outcome.

Assume that each merchant adopts the following strategy. In the first period he decides to embark on a journey. In any subsequent period, he sets out on a new journey if and only if he has never suffered losses on any of his previous journeys.

We next specify the equilibrium strategies of two countries that result in trade. We look for a stationary subgame-perfect equilibrium outcome with the following characteristics. In each period the constant number  $x^*$  of merchants embark on journeys, and the countries demand the taxes  $t_1^*$  and  $t_2^*$ . We assume that  $x^* \leq x_2^m$ , and justify this assumption shortly.

We first show that the second country's optimal tax is  $t_2 = p(x^*) - t_1$ . For, if  $t_2 < p(x^*) - t_1$ , the merchants would earn positive profits, which the second country can exact

by raising the tax to  $p(x^*) - t_1$ . If  $p(x^*) > t_2 > p(x^*) - t_1$  all the  $x^*$  merchants will cross the second territory but suffer losses,  $p(x^*) - t_1 - t_2 < 0$ , and hence they will never travel in the future. Finally, if  $t_2 > p(x^*)$ , a fraction, say,  $x_2$ , of the  $x^*$  merchants will cross the second country and deliver the merchandise, where  $x_2$  is given by  $t_2 = p(x)$  while the remainder, i.e.,  $x^* - x_2$ , of the merchants will choose not to complete their journeys. In this case, however, all  $x^*$  merchants will receive the negative profit  $-t_1$  and will never come back. Thus,  $t_2 = p(x^*) - t_1$  is the only tax consistent with the equilibrium outcome in which there is trade in every period.

Therefore, the equilibrium net revenue per period to the second country is  $[p(x^*) - t_1 - c_2]x^*$ . Adding up over periods leads to the discounted sum of profits:

$$v_2 = [p(x^*) - t_1 - c_2]x^*/(1 - \delta)$$

where  $\delta \in (0, 1)$  is the (common) discount factor. For  $t_2 = p(x^*) - t_1$  to hold in equilibrium, the second country must not have the temptation to act myopically, that is, set the tax at  $p(x^*)$  to exact the entire value of the merchandise. Since this myopic behavior yields the one-time profit of  $[p(x^*) - c_2]x^*$  and no future profits, the no-myopic behavior condition is met if:

$$v_2 = [p(x^*) - t_1 - c_2]x^*/(1 - \delta) \geq [p(x^*) - c_2]x^*,$$

which simplifies to:

$$t_1 \leq \delta[p(x^*) - c_2].$$

The above condition then yields country 2's best responses to  $t_1$  as follows:

$$(3) \quad \begin{aligned} t_2 &= p(x^*) - t_1 && \text{if } t_1 \leq \delta[p(x^*) - c_2] \\ t_2 &= p(x^*) && \text{if } t_1 > \delta[p(x^*) - c_2] \end{aligned}$$

Turning to the behavior of the merchants, suppose that  $t_1 < \delta[p(x^*) - c_2]$ . Then the merchants expect the tax  $t_2 = p(x^*) - t_1$ , once they cross the first country. If a small group of additional merchants (of size  $\varepsilon > 0$ ) decide also to cross the first country, country 2 will adjust the tax to  $t_2 = p(x^* + \varepsilon) - t_1$  as long as  $t_1 \leq \delta[p(x^* + \varepsilon) - c_2]$ . Then, all  $x^* + \varepsilon$  merchants journey to the market, thereby disturbing the candidacy of  $x^*$  as the equilibrium number of merchants who travel. On the other hand, if  $t_1 > \delta[p(x^*) - c_2]$ , country 2 will act myopically. Thus, in the equilibrium, we must have:

$$(4) \quad t_1 = \delta[p(x^*) - c_2].$$

This equation defines a mapping from  $t_1$  to  $x^*$ .

Now, consider country 1, which sets  $t_1$  to maximize the net tax revenue per period,  $(t_1 - c_1)x^*$ , where  $x^*$  is determined by  $t_1$  via (4). It is more convenient to substitute from (4) and restate its problem as:

$$\text{Max}_{x^*} \{ \delta[p(x^*) - c_2] - c_1 \} x^*.$$

The first-order condition is

$$(5) \quad \delta[p(x^*) - c_2] - c_1 + \delta x^* p'(x^*) = 0,$$

which implicitly determines the equilibrium number of merchants  $x^*$  who choose to travel. Evaluated at  $x_2^m$ , the left-hand side of (5) is negative, implying  $x^* < x_2^m$ . This justifies our focus on  $x^* \leq x_2^m$ .

The optimal tax rate for country 1 is

$$(6) \quad t_1^* = \delta[p(x^*) - c_2].$$

By (5) and (6)

$$t_1^* - c_1 = \delta[p(x^*) - c_2] - c_1 = -\delta x^* p'(x^*) > 0,$$

guaranteeing a strictly positive profit for country 1. The optimal tax for country 2,  $t_2^*$ , obtains from substituting for  $t_1^*$  from (6) into (3), and is reported in the next proposition.

**Proposition 2:** In the stationary equilibrium with two nation states

(A) the number  $x^*$  of merchants who journey solves (5), and  $x^* < x_2^m$ ;

(B) the optimal tax for two countries are

$$t_1^* = \delta[p(x^*) - c_2],$$

$$t_2^* = (1 - \delta)p(x^*) + \delta c_2, \text{ and}$$

(C) both countries earn positive net tax revenues.

The intuition for Result 2.C has been given in the introduction but it will be useful to explain it in terms of the model we have just seen. If the tax the merchants paid to country 1 is not too high, country 2 can collect sufficiently large tax revenues. If the sum of such revenues over the long haul exceeds the payoff from the myopic action, country 2 will prefer that trade continues; otherwise it will act myopically. Then, country 1 can raise its tax high enough to make country 2 indifferent between the two options, thereby collecting positive net tax revenues.

In sum, in contrast to the one-period game of Section 2, repeated interplays give rise to trade despite the presence of trade cost, leading to the strictly positive payoffs for both countries. What if there are fewer than  $x^*$  merchants who are willing to travel? Suppose that there are only  $x_0$  potential merchants (where  $x_0 < x^*$ ). In this case, the proposition still holds, as can easily be confirmed, with  $x_0$  replacing  $x^*$  in Results 2.A and 2.B.

#### 4. Many nations states

This section extends the above analysis to the case in which the trade route goes through more than two countries. A case of three countries is sufficient to capture the essential features of such extensions. Look again for stationary equilibrium strategies that induce the same number of merchants to embark on journeys every period.

Assume that country 3 controls the third and final segment of the trade route, with unit cost  $c_3$ , while country 2 is now the middle monopoly. Let

$$x_3^m \equiv \operatorname{argmax} [p(x) - c_3]x, \text{ and}$$

$$\pi_3^m \equiv [p(x_3^m) - c_3]x_3^m$$

denote, respectively, the optimal output and the maximum profit from acting myopically.

Then, a procedure similar to the one employed in the previous section establishes the following best responses for country 3:

$$(7) \quad \begin{aligned} t_3 &= p(x^*) - t_1 - t_2 && \text{if } t_1 + t_2 \leq \delta[p(x^*) - c_3] \\ t_3 &= p(x^*) && \text{if } t_1 + t_2 > \delta[p(x^*) - c_3], \end{aligned}$$

where  $x^*$  again denotes the (yet undetermined) number of merchants who travel the entire trade route in the equilibrium. The conditions in (7) indicate that the sum of the first two taxes holds the key to whether country 3 acts myopically or not.

Turning to country 2, which now controls the middle segment of the trade route, suppose that, observing  $x^*$  merchants crossing the first country, country 2 posts  $t_2 > \delta[p(x^*) - c_3] - t_1$ . Then, the merchants infer from (7) that, once having traversed the second country, country 3 will act myopically. The merchant's net income then would be  $-(t_1 + t_2)$ , whereas he can earn the income  $-t_1$  by abandoning the journey without crossing the second country. Thus, no merchants would cross the second country, yielding zero revenue to country 2. On the other hand, if  $t_2 < \delta[p(x^*) - c_3] - t_1$  country 2 can raise the tax up to  $\delta[p(x^*) - c_3] - t_1$  without triggering myopic behavior from country 3. Thus, the equilibrium tax for country 2 is

$$(8) \quad t_2^* = \delta[p(x^*) - c_3] - t_1.$$

Finally, to be optimal,  $t_2^*$  must give country 2 a non-negative payoff; i.e.,

$$(9) \quad \delta[p(x^*) - c_3] - t_1 \geq c_2.$$

Now, turning to country 1, we show that, if all the  $x^*$  merchants pay  $t_1$  and embark on journeys,  $x^*$  must satisfy (9) with strict equality: i.e.,

$$(10) \quad t_1 = \delta[p(x^*) - c_3] - c_2.$$

If  $t_1$  is strictly less than the right-hand side of (10), more merchants are willing to travel, disturbing the equilibrium in which  $x^*$  merchants travel repeatedly. Eq. (10) then defines a mapping from  $t_1$  to  $x^*$ .

Country 1's problem is now stated: choose  $t_1$  to maximize the net income  $(t_1 - c_1)x^*$  subject to (10). Using (10), the first-order condition is written:

$$(11) \quad \delta[p(x^*) + x^*p'(x^*) - c_3] - c_2 - c_1 = 0,$$

which defines  $x^*$ . The left-hand side of (11) is negative at  $x_3^m$ , implying  $x^* < x_3^m$ . By (10) the optimal tax is

$$(12) \quad t_1^* = \delta[p(x^*) - c_3] - c_2.$$

(11) and (12) imply

$$t_1^* - c_1 = \delta[p(x^*) - c_3] - c_2 - c_1 = -\delta x^* p'(x^*) > 0$$

yielding a strictly positive net revenue for country 1. Substituting from (12) into (8) shows, however, that  $t_2^* = c_2$ . Thus, net tax revenue is zero for country 2. Further substitution shows a positive payoff for country 3.

**Proposition 3:** The model with three countries has a stationary equilibrium, in which

(A)  $x^*$  merchants set out on journeys every period, where  $x^*$  is determined by (11),

(B) the optimal tax rates for country  $i = 1, 2, 3$  are

$$t_1^* = \delta[p(x^*) - c_3] - c_2,$$

$$t_2^* = c_2$$

$$t_3^* = (1 - \delta)p(x^*) + \delta c_3, \text{ so that}$$

(C) only countries 1 and 3 earn strictly positive rents per period.



What is perhaps most striking about this proposition is the fact that country 2 breaks even despite the monopoly position over the middle segment of the trade route through which all the merchants must travel. This result has the follow explanation. State 3 chooses the myopic action over the equilibrium long-term action unless the sum of two taxes the merchants paid are sufficiently low. Then, country 1 can take advantage of his first-mover position to set his tax just high enough to make country 3 indifferent between the myopic and the long-term equilibrium strategy. But that leaves no margin for exploitation of the merchants by country 2. If state 2 sets the tax higher than its cost, no merchants will travel over its territory.

The next proposition generalizes Proposition 3 (the proof is similar and omitted).

**Proposition 4:** The model of  $N$  ( $> 2$ ) segmented roads has a stationary equilibrium, in which the optimal tax rates are

$$t_1^* = \delta[p(x^*) - c_N] - \sum_{k=2}^{N-1} c_k,$$

$$t_k^* = c_k; \quad k = 2, \dots, N-1,$$

$$t_N^* = (1 - \delta)p(x^*) + \delta c_N,$$

where  $x^*$ , the equilibrium number of merchants, is the solution to

$$\delta[p(x) + xp'(x) - c_N] - \sum_{k=1}^{N-1} c_k = 0.$$

## 5. Concluding remarks

All international trade involves the shipment of commodities from one nation to another. Many commodities, before reaching their final destinations, are transshipped

through several nations, each with independent tax authorities. We find that, if trade continues over time, only the nation states occupying the first and the last segment of the trade route can extract the monopoly rent through taxation, while those in the middle cannot, unless they develop sufficient demand for the commodities for themselves.

Our analysis leads to the following speculation. The Silk Road benefited only the Chinese and the Roman Empire as they controlled the beginning and the end of the trade route, while the other nation states failed to capture any profit from traveling merchants. Similar fates may haunt the present-day nations in like positions. For example, Egypt and Panama, despite their unique positions to control the bulk of world trade, seem unable to exploit their monopoly power. Similarly, countries, though which the pipelines carry oil and natural gas to the final destinations, seem unable to capture much of the monopoly rent.

## Appendix

We show that the model of Section 3 has no stationary equilibrium in which the number of merchants who travel is greater than  $x_2^m$ . Suppose that such an equilibrium exists so that  $x^* \geq x_2^m$ . Then, the optimal tax for country 2 is  $t_2 = p(x^*) - t_1$ . If it behaves myopically, country 2 would set the tax equal to  $p(x_2^m)$  instead of  $p(x^*)$  to earn the monopoly rent  $\pi_2^m$  defined in Section 2. Country 2 has no incentive to behave myopically if

$$[p(x^*) - t_1 - c_2]x^*/(1 - \delta) \geq \pi_2^m.$$

This condition simplifies to

$$t_1 \leq p(x^*) - c_2 - (1 - \delta)\pi_2^m/x^*$$

In the equilibrium we have

$$t_1 = p(x^*) - c_2 - (1 - \delta)\pi_2^m/x^*.$$

This equation maps from  $t_1$  to the equilibrium  $x^*$ . Country 1 chooses  $t_1$  to maximize the net tax collection. Equivalently, it chooses  $x^*$  to maximize

$$(t_1 - c_1)x^* = [p(x^*) - c_2 - c_1]x^* - (1 - \delta)\pi_2^m$$

The  $x^*$  therefore fulfils the first-order condition:

$$p(x^*) - c_2 - c_1 + x^*p'(x^*) = 0.$$

Evaluated at  $x_2^m$ , the left-hand side of the above equation is negative, implying  $x^* < x_2^m$ .

This contradicts our initial assumption.  $\square$

**References**

- Feinberg, Y., and Kamien, M. I., 2001, Highway robbery: complementary monopoly and the hold-up problem, *International Journal of Industrial Organization* 19, 1603-1621.
- Gardner, R., Gaston, N., and Masson, R. T., 2002. Tolling the Rhine in 1254: complementary monopoly revisited, unpublished paper
- Karni, E., and Chakrabarti, S. K., 1997, Political structure, taxes, and trade, *Journal of Public Economics* 64, 241-258.