Outsourcing versus technology transfer: Hotelling meets Stackelberg

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Abstract

We consider a Hotelling duopoly with two firms A and B in the final good market. Both can produce the required intermediate good, firm B having a lower cost due to a superior technology. We compare two contracts: outsourcing (A orders the intermediate good from B) and technology transfer (B transfers its technology to A). An outsourcing order acts as a credible commitment on part of A to maintain a specific market share, resulting in an indirect Stackelberg leadership effect that is absent in a technology transfer contract. We show that compared to the situation of no contracts, there are always Pareto improving outsourcing contracts making both firms and all consumers better off, but no Pareto improving technology transfer contracts. It is also shown that if firm B has a relatively large bargaining power in its negotiations with A, then both firms prefer technology transfer while all consumers prefer outsourcing.

Keywords: Outsourcing, Technology transfer, Hotelling duopoly, Stackelberg effect, Pareto improving contracts

JEL Classification: D43, L11, L13

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1 Introduction

In this era of globalization, it has become increasingly common for firms to outsource their required inputs rather than produce them in-house. While many factors[1] influence a firm's decision to outsource, it can be argued that outsourcing is primarily driven by cost considerations. A firm will choose to outsource if the input supplier can offer a price that is lower than the firm's in-house cost. This will be the case if the supplier has a cost advantage in one or more factors of production. Such advantages can be interpreted broadly as the supplier having a superior production technology. For example, the supplier may be able to hire skilled labour at a relatively low wage or it may possess advanced machineries. It is therefore plausible that transfer of technology across firms could be a viable alternative to outsourcing. In fact, like outsourcing, technology transfers have also grown substantially in recent years.[2] As outsourcing and technology transfer broadly serve the same purpose of enabling one firm to use the cost-efficient production process of another firm, a natural question is, what would make firms choose one of these contracts over another? A closely related question is, what are the relative effects of these contracts on the consumers? This paper seeks to address these questions in the context of imperfectly competitive markets.

There could be different possible reasons for firms to prefer outsourcing over technology transfer. For instance, the superior technology may be labour intensive and difficult to transfer due to imperfect mobility of labour. Additionally, transfer of technology may involve other barriers such as intellectual property rights laws, or large initial investments that firms may want to avoid. On the other hand, under technology transfer, a firm can produce its inputs in-house using the superior technology which gives it complete control over its production. Therefore a firm will prefer technology transfer over outsourcing if it wants to maintain a higher quality standard or if it wants to avoid the risk of relying on another firm for its inputs.

Apart from these reasons, strategic considerations play an important role in determining the nature of input production decisions of a firm. The strategic motive will be particularly dominant when the input-seeking firm competes with the supplier in the final good market. This paper aims to shed light on these strategic aspects in a model of price competition. Specifically, we consider a Hotelling duopoly with two firms A and B who are located at the end points of the unit interval in the final good market φ. Consumers are uniformly distributed in this interval and have to incur transportation costs for traveling to the end points. Any consumer buys at most one unit of φ from either A or B. We consider a production process where an intermediate good η is required to manufacture φ. Each firm can convert one unit of good η into one unit of good φ at zero cost. Both A and B can produce η, but firm B has a lower cost due to a superior technology. Outsourcing (firm A orders η from firm B) and technology transfer (firm B transfers its technology to firm A) are two contracts that naturally arise in this situation. We study these contracts by considering unit-based pricing policies for both cases, where the unit price is determined through negotiations between firms A and B. Under an outsourcing contract, firm A can place any order with firm B at the agreed upon price. Under a technology transfer contract,

[1]See, e.g., Jarillo (1993), Vidal and Goetschalckx (1997) and Domberger (1998) for a discussion of the various diverse factors that drive outsourcing.

[2]For some recent empirical evidence on the growth of technology transfer across firms, see, e.g., Mendi (2005), Nagaoka (2005) and Branstetter et al. (2006).

firm A uses the superior technology of firm B by paying a price for each unit of production, i.e., the technology transfer contract is based on a unit royalty.[3] We denote ω to be the *effective* unit cost of firm A in any contract and compare these contracts by fixing ω. We show that these two contracts generate different strategic interaction between firms and has important implications on prices.

Specifically we show that compared to the case of no contracts, prices never rise under outsourcing while this is not necessarily the case under technology transfer. There are always weakly Pareto improving outsourcing contracts that make both firms better off and no consumers worse off. Moreover if the cost difference of firms is relatively large (i.e., firm B's technology is sufficiently superior), there are strictly Pareto improving outsourcing contracts that make both firms as well as all consumers better off. On the other hand, there are no Pareto improving technology transfer contracts: whenever both firms prefer technology transfer over no contracts, there are always some consumers who are worse off. Finally we show that due to the difference in strategic interaction between these two contracts, the incentives of firms and the interest of consumers move in the opposite direction. For any ω, whenever both firms prefer one of these two contracts, all consumers prefer the other one. It is also shown that if the supplier firm B has a relatively large bargaining power in negotiating, then both firms prefer technology transfer while all consumers prefer outsourcing.

When firm A outsources η to firm B, *Hotelling meets Stackelberg*. The volume of the outsourcing order plays an interesting role of information transmission because it credibly informs B that A is committed to maintain a specific market share in the market φ. This market share can be viewed as the Stackelberg leader market share.[4] When the unit price ω is small, the Stackelberg market share is larger than A's market share under no contracts. This large share is sustained in equilibrium by a lower price of firm A. Given that A's commitment of Stackelberg market share is credible, B's equilibrium price is also set lower and prices of both firms fall. This results in lower profit in the market φ for firm B compared to the case of no contracts. So B would accept such an outsourcing contract only if it can obtain a large supplier profit from η to compensate for its losses in the market φ. This is the case when firm B is sufficiently more efficient compared to firm A. The upshot is that when the cost difference of two firms is sufficiently large, there are strictly Pareto improving outsourcing contracts, i.e., both firms prefer outsourcing over no contracts and both set a lower price for φ that makes all consumers better off.

Under technology transfer, firm A acquires B's superior technology and produces η itself using this technology. As a result, firm B knows the quantity of η produced by A only when it receives its payments for technology transfer. As these payments are received *after* profits are realized in the final good market, the informational aspect in outsourcing is completely absent under technology transfer. Moreover since firm B's payments from the transfer depends on the demand of A, it has an incentive to ensure that A's demand is not too small. This creates a distortion that raises the effective cost of B which in turn adversely

[3] We consider unit pricing policies for outsourcing and unit royalty policies for technology transfer because they are most frequently observed in practice. See Robinson and Kalakota (2004) and Vagadia (2007) for evidence on outsourcing and Mendi (2005) and Nagaoka (2005) for technology transfer.

[4] When firms A and B compete in quantities as Cournot duopolists, A's outsourcing order corresponds to the Stackelberg leader output (see Baake et al., 1995; Chen et al., forthcoming). The leadership effect is indirect under price competition: following the outsourcing order by A, equilibrium prices are formed in a way so that A's market share exactly equals the quantity of η it has ordered from B.

affects prices in the market φ. Due to this distortion, technology transfer contracts that are preferred by both firms necessarily make some consumers worse off. Consequently, unlike the case of outsourcing, there are no Pareto improving technology transfer contracts in relation to the situation of no contracts. The difference between outsourcing and technology transfer is driven by two factors: first, the information transmission and the subsequent Stackelberg leadership effect that leads to lower prices under outsourcing is absent under technology transfer, and second, outsourcing orders are obtained upfront before firms set their prices, so outsourcing has no distortive effect.

The existing literature has studied horizontal outsourcing (i.e., a firm outsources to its rival) under different models of price competition such as a Hotelling duopoly (Shy and Stenbacka, 2003),[5] a duopoly with differentiated products (Chen et al., 2004) and a Bertrand duopoly (Arya et al., 2007). It is concluded in these papers that horizontal outsourcing is inefficient and leads to higher prices in the final good market. To a certain extent, we obtain similar implications under technology transfer where we show that there are no Pareto improving contracts. In contrast, we show that under outsourcing, prices never rise and there are always Pareto improving contracts. Thus our result on outsourcing sharply differs with the conclusion of the existing literature.

This difference arises because the existing literature generally treats outsourcing and technology transfer equivalently. Specifically, it overlooks the informational aspect of outsourcing which is the main focus of this paper. The information transmission in outsourcing is driven by our presumed sequence of events. In our model, firm A places its outsourcing order of η first and then prices are set in the market φ. The papers mentioned before implicitly assume an alternative sequence where the input-seeking firm places its outsourcing order with its rival after firms set their prices in the final good market. Under this sequence, outsourcing does not transmit any information to the supplier firm prior to price competition. Since outsourcing order is not received upfront, to obtain higher profit from outsourcing the supplier has to ensure that the input-seeking firm's demand is not too small. As a result, the distortive effect of technology transfer is present in outsourcing which explains why outsourcing contracts are inefficient under the sequence assumed in the existing literature.

It can be argued that our presumed sequence is more realistic. An outsourcing order takes time to process for logistics reasons. Additionally, compared to in-house production, an outsourcing order may have to pass through more stages of inspection. These factors will be particularly dominant if the supplier is a foreign firm, which has been a frequently observed occurrence in recent years. Therefore, if a firm places its outsourcing order after receiving its demand, it may not be able to meet its demand on time. For this reason it is natural to assume that firms negotiate and sign an outsourcing contract well in advance before the final goods market meets. Our approach is also consistent with the literature of outsourcing under quantity competition. In these models, the input-seeking firm chooses its outsourcing order first and then firms choose quantities in the final good market. The Stackelberg leadership effect is direct under quantity competition: by placing an outsourcing order with a rival firm in a Cournot duopoly, the input-seeking firm can establish itself as the Stackelberg leader (see Baake et al., 1995; Chen et al., forthcoming). The leadership effect is indirect in our model where firms compete in prices in the final goods market. Following

[5]The primary focus of Shy and Stenbacka (2003) is vertical outsourcing (i.e. firms outsource to an outside supplier), although they consider horizontal outsourcing as well.

the outsourcing order by firm A, equilibrium prices are formed in a way so that A's market share exactly equals the quantity of intermediate good it has ordered from B. By showing the presence of the leadership effect under price competition, this paper bridges the gap in the existing literature between the outsourcing models of quantity and price competitions.

This paper is also related to the literature of capacity commitments in duopolies. When firm A places an outsourcing order with firm B, the volume of the order can be viewed as a capacity that A builds prior to price competition. If the demand of A in the market φ does not exceed its capacity, it can meet its demand at zero marginal cost. However, if the demand exceeds the capacity, A meets the additional demand by producing η in-house that raises its marginal cost. We show that in equilibrium, firm A's demand exactly equals its capacity. This implies that A does not produce η in-house and there is no unutilized capacity. Thus, an outsourcing contract in our paper is a natural quantity precommitment in the spirit of Kreps and Scheinkman (1983). They have shown that if firms in a Bertrand duopoly can make such commitments by building prior capacities, then prices rise to the Cournot level. This paper presents an interesting contrast by showing that when the precommitment is made by an input-seeking firm through an outsourcing order, prices either fall or stay the same.

The paper is organized as follows. We present the model in Section 2. Three contractual settings—no contracts, outsourcing and technology transfer, are studied in Section 3. Comparison of outsourcing and technology transfer contracts is carried out in Section 4. We conclude in Section 5. Most proofs are relegated to the Appendix.

2 The model

The final good market: The market for the final good φ is a linear city Hotelling duopoly with two firms A and B. Firm A is located at point 0 and firm B at point 1 of the unit interval $[0, 1]$. Firms compete in prices.

Consumers are uniformly distributed in $[0, 1]$. Any consumer buys either one unit of good φ, or buys nothing. Consumers receive utility $V > 0$ from good φ and utility 0 from not buying.

The unit cost of transportation is $\tau > 0$. For a consumer at location $x \in [0, 1]$, the transportation cost to travel to firm A is τx, while the cost to travel to firm B is $\tau(1 - x)$. A consumer who buys one unit of good φ from either A or B gets utility V, pays the price and incurs the cost of transportation.

Let $p_A, p_B \geq 0$ be the prices set by firms A, B and denote $p \equiv (p_A, p_B)$. Given any p, let $u_x^p(i)$ be the net utility of the consumer at location $x \in [0, 1]$ from purchasing good φ from firm i, so that

$$u_x^p(i) = \begin{cases} V - p_A - \tau x & \text{if } i = A \\ V - p_B - \tau(1 - x) & \text{if } i = B \end{cases} \tag{1}$$

We assume that V is a sufficiently large positive number, i.e., consumers receive a large utility from purchasing good φ, so that not buying the good is never an optimal choice. Under this assumption, any consumer buys the good from either firm A or firm B and consequently the market φ is *covered*. A consumer at location x determines her optimal purchasing choice by comparing $u_x^p(A)$ and $u_x^p(B)$ from (1).

Demand of firms: Let $D_A(p)$ and $D_B(p)$ be the demand received by firms A, B when they set prices p_A, p_B. It follows from (1) that $u_x^p(A) \gtreqless u_x^p(B) \Leftrightarrow x \lesseqgtr \widetilde{x}(p)$ where

$$\widetilde{x}(p) = (p_B - p_A + \tau)/2\tau \tag{2}$$

So a consumer at location $x \in [0,1]$ buys from A if $x \leq \widetilde{x}(p)$ and from B if $x > \widetilde{x}(p)$. Observe that if $p_A \geq p_B + \tau$, then $\widetilde{x}(p) \leq 0$ and all consumers buy from B. On the other hand, if $p_B \geq p_A + \tau$, then $\widetilde{x}(p) \geq 1$ and all consumers buy from A. If $p_A < p_B + \tau$ and $p_B < p_A + \tau$, then $0 < \widetilde{x}(p) < 1$. In that case, consumers at location $x \in [0, \widetilde{x}(p)]$ buy from A and $x \in (\widetilde{x}(p), 1]$ from B. Hence we conclude that

$$(D_A(p), D_B(p)) = \begin{cases} (0,1) & \text{if } p_A \geq p_B + \tau \\ (1,0) & \text{if } p_B \geq p_A + \tau \\ (\widetilde{x}(p), 1 - \widetilde{x}(p)) & \text{if } p_A < p_B + \tau \text{ and } p_B < p_A + \tau \end{cases} \tag{3}$$

The intermediate good: An intermediate good η is required to produce φ. Both firms can convert one unit of good η into one unit of good φ at the same constant marginal cost, which we normalize to zero.

The constant marginal cost of production of good η is $\overline{c} > 0$ for A and $\underline{c} > 0$ for B. Firm B has a superior technology for producing η, so its cost is lower, i.e., $\underline{c} < \overline{c}$. We also assume that the costs are sufficiently small. Specifically, it is assumed that

$$0 < \underline{c} < \overline{c} < \tau \tag{4}$$

The *effective* unit cost of η for a firm will depend on the nature of contracts that A and B have in the intermediate good market. We consider the following possibilities:

(i) No contract between A and B;

(ii) Outsourcing contract between A and B: A orders η from B;

(iii) Technology transfer from B to A: firm B transfers its superior technology of producing η to firm A.

Before formally describing the three contractual situations above, it will be useful for our analysis to introduce the Hotelling duopoly game $\mathbb{H}(c_A, c_B)$.

The Hotelling duopoly game $\mathbb{H}(c_A, c_B)$: This is the standard Hotelling duopoly game played between firms A and B in the final good market φ, where the constant unit cost of producing the intermediate good η is $c_A \geq 0$ for firm A and $c_B \geq 0$ for firm B and each firm can transform one unit of η to one unit of φ at zero cost. This game has the following stages.

Stage 1: Firms A and B simultaneously set prices $p_A, p_B \geq 0$. For any $p \equiv (p_A, p_B)$, firm i receives the demand $D_i(p)$, which is given by (3).

Stage 2: Observing $D_i(p)$, firms A and B simultaneously choose $q_A, q_B \geq 0$ where

$$q_i = \text{ the quantity of } \eta \text{ that firm } i \text{ produces in order to fulfill its demand of } \varphi.$$

The *demand fulfilling* constraints are $q_A \geq D_A(p)$ and $q_B \geq D_B(p)$. If the cost of producing η is positive for firm i, optimality requires that it produces $q_i = D_i(p)$ units of η and transforms these $D_i(p)$ units to good φ to fulfill its demand. If the cost is zero, it is optimal for i to produce any $q_i \geq D_i(p)$ units of η and transform $D_i(p)$ units to good φ to fulfill its demand. In either case, the payoff (profit) functions of A and B in $\mathbb{H}(c_A, c_B)$ are $\Phi_A(p) = (p_A - c_A)D_A(p)$ and $\Phi_B(p) = (p_B - c_B)D_B(p)$.

Lemma 1 characterizes Subgame Perfect Nash Equilibrium (SPNE) of $\mathbb{H}(c_A, c_B)$.

Lemma 1 *Let $c_A, c_B < \tau$. The game $\mathbb{H}(c_A, c_B)$ has a unique SPNE. For $i \in \{A, B\}$, let $p_i(c_A, c_B)$, $D_i(c_A, c_B)$ and $\Phi_i(c_A, c_B)$ be the SPNE price, market share and profit of firm i:*

(i) $p_A = \tau + (2c_A + c_B)/3$, $p_B = \tau + (c_A + 2c_B)/3$.

(ii) $D_A = 1/2 - (c_A - c_B)/6\tau$, $D_B = 1 - D_A = 1/2 + (c_A - c_B)/6\tau$.

(iii) $\Phi_A = (3\tau - c_A + c_B)^2/18\tau$, $\Phi_B = (3\tau + c_A - c_B)^2/18\tau$.

Proof See the Appendix. ■

3 Three contractual settings

3.1 No contracts between A and B

When there are no contracts between firms A and B in the intermediate good market η, the unit cost of producing η is $\overline{c}$ for firm A and $\underline{c}$ for firm B. Accordingly, the Hotelling duopoly game $\mathbb{H}(\overline{c}, \underline{c})$ is played between A and B in the market φ. Denote

$$\underline{\theta} \equiv (2\underline{c} + \overline{c})/3 \text{ and } \overline{\theta} \equiv (\underline{c} + 2\overline{c})/3$$

Proposition 1 *When there are no contracts between firms A and B, the Hotelling duopoly game $\mathbb{H}(\overline{c}, \underline{c})$ is played. This game has a unique SPNE. For $i \in \{A, B\}$, let p_i^0, D_i^0 and Φ_i^0 be the SPNE price, demand and profit of firm i. Then*

(i) $p_A^0 = \tau + \overline{\theta}$, $p_B^0 = \tau + \underline{\theta}$.

(ii) $D_A^0 = 1/2 - (\overline{c} - \underline{c})/6\tau$, $D_B^0 = 1 - D_A^0 = 1/2 + (\overline{c} - \underline{c})/6\tau$;

(iii) $\Phi_A^0 = (3\tau - \overline{c} + \underline{c})^2/18\tau$, $\Phi_B^0 = (3\tau + \underline{c} - \overline{c})^2/18\tau$.

Proof Follows from Lemma 1 by taking $c_A = \overline{c}$ and $c_B = \underline{c}$. ■

3.2 Outsourcing contract between A and B

When there is an outsourcing contract between A and B, firm A has two options of acquiring the intermediate good η: (i) it can order η from firm B or (ii) it can produce it in-house at unit cost $\overline{c}$. We do not impose any exclusivity restriction on outsourcing contracts. That is, firm A can order η from firm B *as well as* produce it in-house. Firm B produces its required η entirely by itself at unit cost $\underline{c}$.

We consider linear unit pricing contracts: firm B charges a constant price for each unit of η that it supplies to firm A. The unit price is determined through negotiations between firms A and B. Under outsourcing contracts, the strategic interaction between A and B is described as follows.

Negotiation stage: In the beginning, firms A and B negotiate[6] on the unit price ω at which B can supply η to A. As firm A can produce η itself at unit cost $\overline{c}$, an outsourcing contract can lower its cost of production only if $\omega < \overline{c}$. Since firm B's unit cost of η is $\overline{c}$, it obtains a positive profit as a supplier only if $\omega > \overline{c}$. For this reason, we restrict $\omega \in (\underline{c}, \overline{c})$.

If firms do not agree on a price, firm A produces the required η entirely by itself at cost $\overline{c}$ and the game $\mathbb{H}(\overline{c}, \underline{c})$ is played in the final good market. If firms agree on a price $\omega \in (\underline{c}, \overline{c})$, the game $\Gamma^S(\omega)$ is played between A and B.

The game $\Gamma^S(\omega)$: It is an extensive form game that has the following stages.

Stage I: Firm A chooses the amount $K \in [0, 1]$ of η to order[7] from firm B. Firm A receives K units of η by paying ωK to firm B and B obtains the supplier profit $(\omega - \underline{c})K$.

Stage II: Firms A, B play the Hotelling duopoly game $\mathbb{H}^K(\overline{c}, \underline{c})$ that has the following stages.

Stage 1: Firms A, B simultaneously announce prices p_A, p_B for the final good market φ. For any $p \equiv (p_A, p_B)$, the demand received by firm $i \in \{A, B\}$ is $D_i(p)$, given by (3).

Stage 2: Observing $D_i(p)$, firms A, B simultaneously choose $q_A, q_B \geq 0$ where

$$q_i = \text{ the quantity of } \eta \text{ that firm } i \text{ produces in order to fulfill its demand of } \varphi$$

As A already has K units of η from stage 1, its demand fulfilling constraint is

$$K + q_A \geq D_A(p) \tag{5}$$

As firm B produces η entirely by itself, the corresponding constraint for B is

$$q_B \geq D_B(p) \tag{6}$$

Each firm fulfills its demand, profits are realized and the game terminates.

Since the unit cost of producing η is positive for each firm, by (6), optimality requires that firm B produces $q_B = D_B(p)$ units of η and transforms $D_B(p)$ units to good φ to fulfill its demand.

By (5), if $D_A(p) \leq K$ (firm A's demand does not exceed the amount of η it has ordered from B), then it is optimal for A to choose $q_A = 0$, (i.e., it does not produce η in-house) and

[6] Instead of explicitly modeling the bargaining process through which A and B determine ω, we completely characterize the outcomes for all possible values of ω. The solution of a particular bargaining process with specific bargaining powers of A and B can be immediately obtained from our conclusions. See Section 4.2.

[7] Since the maximum demand that a firm can have is 1, there is no loss of generality in restricting $K \leq 1$. In our model firms A and B negotiate on the price ω and then A chooses the outsourcing order K. Alternatively, one can allow A and B to negotiate on both ω and K. Our qualitative conclusions remain unaltered under this alternative.

transform $D_A(p)$ units of η to φ. If $D_A(p) > K$, it is optimal to choose $q_A = D_A(p) - K$ (i.e., firm A produces exactly the additional amount of η that it needs to meet its demand) and transform $D_A(p)$ units of η to φ. Therefore, $q_A = \max\{0, D_A(p) - K\}$.

Payoffs of firms in $\Gamma^S(\omega)$: We can write the payoffs of firms by using the optimal values of q_A, q_B. Firm B's payoff has three components: (i) revenue from market φ, (ii) cost of producing q_B units of η to fulfill its demand and (iii) profit from supplying K units of η to A at price ω. Since firm B's unit cost of η is $\underline{c}$ and $q_B = D_B(p)$, its payoff is

$$\Pi_B^\omega(K, p) = p_B D_B(p) - \underline{c} q_B + (\omega - \underline{c})K = (p_B - \underline{c})D_B(p) + (\omega - \underline{c})K \tag{7}$$

Firm A's payoff also has three components: (i) revenue from market φ, (ii) cost of producing q_A units of η in-house to fulfill its demand and (iii) its payment to firm B for acquiring K units of η at price ω. Since firm A's unit cost of η is $\bar{c}$ and $q_A = \max\{0, D_A(p) - K\}$, its payoff is

$$\Pi_A^\omega(K, p) = p_A D_A(p) - \bar{c} q_A - \omega K = \begin{cases} p_A D_A(p) - \omega K \text{ if } D_A(p) \leq K \\ p_A D_A(p) - \bar{c}(D_A(p) - K) - \omega K \text{ if } D_A(p) > K \end{cases} \tag{8}$$

We determine SPNE of $\Gamma^S(\omega)$ by backward induction. So we begin from stage II.

3.2.1 Stage II of $\Gamma^S(\omega)$: The Hotelling duopoly game $\mathbb{H}^K(\bar{c}, \underline{c})$

The game $\mathbb{H}^K(\bar{c}, \underline{c})$ can be viewed as a Hotelling duopoly game in which firm A has built a "capacity" of K prior to the game.[8] Specifically, in this game:

(i) Firm B has constant unit cost $\underline{c}$.

(ii) Firm A has capacity K which is commonly known between A and B. If the demand received by A does not exceed K, it can fulfill the demand at zero unit cost. However, if its demand exceeds K, A has to incur the cost $\bar{c}$ for every additional unit.

Observe from (8) that for firm A, ωK is the cost of capacity K that it pays upfront to firm B before stage II, so ωK plays no role from stage II onwards. From (8), firm A's profit in $\mathbb{H}^K(\bar{c}, \underline{c})$ is

$$\Phi_A^K(p) = \begin{cases} p_A D_A(p) \text{ if } D_A(p) \leq K \\ p_A D_A(p) - \bar{c}(D_A(p) - K) = (p_A - \bar{c})D_A(p) + \bar{c}K \text{ if } D_A(p) > K \end{cases} \tag{9}$$

Therefore, firm A has unit cost zero if $D_A(p) \leq K$, while its effective unit cost is $\bar{c} > 0$ if $D_A(p) > K$. It follows from (7) that $(\omega - \underline{c})K$ is the profit that firm B obtains upfront before stage II and it plays no role thereafter. Ignoring these terms, from (7), firm B's profit in $\mathbb{H}^K(\bar{c}, \underline{c})$ is

$$\Phi_B^K(p) = (p_B - \underline{c})D_B(p) \tag{10}$$

Lemma 2 characterizes SPNE of the Hotelling duopoly game $\mathbb{H}^K(\bar{c}, \underline{c})$. Recall that for $i \in \{A, B\}$, $p_i(c_A, c_B)$, $D_i(c_A, c_B)$ and $\Phi_i(c_A, c_B)$ denote the SPNE price, market share and profit of firm i in the standard Hotelling game $\mathbb{H}(c_A, c_B)$.

Lemma 2 $\mathbb{H}^K(\bar{c}, \underline{c})$ *has a unique SPNE that has the following properties.*

[8] When $K = 0$, $\mathbb{H}^K(\bar{c}, \underline{c})$ becomes the standard Hotelling duopoly game $\mathbb{H}(\bar{c}, \underline{c})$.

(i) *If $K < D_A(\overline{c}, \underline{c})$, the prices and market shares of firms are the same as in the SPNE of $\mathbb{H}(\overline{c}, \underline{c})$. The profits are $\Phi_A^K = \Phi_A(\overline{c}, \underline{c}) + \overline{c}K$ and $\Phi_B^K = \Phi_B(\overline{c}, \underline{c})$. Firm A fully utilizes its capacity K and in addition produces $D_A(\overline{c}, \underline{c}) - K$ units of η in-house to fulfill its demand.*

(ii) *If $K > D_A(0, \underline{c})$, the prices, market shares and profits of firms are the same as in the SPNE of $\mathbb{H}(0, \underline{c})$. Firm A does not utilize $K - D_A(0, \underline{c})$ units of its capacity and does not produce η in-house.*

(iii) *If $K \in [D_A(\overline{c}, \underline{c}), D_A(0, \underline{c})]$, the prices of firms A, B are*

$$p_A^K = 3\tau + \underline{c} - 4\tau K \text{ and } p_B^K = 2\tau + \underline{c} - 2\tau K \tag{11}$$

The market share of firm A is K and that of firm B is $1 - K$. Firm A fully utilizes its capacity K and does not produce η in-house. The profits are $\Phi_A^K = p_A^K K$ and $\Phi_B^K = \left(p_B^K - \underline{c}\right)(1 - K)$.

Proof See the Appendix. ■

Observe that in the game $\mathbb{H}^K(\overline{c}, \underline{c})$, firm B's unit cost is always $\overline{c}$. For firm A, the minimum possible unit cost is 0 while the maximum possible unit cost is $\overline{c}$. Therefore, in an SPNE of $\mathbb{H}^K(\overline{c}, \underline{c})$ the maximum market share that firm A can have is $D_A(0, \underline{c})$ (its SPNE market share in the standard Hotelling game $\mathbb{H}(0, \underline{c})$), while the minimum market share that it can have is $D_A(\overline{c}, \underline{c})$ (the corresponding market share in $\mathbb{H}(\overline{c}, \underline{c})$).

Lemma 2 shows that if the capacity of firm A is too small [$K < D_A(\overline{c}, \underline{c})$], building such a capacity gives A no strategic advantage in $\mathbb{H}^K(\overline{c}, \underline{c})$ and the game yields the same SPNE outcome as $\mathbb{H}(\overline{c}, \underline{c})$. On the other hand, if the capacity is too large [$K > D_A(0, \underline{c})$], the game results in the same SPNE outcome as $\mathbb{H}(0, \underline{c})$ where part of the capacity remains unutilized (given positive cost of capacity, it is clear that building such large capacity cannot be optimal for firm A). Intermediate capacities [$D_A(\overline{c}, \underline{c}) \leq K \leq D_A(0, \underline{c})$] have a commitment value in that for these values of K, the SPNE prices are such that the market share of A in $\mathbb{H}^K(\overline{c}, \underline{c})$ exactly equals K. As a result, the capacity is fully utilized and A does not produce η in-house. Such intermediate capacities have the effect of establishing firm A as the Stackelberg leader in the final good market.

Figure 1 illustrates this Stackelberg effect. It identifies the SPNE (p_A^K, p_B^K) of $\mathbb{H}^K(\overline{c}, \underline{c})$ for different values of K. Since firm B's unit cost is always $\underline{c}$, its best response is the same as in a standard Hotelling game, given by the line B_1B_2. Firm A's unit cost depends on its demand and its best response is a piecewise linear function that has three segments. If B's price p_B is relatively small, A's best response is the same as in the standard Hotelling game $\mathbb{H}(0, \underline{c})$, given by A_1A_2. On the other hand, if p_B is relatively large, A's best response is the same as in $\mathbb{H}(\overline{c}, \underline{c})$, given by A_3A_4. For intermediate values of p_B, its best response A_2A_3 is such that the demand it receives is exactly equal to its capacity K.

Figure 1(a) corresponds to the case $K < D_A(\overline{c}, \underline{c})$. For this case, B_1B_2 intersects the best response of A at the segment A_3A_4. The SPNE is the same as in $\mathbb{H}(\overline{c}, \underline{c})$. Figure 1(b) corresponds to the case $K > D_A(0, \overline{c})$ where B_1B_2 intersects the best response of A at the segment A_1A_2 and the SPNE is the same as in $\mathbb{H}(0, \underline{c})$. Figure 1(c) corresponds to $K \in [D_A(\underline{c}, \overline{c}), D_A(0, \overline{c})]$. For this case B_1B_2 intersects the best response of A at the intermediate segment A_2A_3. The SPNE (p_A^K, p_B^K) is such that firm A's market share exactly equals its

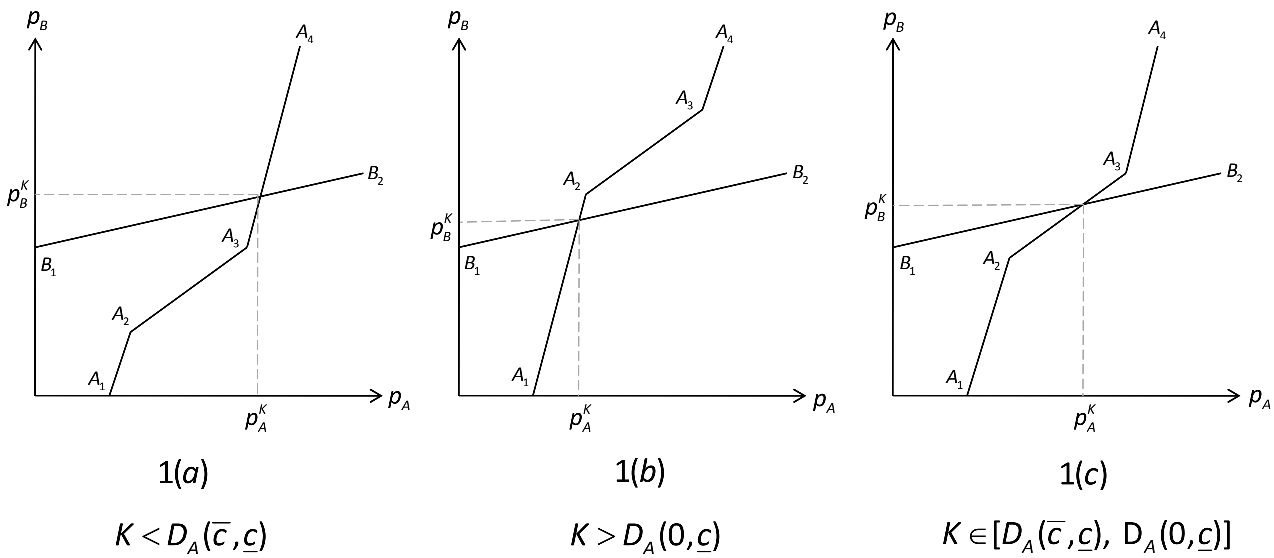

Figure 1: Hotelling Meets Stackelberg

capacity K, effectively establishing firm A as the Stackelberg leader in the Hotelling duopoly. This is where *Hotelling meets Stackelberg*.

3.2.2 Stage I of $\Gamma^S(\omega)$

Now we move back to stage I of $\Gamma^S(\omega)$ where firm A chooses its outsourcing order $K \in [0,1]$ of η. For any such K, the game $\mathbb{H}^K(\overline{c}, \underline{c})$ is played in stage II whose unique SPNE is given in Lemma 2. Let Φ_A^K be the SPNE profit of firm A in $\mathbb{H}^K(\overline{c}, \underline{c})$. In any SPNE play of $\Gamma^S(\omega)$, when firm A orders K units of η from firm B in stage I, its payoff is $\Phi_A^K - \omega K$ (its SPNE profit in $\mathbb{H}^K(\overline{c}, \underline{c})$ net of its payment ωK that it makes to firm B). By Lemma 2, the payoff of A is

$$\Pi_A^\omega(K) = \begin{cases} \Phi_A(\overline{c}, \underline{c}) + \overline{c}K - \omega K & \text{if } K < D_A(\overline{c}, \underline{c}) \\ p_A^K K - \omega K & \text{if } K \in [D_A(\overline{c}, \underline{c}), D_A(0, \underline{c})] \\ \Phi_A(0, \underline{c}) - \omega K & \text{if } K > D_A(0, \underline{c}) \end{cases} \tag{12}$$

The payoff of firm B is its SPNE profit in $\mathbb{H}^K(\overline{c}, \underline{c})$ plus its input supplier profit $(\omega - \underline{c})\,K$. By Lemma 2, this payoff is

$$\Pi_B^\omega(K) = \begin{cases} \Phi_B(\overline{c}, \underline{c}) + (\omega - \underline{c})K & \text{if } K < D_A(\overline{c}) \\ \left(p_B^K - \underline{c}\right)(1 - K) + (\omega - \underline{c})K & \text{if } K \in [D_A(\overline{c}), D_A(0)] \\ \Phi_B(0, \underline{c}) + (\omega - \underline{c})K & \text{if } K > D_A(0) \end{cases} \tag{13}$$

To determine SPNE of $\Gamma^S(\omega)$, in stage I, we solve the single-person decision problem of firm A which is to choose $K \in [0,1]$ to maximize $\Pi_A^\omega(K)$ given by (12). Proposition 2 characterizes SPNE of any outsourcing game $\Gamma^S(\omega)$.

Proposition 2 *For any $\omega \in (\underline{c}, \overline{c})$, $\Gamma^S(\omega)$ has a unique SPNE. Let $K(\omega)$ be the amount of η that firm A orders from firm B and for $i \in \{A, B\}$, let $p_i^S(\omega)$, $D_i^S(\omega)$ and $\Pi_i^S(\omega)$ be the price, market share and payoff of firm i in the SPNE. The SPNE has the following general properties.*

(i) $D_A^S = K(\omega)$, *i.e., the demand that firm A receives in the market φ exactly equals the quantity of η that it orders from firm B. Consequently firm A fully utilizes the amount of η that it orders from B and does not produce η in-house.*

(ii) $\Pi_A^S(\omega)$ *is decreasing and* $\Pi_B^S(\omega)$ *is increasing in ω. Moreover $\Pi_A^S(\omega) > \Phi_A^0$, i.e., compared to no contracts, firm A is better off.*

(iii) *Compared to no contracts, no consumer is worse off.*

The SPNE has the following specific properties.

(I) *Let $\overline{c} - \underline{c} > (3/4)\tau$. There is $\widehat{c} \in (\underline{c}, \overline{c})$ such that*

(a) *If $\omega \in (\underline{c}, \widehat{c})$, then $K(\omega) = 3/8 - (\omega - \underline{c})/8\tau \in (D_A(\overline{c}, \underline{c}), D_A(0, \underline{c}))$. The market share of firm A is $K(\omega)$ and that of firm B is $1 - K(\omega)$. The prices are*

$$p_A^S(\omega) = (3\tau + \underline{c} + \omega)/2 < p_A^0 \text{ and } p_B^S(\omega) = (5\tau + 3\underline{c} + \omega)/4 < p_B^0$$

Consequently all consumers are better off compared to no contracts. The payoffs are

$$\Pi_A^S(\omega) = p_A^S(\omega)K(\omega) - \omega K(\omega) \text{ and } \Pi_B^S(\omega) = \left(p_A^S(\omega) - \underline{c}\right)(1 - K(\omega)) + (\omega - \underline{c})\, K(\omega)$$

There is $\widetilde{c} \in (\underline{c}, \widehat{c})$ such that $\Pi_B^S(\omega) \gtreqless \Phi_B^0 \Leftrightarrow \omega \gtreqless \widetilde{c}$, i.e., compared to no contracts, firm B is better off only if $\omega \in (\widetilde{c}, \widehat{c})$.

(b) *If $\omega \in [\widehat{c}, \overline{c})$, then $K(\omega) = D_A(\overline{c}, \underline{c}) = D_A^0$. The prices and market shares of firms are exactly the same as in the case of no contracts. The payoffs are*

$$\Pi_A^S(\omega) = \Phi_A^0 + (\overline{c} - \omega)D_A^0 \text{ and } \Pi_B^S(\omega) = \Phi_B^0 + (\omega - \underline{c})D_A^0$$

Compared to no contracts, both firms are better off and consumers are neither better off nor worse off.

(c) *An outsourcing contract is strictly Pareto improving (both firms and all consumers are better off) if $\omega \in (\widetilde{c}, \widehat{c})$ and weakly Pareto improving (both firms are better off and no consumer is worse off) if $\omega \in [\widehat{c}, \overline{c})$.*

(II) *Let $\overline{c} - \underline{c} \leq (3/4)\tau$. Then for any $\omega \in (\underline{c}, \overline{c})$, $K(\omega) = D_A(\overline{c}, \underline{c})$ and the conclusion is the same as in* (I)(b). *Consequently an outsourcing contract is weakly Pareto improving for all $\omega \in (\underline{c}, \overline{c})$.*

Proof See the Appendix. ■

To see the intuition for Proposition 2, recall that firm A's outsourcing order of η is equivalent to a capacity built by A prior to price competition. The volume of the order transmits the information to B that A commits to maintain a specific share in the market φ which indirectly establishes firm A as the Stackelberg leader in the market φ. The supplier price ω is the unit cost of building the capacity for firm A. When ω is relatively large, the Stackelberg leader market share coincides with A's market share under no contracts. For this case firm A does not utilize its Stackelberg leader advantage since capacity building is relatively costly (Prop 2(I)(b)). On the other hand, when ω is relatively small, the Stackelberg leader market share is larger than A's market share under no contracts. In such a case, capacity building is relatively less expensive which enables firm A to utilize its leadership advantage (Prop 2(I)(a)). The Stackelberg leader market share is sustained in equilibrium by a lower price of firm A. Given that A's commitment to maintain this share is credible, equilibrium reasoning implies that B's equilibrium price is also set lower, so that prices of both firms fall. This results in lower profit for firm B in the market φ compared to the situation of no contracts. This will be acceptable to B only if it can recover its losses in the final good market φ from its supplier profit in the market η, which could be the case only when B is significantly more efficient compared to A in the production of η. Consequently, if the cost difference of two firms is sufficiently large [specifically, $\overline{c} - \underline{c} > (3/4)\tau$], there are strictly Pareto improving outsourcing contracts: consumers are better off since prices of both firms fall, firm A is better off due to its Stackelberg leadership advantage and firm B is also better off since its supplier profit from market η more than offsets its losses from market φ.

3.3 Technology transfer contract between A and B

When firm B transfers its superior technology to firm A, both A and B can produce the intermediate good η at lower cost $\underline{c}$. As in the case of outsourcing contract, we consider linear unit pricing contracts. The unit pricing contract for technology transfer is the *unit royalty* contract where the rate of royalty is denoted by r. The strategic interaction between A and B under technology transfer is described as follows.

Negotiation stage: In the beginning, firms A and B negotiate on the unit royalty r. Under the unit royalty contract, firm A uses the superior technology of firm B. In return, A pays B the royalty r for each unit of η that it produces using the superior technology. So, firm A's *effective unit cost* of η is $\underline{c} + r$. As A can produce η itself at unit cost $\overline{c}$, a royalty contract can lower its cost of production only if $\underline{c} + r < \overline{c}$ or $r < \overline{c} - \underline{c}$. On the other hand, firm B can obtain a positive revenue from technology transfer only if $r > 0$. So we restrict $r \in (0, \overline{c} - \underline{c})$.

To compare royalty contracts with outsourcing contracts, it will be convenient to denote $\omega \equiv \underline{c} + r$. Then ω represents the *effective unit cost* of η for firm A under the superior technology, while $r = \omega - \underline{c}$ represents the *unit profit* of firm B from technology transfer. Since $r \in (0, \overline{c} - \underline{c})$, we have $\omega \in (\underline{c}, \overline{c})$.

If firms do not agree on a price, firm A produces the required η entirely by itself at cost $\overline{c}$ and the game $\mathbb{H}(\overline{c}, \underline{c})$ is played in the final good market. If firms agree on a price $\omega \in (\underline{c}, \overline{c})$, firm B transfers its superior technology to firm A and the game $\Gamma^T(\omega)$ is played firms between A and B.

Remark 1 Observe that the interpretation of ω is the same as in outsourcing contracts. For firm A, ω is the unit cost of obtaining η from firm B. For firm B, $(\omega - \underline{c})$ is the unit profit from supplying η to A. The difference between outsourcing and technology transfer is that under outsourcing, A chooses the quantity of η and places its order with B *before* firms set their prices for the final good market φ. Firm B produces η using its superior technology and supplies η to A at price ω. In contrast, under technology transfer, A uses the superior technology to produce η itself *after* prices are set and its demand is known. This difference, which is generally overlooked in the existing literature, alters the strategic interaction and affects the prices of the final good φ.

The game $\Gamma^T(\omega)$: It is an extensive form game that has the following stages.

Stage I: Firms A and B simultaneously announce prices p_A, p_B for the final good market φ. For any $p \equiv (p_A, p_B)$, the demand received by firm $i \in \{A, B\}$ is $D_i(p)$, given by (3).

Stage II: Observing $D_i(p)$, firms A and B simultaneously choose $q_A, q_B \geq 0$ where

$$q_i = \text{ the quantity of } \eta \text{ that firm } i \text{ produces in order to fulfill its demand of } \varphi$$

The demand fulfilling constraints for firms A, B are

$$q_A \geq D_A(p) \text{ and } q_B \geq D_B(p) \tag{14}$$

Each firm fulfills its demand, profits are realized, firm A makes its royalty payments to firm B and the game terminates.

If firm A produces η using its pre-contract inferior technology, its unit cost is $\overline{c}$. If it produces η using the superior technology, its unit cost is $\omega < \overline{c}$. So it is optimal for firm A to produce η entirely using the superior technology. Firm B's unit cost of producing η is $\underline{c} > 0$. Since both ω and $\overline{c}$ are positive, by (14), optimality requires that for $i \in \{A, B\}$, firm i produces $q_i = D_i(p)$ units of η and transforms $D_i(p)$ units to good φ to fulfill its demand.

Payoffs of firms in $\Gamma^T(\omega)$: Using optimal values of q_A, q_B, we can write the payoff of each firm. Firm A's payoff has two components: (i) revenue from market φ, (ii) total effective cost of producing q_A units of η to fulfill its demand. Observe that this total effective cost is $(\underline{c} + r)q_A = \omega q_A$, so it includes firm A's royalty payments to firm B. As $q_A = D_A(p)$, the payoff of firm A is

$$\Pi_A^\omega(p) = p_A D_A(p) - \omega q_A = (p_A - \omega) D_A(p) \tag{15}$$

Firm B's payoff has three components: (i) revenue from market φ, (ii) cost of producing q_B units of η to fulfill its demand and (iii) profit from technology transfer $rq_A = (\omega - \underline{c})q_A$. Since firm B's unit cost of η is $\underline{c}$ and $q_i = D_i(p)$, its payoff is

$$\Pi_B^\omega(p) = p_B D_B(p) - \underline{c} q_B + (\omega - \underline{c}) q_A = (p_B - \underline{c}) D_B(p) + (\omega - \underline{c}) D_A(p)$$

From (3), $D_A(p) + D_B(p) = 1$. Using this in the expression above, the payoff of firm B is

$$\Pi_B^\omega(p) = (p_B - \underline{c}) D_B(p) + (\omega - \underline{c})(1 - D_B(p)) = (p_B - \omega) D_B(p) + (\omega - \underline{c}) \tag{16}$$

Since $(\omega - \underline{c})$ is a constant, from (16) it follows that, firm B in effect solves the problem of a firm that has unit cost ω. By (15), firm A has unit cost ω. Therefore, firms A and B effectively play the Hotelling duopoly game $\mathbb{H}(\omega, \omega)$ and SPNE of $\Gamma^T(\omega)$ coincides with SPNE of $\mathbb{H}(\omega, \omega)$ with the only modification that firm B's payoff has an additional constant $(\omega - \underline{c})$.

Proposition 3 *For any $\omega \in (\underline{c}, \overline{c})$, $\Gamma^T(\omega)$ has a unique SPNE. For $i \in \{A, B\}$, let $p_i^T(\omega)$, $D_i^T(\omega)$ and $\Pi_i^T(\omega)$ be the price, market share and payoff of firm i in the SPNE $\Gamma^T(\omega)$. The SPNE has the following properties.*

(I) *The prices and market shares of firms are the same as in the SPNE of $\mathbb{H}(\omega, \omega)$. Each firm sets the same price $\tau + \omega$ and obtains the same market share $1/2$. The payoffs are $\Pi_A^T(\omega) = \tau/2$ and $\Pi_B^T(\omega) = \tau/2 + (\omega - \underline{c})$, i.e., $\Pi_A^T(\omega)$ is a constant and $\Pi_B^T(\omega)$ is increasing in ω.*

(II) *$\Pi_A^T(\omega) > \Phi_A^0$, i.e., compared to no contracts, firm A is better off.*

(III) *There are constants $\underline{c} < \underline{\theta} < \widehat{\theta} < \overline{\theta} < \overline{c}$ such that*

(a) *Compared to no contracts, all consumers are better off if $\omega \in (\underline{c}, \underline{\theta})$ and all consumers are worse off if $\omega \in (\overline{\theta}, \overline{c})$. If $\omega \in [\underline{\theta}, \overline{\theta}]$, then $\exists\ \lambda(\omega) \in (0, 1/2]$ such that consumers at location $x \in [0, \lambda]$ are better off and $x \in (\lambda, 1]$ are worse off.*

(b) *$\Pi_B^T(\omega) \gtreqless \Phi_B^0 \Leftrightarrow \omega \gtreqless \widehat{\theta}$, i.e., compared to no contracts firm B is better off only if $\omega \in (\widehat{\theta}, \overline{c})$.*

(c) *Whenever both firms prefer technology transfer over no contracts [i.e., if $\omega \in (\widehat{\theta}, \overline{c})$], there are always some consumers who prefer no contracts over technology transfer. Consequently, there is no technology transfer contract that is Pareto improving (i.e., making both firms as well as all consumers better off).*

Proof See the Appendix. ■

To see the intuition for Proposition 3, first observe that in contrast to the case of outsourcing, firm B does not receive its revenue from technology transfer upfront. It is received *after* the price competition stage in the form of royalty payments. To obtain relatively large royalty payments from technology transfer, B has an incentive to ensure that A's share in the market φ is not too small. This has a distortive effect which causes B's effective unit cost to rise to $\omega > \underline{c}$ [see (16)]. As A's unit cost falls to $\omega < \overline{c}$, firm A has an efficiency gain while B has an efficiency loss. The resulting effect on consumers depends on which one of these opposing factors dominates. When ω is sufficiently small ($\omega < \underline{\theta}$), the efficiency gain of A dominates, prices of both firms fall and all consumers are better off. When ω is sufficiently large ($\omega > \overline{\theta}$), the efficiency loss of B dominates, prices of both firms rise and all consumers are worse off. For intermediate values of ω ($\omega \in [\underline{\theta}, \overline{\theta}]$), the effect on consumers is ambiguous and it depends on their location. Consumers who are close to A ($x < \lambda$) benefit from the efficiency gain of A and therefore are better off. In contrast, consumers who are close to B ($x \geq \lambda$) are adversely affected by the efficiency loss of B and are worse off (Prop 3(III)(a)).

Observe that all consumers are better off under technology transfer compared to no contract only if ω is sufficiently small ($\omega < \underline{\theta}$). However, when ω is small, B obtains a lower revenue from royalty. For this reason, firm B prefers technology transfer over no contract only if ω is relatively large, in which case there are always some consumers who are worse off. This explains why there is no Pareto improving technology transfer contract (Prop 3(III)(c)).

4 Outsourcing versus technology transfer

Having characterized the outcomes of outsourcing and technology transfer games, in this section we compare these two contracts from the points of view of the two firms as well as the consumers.

4.1 Comparison of contracts with same ω

Recall that under both outsourcing and technology transfer, ω is firm A's effective unit cost of obtaining η and $(\omega - \underline{c})$ is firm B's unit profit from the market η. Proposition 4 compares these two contracts by keeping ω fixed across contracts, so that the effects of cost efficiency (for firm A) and supplier profits (for firm B) are the same across contracts. Therefore this proposition identifies the differences between these two contracts that are purely driven by the salient strategic aspects of these contracts: the Stackelberg leadership effect for outsourcing and the distortive effect for technology transfer.

Proposition 4 *Let $\omega \in (\underline{c}, \overline{c})$. There are constants $\alpha, \beta, \underline{\theta}, \overline{\theta} \in (\underline{c}, \overline{c})$, satisfying $\alpha < \underline{\theta} < \beta < \overline{\theta}$ such that the following hold.*

(I) *If $\omega \in (\underline{c}, \alpha)$, both firms prefer outsourcing and if $\omega \in (\beta, \overline{c})$, both firms prefer technology transfer. If $\omega \in [\alpha, \beta]$, then firm A prefers technology transfer while firm B prefers outsourcing.*

(II) *If $\omega \in (\underline{c}, \underline{\theta})$, all consumers prefer technology transfer and if $\omega \in (\overline{\theta}, \overline{c})$, all consumers prefer outsourcing. If $\omega \in [\underline{\theta}, \overline{\theta}]$, then $\exists\ \lambda(\omega) \in (0, 1/2]$ such that consumers at location $x \in [0, \lambda]$ prefer technology transfer while consumers at $x \in (\lambda, 1]$ prefer outsourcing.*

(III) *Whenever both firms prefer a specific contract, all consumers prefer the other contract. Specifically if $\omega \in (\underline{c}, \alpha)$, both firms prefer outsourcing and all consumers prefer technology transfer. If $\omega \in (\beta, \overline{c})$, both firms prefer technology transfer and all consumers prefer outsourcing.*

Proof See the Appendix. ■

Firm A's payoff under technology transfer is a constant $\tau/2$, while its payoff under outsourcing is decreasing in ω. Accordingly, A prefers outsourcing for relatively small values of ω and technology transfer for relatively large values of ω. Firm B's payoff has two components: profit from the final good market φ and profit from the intermediate good market η. We have seen that under technology transfer, there is a distortive effect that raises the effective cost of B. As a result, the profit of B in φ is lower under technology transfer than outsourcing. Therefore, if B is solely interested in the profits from the market φ, it would prefer outsourcing. On the other hand, if B is only interested in the profits from the market η, it would prefer technology transfer since its supplier profit from η increases with the market share of A, which is higher under technology transfer. Consequently the two components of B's payoff conflict with each other. This trade-off is settled by the magnitude of ω. When ω is relatively small, the profit from η does not contribute significantly to B's payoff. As a result, the effect of the market φ dominates and B prefers outsourcing. On the other hand, when ω is relatively large, the profit from η contributes significantly to B's payoff, so it prefers technology transfer.

For relatively large values of ω, prices under outsourcing are the same as in the case of no contracts, but prices under technology transfer exceed the no contract levels. Accordingly, all consumers prefer outsourcing for relatively large values of ω. On the other hand, for relatively small values of ω, prices under outsourcing may fall, but prices under technology transfer fall significantly below the no contract levels. Consequently all consumers prefer technology transfer for relatively small values of ω. For intermediate values of ω, the price of firm A falls while the price of B rises under technology transfer. As a result, the preference of consumers depends on their location as in Proposition 3.

Finally it is shown in Proposition 4 that the interest of consumers and incentives of firms conflict each other. Whenever both firms prefer one of the two contracts, all consumers prefer the other one.

4.2 Comparison of contracts under bargaining

We have characterized the outcomes of outsourcing and technology transfer contracts generally for all $\omega \in (\underline{c}, \overline{c})$ without explicitly specifying the bargaining schemes or the relative bargaining powers of the negotiating firms A and B. However, our results can be directly applied to any specific bargaining scheme as follows.

1. Outsourcing: For $\Gamma^S(\omega)$, it follows from Proposition 2 that there is $\widetilde{c} \in [\underline{c}, \overline{c})$ such that for any $\omega \in (\widetilde{c}, \overline{c})$, both firms A and B are better off compared to the situation of no contracts. Since $\Pi_A^S(\omega)$ is decreasing and $\Pi_B^S(\omega)$ is increasing in ω, if the bargaining power of firm B is relatively large, ω would be close to $\overline{c}$, whereas if firm A has a relatively large bargaining power, ω would be close to $\widetilde{c}$.

2. Technology transfer: For $\Gamma^T(\omega)$, by Proposition 3, there is $\widehat{\theta} \in (\underline{c}, \overline{c})$ such that for any $\omega \in (\widehat{\theta}, \overline{c})$, both firms A and B are better off compared to the situation of no contracts. Since $\Pi_A^T(\omega)$ is a constant and $\Pi_B^T(\omega)$ is increasing in ω, for this case, the solution of standard bargaining schemes (e.g., the Nash bargaining) would be $\omega = \overline{c}$.

In Proposition 4, we have compared the two contracts by keeping ω fixed across contracts. One important conclusion of this comparison is that the interest of consumers and incentives of firms conflict each other. Whenever both firms prefer a specific contract, all consumers prefer the other one. A natural question is if this conclusion is robust to particular bargaining schemes, because the solution of a particular bargaining scheme with given bargaining powers may not result in the same value of ω under outsourcing and technology transfer. Proposition 5 addresses this question for situations where the bargaining power of firm B (the supplier firm) is relatively large, which is usually the case assumed in the existing literature.

For clarity of presentation, we assume that under each of these contracts—outsourcing and technology transfer—the unit price ω is determined by the Nash bargaining solution with specific bargaining powers of the negotiating firms A, B. Denote the bargaining power of firm B by $\gamma \in (0,1)$, so that the bargaining power of firm A is $1-\gamma \in (0,1)$. Let $\omega^S(\gamma)$ and $\omega^T(\gamma)$ be the respective Nash bargaining solutions under outsourcing and technology transfer.

Proposition 5

(I) *There is* $c^* \in (\underline{c}, \overline{c})$ *such that for* $\omega \in (c^*, \overline{c})$, $p_i^S(\omega) = p_i^0 < p_i^T(\omega) < p_i^T(\overline{c})$.

(II) $\exists\ \gamma^* \in (0,1)$ *such that the following hold whenever firm* B *has bargaining power* $\gamma \in (\gamma^*, 1)$.

(a) $\omega^T(\gamma) = \overline{c}$ *and* $\omega^S(\gamma) \in (c^*, \overline{c})$.

(b) $\Pi_A^S(\omega^S(\gamma)) < \Pi_A^T(\omega^T(\gamma)) = \tau/2$ *and* $\Pi_B^S(\omega^S(\gamma)) < \Pi_B^T(\omega^T(\gamma)) = \tau/2 + \overline{c} - \underline{c}$, *i.e., both firms prefer technology transfer to outsourcing.*

(c) *For* $i \in \{A, B\}$, $p_i^S(\omega^S(\gamma)) = p_i^0 < p_i^T(\omega^T(\gamma)) = p_i^T(\overline{c})$, *i.e., all consumers prefer outsourcing to technology transfer.*

Proof See the Appendix. ■

Proposition 5 shows that the result that the interest of consumers and incentives of firms conflict with each other is robust to the introduction of specific bargaining processes. In particular, if the supplier firm has relatively large or full bargaining power over the input-seeking firm under both outsourcing and technology transfer contracts, then both firms would prefer technology transfer. In such a case, technology transfer results in higher prices which is detrimental for consumers.

5 Concluding remarks

This paper has compared two contracts that are frequently observed in industry practices: outsourcing and technology transfer. Departing from the existing literature, we have shown that these two contracts generate different strategic interactions that alter incentives of firms and have important effects on prices. Identifying the Stackelberg leadership effect in a Hotelling duopoly model, we have shown that there are always Pareto improving outsourcing contracts that make both firms and all consumers better off. In contrast, there are no Pareto improving technology transfer contracts. Due to the difference in strategic interaction between these contracts, the interest of consumers and incentives of firms move in completely opposite directions. When firms prefer outsourcing, all consumers prefer technology transfer and when firms prefer technology transfer, all consumers prefer outsourcing.

Appendix

We begin with Lemma A1 which will be used to prove Lemma 1.

Lemma A1 *Let* $c_A, c_B < \tau$. *Let* $i, j \in \{A, B\}$ *and* $i \neq j$. *In the game* $\mathbb{H}(c_A, c_B)$:

(i) *The best response of firm* i *to firm* j*'s price* p_j *is*

$$b_{c_i}(p_j) = \begin{cases} (p_j + \tau + c_i)/2 & \textit{if } p_j \leq 3\tau + c_i \\ p_j - \tau & \textit{if } p_j > 3\tau + c_i \end{cases} \tag{17}$$

(ii) *If* (p_A, p_B) *is an SPNE of* $\mathbb{H}(c_A, c_B)$*, then* $p_i \leq 3\tau + c_j$ *for* $i, j \in \{A, B\}$*,* $i \neq j$*.*

Proof (i) By (3), if $p_i \leq p_j - \tau$, then $D_i = 1$ and i's payoff is $p_i - c_i$, which is strictly increasing in p_i. If $p_i \geq p_j + \tau$, then $D_i = 0$ and i's payoff is zero. Therefore, to determine best response of i, it is sufficient to consider $p_i \in [p_j - \tau, p_j + \tau]$. In that case, by (2) and (3), $D_i = (p_j - p_i + \tau)/2\tau$ and i's payoff is $\Phi_i = (p_i - c_i)(p_j - p_i + \tau)/2\tau$. Since $c_i < \tau$, we have $p_j + \tau > c_i$. Hence the unconstrained maximum of Φ_i with respect to p_i is attained at $b(p_j) = (p_j + \tau + c_i)/2 < p_j + \tau$. The result in (17) follows by noting that $b(p_j) \geq p_j - \tau$ iff $p_j \leq 3\tau + c_j$.

(ii) Suppose (p_A, p_B) is an SPNE and $p_j > 3\tau + c_i$. Then by (17), $p_i = b_{c_i}(p_j) = p_j - \tau$. In that case, $D_j = 0$ and firm j obtains zero payoff. Let j deviate to set the price $p'_j = p_i = p_j - \tau$. Following this deviation, by (2) and (3), firm j will receive demand 1/2 and payoff $(p_j - c_j)/2$. Since $p_j > 3\tau + c_j > c_j$, firm j's post-deviation payoff is positive. This shows that firm j has improved its payoff following the deviation, a contradiction. ∎

Proof of Lemma 1 By Lemma A1(ii), to find SPNE of $\mathbb{H}(c_A, c_B)$, it is sufficient to consider $p_i \leq 3\tau + c_i$ for $i \in \{A, B\}$. Then by (17), the best response of A is to set $p_A = (p_B + \tau + c_A)/2$ and the best response of B is to set $p_B = (p_A + \tau + c_B)/2$. The system of best response equations has a unique solution where $p_A = \tau + (2c_A + c_B)/3$ and $p_B = \tau + (c_A + 2c_B)/3$. This proves (i). Parts (ii)-(iii) follow directly from (i). ∎

Lemma A2 will be used to prove Lemma 2.

Lemma A2 *Denote* $p \equiv (p_A, p_B)$*,* $g(p_B) := p_B + \tau - 2\tau K$*,* $\underline{p}(K) := 4\tau K - \tau$ *and* $\overline{p}(K) := 4\tau K - \tau + \overline{c}$*. In the game* $\mathbb{H}^K(\underline{c}, \overline{c})$*:*

(i) $D_A(p) \lesseqqgtr K \Leftrightarrow p_A \gtreqqless g(p_B)$.

(ii) *The profit of firm A is*

$$\Phi_A^K(p) = \begin{cases} p_A - \overline{c} + \overline{c}K & \text{if } \; p_A < p_B - \tau \\ (p_A - \overline{c})(p_B - p_A + \tau)/2\tau + \overline{c}K & \text{if } \; p_B - \tau \leq p_A < g(p_B) \\ p_A(p_B - p_A + \tau)/2\tau & \text{if } \; g(p_B) \leq p_A \leq p_B + \tau \\ 0 & \text{if } \; p_A > p_B + \tau \end{cases} \tag{18}$$

(iii) *The best response of A to B's price* p_B *is*

$$b_A^K(p_B) = \begin{cases} b_0(p_B) = (p_B + \tau)/2 & \text{if } \; p_B < \underline{p} \\ g(p_B) & \text{if } \; \underline{p} \leq p_B \leq \overline{p} \\ b_{\overline{c}}(p_B) = (p_B + \tau + \overline{c})/2 & \text{if } \; \overline{p} < p_B \leq 3\tau + \overline{c} \\ b_{\overline{c}}(p_B) = p_B - \tau & \text{if } \; p_B > 3\tau + \overline{c} \end{cases} \tag{19}$$

(iv) *Consider the demand that firm A receives when it sets price* $p_A = b_A^K(p_B)$*. This demand is less than K if* $p_B < \underline{p}$*, more than K if* $p_B > \overline{p}$ *and exactly equals K if* $\underline{p} \leq p_B \leq \overline{p}$*.*

(v) *The profit of firm B is*

$$\Phi_B^K(p) = \begin{cases} p_A - \underline{c} & \text{if } \; p_B < p_A - \tau \\ (p_B - \underline{c})(p_A - p_B + \tau)/2\tau & \text{if } \; p_A - \tau \leq p_B \leq p_A + \tau \\ 0 & \text{if } \; p_B > p_A + \tau \end{cases} \tag{20}$$

(vi) *The best response of B to A's price* p_A *is*

$$b_B^K(p_A) = b_{\underline{c}}(p_A) = \begin{cases} (p_A + \tau + \underline{c})/2 & \text{if } \; p_A \leq 3\tau + \underline{c} \\ p_A - \tau & \text{if } \; p_B > 3\tau + \underline{c} \end{cases} \tag{21}$$

(vii) *If* (p_A, p_B) *is an SPNE of* $\mathbb{H}(c_A, c_B)$, *then* $p_A \leq 3\tau + \underline{c}$ *and* $p_B \leq 3\tau + \overline{c}$.

Proof (i) Observe that since $K \in [0,1]$, we have $p_B - \tau \leq g(p_B) \leq p_B + \tau$. It follows from (3) that if $p_A \leq p_B - \tau$, then $D_A(p) = 1 \geq K$ and if $p_A \geq p_B + \tau$, then $D_A(p) = 0 \leq K$. Now consider $p_A \in [p_B - \tau, p_B + \tau]$. Then from (2) and (3), we have $D_A(p) = (p_B - p_A + \tau)/2\tau \lesseqqgtr K \Leftrightarrow p_A \gtreqqless g(p_B)$. This completes the proof of (i).

(ii) Observe from (9) that $\Phi_A^K(p) = (p_A - \overline{c})D_A(p) + \overline{c}K$ if $D_A(p) \geq K$. The first expression of (18) follows by noting that $D_A(p) = 1 \geq K$ for $p_A < p_B - \tau$. Since $D_A(p) = (p_B - p_A + \tau)/2\tau \geq K$ for $p_A \in [p_B - \tau, g(p_B)]$ (by part (i)), the second expression follows.

Again from (9), $\Phi_A^K(p) = p_A D_A^p$ if $D_A(p) \leq K$. Since $D_A(p) = (p_B - p_A + \tau)/2\tau \leq K$ for $p_A \in [g(p_B), p_B + \tau]$ (by part (i)), the third expression of (18) follows. The last expression follows by noting that $D_A(p) = 0 \leq K$ for $p_A > p_B + \tau$.

(iii) It follows from (18) that $\Phi_A^K(p)$ is strictly increasing for $p_A \leq p_B - \tau$ and it equals zero for $p_A \geq p_B + \tau$. Therefore, to determine best response of A, it is sufficient to consider $p_A \in [p_B - \tau, p_B + \tau]$.

Let $E_1 = [p_B - \tau, g(p_B)]$ and $E_2 = [g(p_B), p_B + \tau]$. Observe from (18) that for $p_A \in E_1$, firm A's effective unit cost is $\overline{c}$ and its problem is the same as in the standard Hotelling game $\mathbb{H}(\overline{c}, c_B)$. Taking $i = A$ and $c_A = \overline{c}$ in (17) of Lemma A1, the unconstrained maximum of $\Phi_A^K(p)$ over $p_A \in E_1$ is attained at $p_A = b_{\overline{c}}(p_B)$. Note from (17) that if $p_B > 3\tau + \overline{c}$, then $b_{\overline{c}}(p_B) = p_B - \tau$. If $p_B \leq 3\tau + \overline{c}$, then $b_{\overline{c}}(p_B) = (p_B + \tau + \overline{c})/2 \lesseqqgtr g(p_B) \Leftrightarrow p_B \gtreqqless \overline{p}$ where $\overline{p} := 4\tau K - \tau + \overline{c} \leq 3\tau + \overline{c}$. Hence we conclude that

$$\arg\max_{p_A \in E_1} \Phi_A^K(p) = \begin{cases} g(p_B) & \text{if } p_B < \overline{p} \\ (p_B + \tau + \overline{c})/2 & \text{if } \overline{p} \leq p_B \leq 3\tau + \overline{c} \\ p_B - \tau & \text{if } p_B > 3\tau + \overline{c} \end{cases} \tag{22}$$

Observe from (18) that for $p_A \in E_2$, firm A's effective unit cost is 0 and its problem is the same as in the standard Hotelling game $\mathbb{H}(0, c_B)$. Taking $i = A$ and $c_A = 0$ in (17) of Lemma A1, the unconstrained maximum of $\Phi_A^K(p)$ over $p_A \in E_2$ is attained at $p_A = b_0(p_B)$. Note from (17) that if $p_B > 3\tau$, then $b_0(p_B) = p_B - \tau \leq g(p_B)$, so the maximum is attained at $p_A = g(p_B)$. If $p_B \leq 3\tau$, then $b_0(p_B) = (p_B + \tau)/2 \gtreqqless g(p_B) \Leftrightarrow p_B \lesseqqgtr \underline{p}$ where $\underline{p} := 4\tau K - \tau \leq 3\tau$. Hence we conclude that

$$\arg\max_{p_A \in E_2} \Phi_A^K(p) = \begin{cases} (p_B + \tau)/2 & \text{if } p_B \leq \underline{p} \\ g(p_B) & \text{if } p_B > \underline{p} \end{cases} \tag{23}$$

As $g(p_B) \in E_1 \cap E_2$, choosing $p_A = g(p_B)$ is feasible for both E_1 and E_2. Using this fact, the result in (19) follows from (22)-(23).

(iv) It follows from (iii) that $b_A^K(p_B) > g(p_B)$ if $p_B < \underline{p}$, $b_A^K(p_B) < g(p_B)$ if $p_B > \overline{p}$ and $b_A^K(p_B) = g(p_B)$ if $\underline{p} \leq p_B \leq \overline{p}$. Using this fact, the result follows from (i).

(v)-(vi) Noting that firm B's constant unit cost of η is $\underline{c}$, (20) follows from (2) and (3), and (21) follows from (17) by taking $i = B$ and $c_B = \underline{c}$.

(vii) Follows from (19) and (21) by the same reasoning as the proof of Lemma A1(ii). ■

Proof of Lemma 2 Using Lemma A2(vii), to find SPNE of $\mathbb{H}^K(\underline{c}, \overline{c})$, consider $p_A \leq 3\tau + \underline{c}$ and $p_B \leq 3\tau + \overline{c}$. From (19), firm A's best response $b_A^K(p_B)$ is piecewise linear with three segments: $b_{\overline{c}}(p_B)$ (if $p_B > \overline{p}$), $b_0(p_B)$ (if $p_B < \underline{p}$) and $g(p_B)$ (if $p_B \in [\underline{p}, \overline{p}]$). From (21), firm B's best response is linear, given by $b_{\underline{c}}(p_B)$. Hence any segment of $b_A^K(p_B)$ can intersect $b_{\underline{c}}(p_B)$ at most once. It will be useful to recall that for $i = 1, 2$, the SPNE price and market share of firm i in $\mathbb{H}(c_A, c_B)$ are denoted by $p_i(c_A, c_B)$ and $D_i(c_A, c_B)$.

Note that $b_{\overline{c}}(p_B)$ is the best response of A in the standard Hotelling game $\mathbb{H}(\overline{c}, \underline{c})$. Firm B's best response in this game is $b_{\underline{c}}(p_A)$. By Lemma 1(II), the unique solution of the system $(p_A = b_{\overline{c}}(p_B), p_B = b_{\underline{c}}(p_A))$ has $p_A = p_A(\overline{c}, \underline{c})$ and $p_B = p_B(\overline{c}, \underline{c})$. We note that $p_B(\overline{c}, \underline{c}) \gtreqless \overline{p} \Leftrightarrow K \lesseqgtr D_A(\overline{c}, \underline{c})$. Hence we have an SPNE with $p_B > \overline{p}$ iff $p_B = p_B(\overline{c}, \underline{c}) > \overline{p}$, which holds iff $K < D_A(\overline{c}, \underline{c})$ (see Figure 1(a)). For this case, firm A fully utilizes its capacity K and moreover produces $D_A(\overline{c}, \underline{c}) - K$ units of η in-house to meet its demand.

Next observe that $b_0(p_B)$ is the best response of A in the standard Hotelling game $\mathbb{H}(0, \underline{c})$. Firm B's best response in this game is $b_{\underline{c}}(p_A)$. By Lemma 1(II), the unique solution of the system $(p_A = b_0(p_B), p_B = b_{\underline{c}}(p_A))$ has $p_A = p_A(0, \underline{c})$ and $p_B = p_B(0, \underline{c})$. We note that $p_B(0, \underline{c}) \lesseqgtr \underline{p} \Leftrightarrow K \gtreqless D_A(0, \underline{c})$. Hence we have an SPNE with $p_B < \underline{p}$ iff $p_B = p_B(0, \underline{c}) < \underline{p}$, which holds iff $K > D_A(0, \underline{c})$ (see Figure 1(b)). For this case, firm A does not utilize $K - D_A(0, \underline{c})$ units of its capacity and does not produce η in-house.

Finally observe that the unique solution of $(p_A = g(p_B), p_B = b_{\underline{c}}(p_A))$ has $p_A = 3\tau + \underline{c} - 4\tau K$ and $p_B = 2\tau + \underline{c} - 2\tau K$. Note that $2\tau + \underline{c} - 2\tau \gtreqless \underline{p} \Leftrightarrow K \lesseqgtr D_A(0, \underline{c})$ and $2\tau + \underline{c} - 2\tau K \lesseqgtr \overline{p} \Leftrightarrow K \gtreqless D_A(\overline{c}, \underline{c})$. Hence we have an SPNE with $p_B \in [\underline{p}, \overline{p}]$ iff $p_B = 2\tau + \underline{c} - 2\tau K \in [\underline{p}, \overline{p}]$, which holds iff $K \in [D_A(\overline{c}, \underline{c}), D_A(0, \underline{c})]$ (see Figure 1(c)). For this case, firm A's SPNE market share exactly equals its capacity K. It fully utilizes its capacity and does not produce η in-house.

The results (i)-(iii) of Lemma 2 follow from the conclusions of the last three paragraphs.

■

Proof of Proposition 2 We prove the specific properties (I)-(II) of Proposition 2. The general properties will follow directly from the specific properties.

(I) Here we solve the problem of firm A in Stage 1 where A chooses $K \in [0, 1]$ to maximize $\Pi_A^\omega(K)$ given in (12). As in the last case, $\Pi_A^\omega(K)$ is strictly increasing for $K \leq D_A(\overline{c}, \underline{c})$ and strictly decreasing for $K \geq D_A(0, \underline{c})$. So it is sufficient to consider $K \in [D_A(\overline{c}, \underline{c}), D_A(0, \underline{c})]$. Then by (11) and (12),

$$\Pi_A^\omega(K) = p_A^K K - \omega K = (3\tau + \underline{c} - \omega - 4\tau K) K.$$

Since $\tau > \overline{c} > \omega$, we have $3\tau + \underline{c} - \omega > 0$. Hence the unconstrained maximum of $\Pi_A^\omega(K)$ is attained at $\Theta(\omega) := 3/8 - (\omega - \underline{c})/8\tau < D_A(0, \underline{c}) = 1/2 + \underline{c}/6\tau$. Therefore, over $K \in [D_A(\overline{c}, \underline{c}), D_A(0, \underline{c})]$, the maximizer of $\Pi_A^\omega(K)$ is

$$K(\omega) = \min\{\Theta(\omega), D_A(\overline{c}, \underline{c})\} \tag{24}$$

Comparing $\Theta(\omega)$ with $D_A(\overline{c}, \underline{c}) = 1/2 - (\overline{c} - \underline{c})/6\tau$, we have

$$\Theta(\omega) \gtreqless D_A(\overline{c}, \underline{c}) \Leftrightarrow \omega \lesseqgtr \widehat{c} \text{ where } \widehat{c} \equiv 4\overline{c}/3 - \underline{c}/3 - \tau \tag{25}$$

Observe that (i) $\overline{c} - \widehat{c} = \tau + \underline{c}/3 - \overline{c}/3 > 0$ and (ii) $\widehat{c} - \underline{c} = (4/3)\left[\overline{c} - \underline{c} - (3/4)\tau\right]$. Hence

$$\widehat{c} \gtreqless \underline{c} \Leftrightarrow \overline{c} - \underline{c} \gtreqless (3/4)\tau \tag{26}$$

From (24), (25) and (26), we conclude that

(1) If $\bar{c} - \underline{c} \leq (3/4)\tau$, then $K(\omega) = D_A(\bar{c}, \underline{c})$ for all $\omega \in (\underline{c}, \bar{c})$.

(2) If $\bar{c} - \underline{c} > (3/4)\tau$, then (i) $K(\omega) = \Theta(\omega)$ for $\omega \in (\underline{c}, \widehat{c})$ and (ii) $K(\omega) = D_A(\bar{c}, \underline{c})$ for $\omega \in [\widehat{c}, \bar{c})$.

The results of (II)(b) and (III) of Prop 2 follow from (1) and (2)(ii) above.

To prove (II)(a) of Prop 2, observe from (2)(i) above that if $\bar{c} - \underline{c} > (3/4)\tau$ and $\omega \in (\underline{c}, \widehat{c})$, then $K(\omega) = \Theta(\omega) \in (D_A(\bar{c}, \underline{c}), D_A(0, \underline{c}))$ where $\Theta(\omega) = 3/8 - (\omega - \underline{c})/8\tau$. From Lemma 2(iii), it follows that the market share of firm A is $\Theta(\omega)$, while the share of B is $1 - \Theta(\omega)$. Taking $K = \Theta(\omega)$ in (11), it follows that

$$p_A^S(\omega) = (3\tau + \underline{c} + \omega)/2 \text{ and } p_B^S(\omega) = (5\tau + 3\underline{c} + \omega)/4.$$

Note from Prop 1(II) that under no contracts, the prices are

$$p_A^0 = \tau + \bar{\theta} \text{ and } p_B^0 = \tau + \underline{\theta} \text{ where } \underline{\theta} \equiv (2\underline{c} + \bar{c})/3 \text{ and } \bar{\theta} \equiv (\underline{c} + 2\bar{c})/3.$$

As $\omega < \widehat{c}$, we have $p_A^0 - p_A^S(\omega) = (\widehat{c} - \omega)/2 > 0$ and $p_B^0 - p_B^S(\omega) = (\widehat{c} - \omega)/4 > 0$. Hence all consumers are better off.

The payoffs of the firms are obtained from (12) and (13) by using the values of p_A^S, p_B^S and taking $K = \Theta(\omega)$. Note from (12) that since $\omega < \bar{c}$, firm A can be better off compared to the case of no contracts by simply choosing $K = D_A(\bar{c}, \underline{c})$. Therefore, under its optimal choice $K(\omega)$, it must be better off. The payoff of B is

$$\Pi_B^S(\omega) = (5\tau + \omega - \underline{c})^2/32\tau + (\omega - \underline{c})(3\tau + \underline{c} - \omega)/8\tau \tag{27}$$

which is strictly increasing in ω. Recall from Prop 1 that under no contracts, B obtains $\Pi_B^0 = (3\tau + \bar{c} - \underline{c})^2/18\tau$. Hence $\Pi_B^S(\omega) - \Pi_B^0$ is strictly increasing in ω. Note that since $\tau > \bar{c}$ and $\bar{c} - \underline{c} > (3/4)\tau$, we have

$$\Pi_B^S(\underline{c}) - \Pi_B^0 = (27\tau - 4\bar{c} + 4\underline{c})[(3/4)\tau - \bar{c} + \underline{c}]/72\tau < 0 \text{ and}$$

$$\Pi_B^S(\widehat{c}) - \Pi_B^0 = 2(3\tau - \bar{c} + \underline{c})[\bar{c} - \underline{c} - (3/4)\tau]/9\tau > 0.$$

Hence $\exists\ \widetilde{c} \in (0, \widehat{c})$ such that $\Pi_B^S(\omega) \gtreqless \Pi_B^0 \Leftrightarrow \omega \gtreqless \widetilde{c}$. This completes the proof of II(a). Part (II)(c) follows from (II)(a) and (b). ∎

Proof of Proposition 3 (I) From (15) and (16) it follows that SPNE prices and market shares of $\Gamma^T(\omega)$ coincide with SPNE of game $\mathbb{H}(\omega, \omega)$. Taking $c_A = \omega$ and $c_B = \omega$ in Lemma 1, the prices and market shares are obtained. Using the SPNE prices and market shares, the payoffs are obtained from (15) and (16).

(II) Follows directly from part (I) and Proposition 1(iii).

(III)(a) Recall from Prop 1 that when there are no contracts, the SPNE prices are $p_A^0 = \tau + \bar{\theta}$ and $p_B^0 = \tau + \underline{\theta}$ where $\underline{c} < \underline{\theta} < \bar{\theta} < \bar{c}$ with

$$\underline{\theta} \equiv (2\underline{c} + \bar{c})/3 \text{ and } \bar{\theta} \equiv (\underline{c} + 2\bar{c})/3 \tag{28}$$

The SPNE prices in $\Gamma^T(\omega)$ are $p_A^T(\omega) = p_B^T(\omega) = \tau + \omega$. Therefore, if $\omega \in (\underline{c}, \underline{\theta})$, then $p_i^T(\omega) < p_i^0$ for $i \in \{A, B\}$ and all consumers prefer technology transfer over no contracts. If

$\omega \in (\overline{\theta}, \overline{c})$, $p_i^T(\omega) > p_i^0$ for $i \in \{A, B\}$ and all consumers prefer no contracts over technology transfer.

If $\omega \in [\underline{\theta}, \overline{\theta}]$, then $p_A^T(\omega) \leq p_A^0$ and $p_B^T(\omega) \geq p_B^0$. Note that in $\Gamma^T(\omega)$, firm A's SPNE market share is $1/2 > D_A^0$ where $D_A^0 = D_A(\overline{c}, \underline{c})$ is the SPNE market share of firm A under no contracts. Consider the consumers at $x \in [0, D_A^0]$. In both cases (i.e., no contracts and $\Gamma^T(\omega)$), they buy from firm A. As $p_A^T(\omega) \leq p_A^0$, these consumers are better off in $\Gamma^T(\omega)$. Next consider the consumers at $x \in [1/2, 1]$. In both cases they buy from firm B. As $p_B^T(\omega) \geq p_B^0$, they are worse off in $\Gamma^T(\omega)$. Finally consider any consumer at $x \in [D_A^0, 1/2)$. When there is no contract, such a consumer buys from firm B to obtain the net utility

$$U_x^0 = V - p_B^0 - \tau(1-x) = V - (\tau + \underline{\theta}) - \tau(1-x)$$

In $\Gamma^T(\omega)$, this consumer buys from A to obtain the net utility

$$U_x^T = V - p_A^S - \tau x = V - (\tau + \omega) - \tau x$$

Hence $U_x^T - U_x^0 \gtreqqless 0 \Leftrightarrow x \lesseqqgtr \lambda(\omega) := 1/2 - (\omega - \underline{\theta})/2\tau$. Since $\omega \geq \underline{\theta}$, we have $\lambda(\omega) \leq 1/2$. Since $D_A^0 = 1/2 - (\overline{c} - \underline{c})/6\tau$, from (28) we have $\lambda(\omega) - D_A^0 = (\overline{\theta} - \omega)/2\tau \geq 0$ (since $\omega \leq \overline{\theta}$). Thus $\lambda(\omega) \in [D_A^0, 1/2]$. We conclude that consumers at $x \in [D_A^0, \lambda]$ prefer technology transfer while consumers at $x \in (\lambda, 1/2)$ prefer no contracts. Since consumers at $x \in [0, D_A^0)$ prefer technology transfer and $x \in [1/2, 1]$ prefer no contracts, the proof of (III)(a) is complete.

(III)(b) Note that $\Pi^T(\omega) = \tau/2 + (\omega - \underline{c})$ and $\Phi_B^0 = (3\tau + \overline{c} - \underline{c})^2/18\tau$. Denoting $f(\omega) := \Pi^T(\omega) - \Phi_B^0$, note that $f(\omega)$ is increasing, $f(\underline{c}) = -(\overline{c} - \underline{c})(6\tau + \overline{c} - \underline{c})/18\tau < 0$ and $f(\overline{c}) = (\overline{c} - \underline{c})(12\tau - \overline{c} + \underline{c})/18\tau > 0$. Hence $\exists\ \widehat{\theta} \in (\underline{c}, \overline{c})$ such that $\Pi^T(\omega) \gtreqqless \Phi_B^0 \Leftrightarrow \omega \gtreqqless \widehat{\theta}$. Standard computations show that $\widehat{\theta} \equiv \underline{\theta} + (\overline{c} - \underline{c})^2/18\tau$. Therefore, $\widehat{\theta} > \underline{\theta}$. Comparing $\widehat{\theta}$ with $\overline{\theta}$ from (28), we have $\overline{\theta} - \widehat{\theta} = (\overline{c} - \underline{c})(6\tau + \underline{c} - \overline{c})/18\tau > 0$ proving that $\underline{\theta} < \widehat{\theta} < \overline{\theta}$.

(III)(c) Follows from parts (a) and (b). ∎

Lemma A3 will be used to prove Proposition 4.

Lemma A3 *Let $\omega \in (\underline{c}, \overline{c})$. There are constants $\alpha, \beta \in (\underline{c}, \overline{c})$ such that*

(I) $\Pi_A^T(\omega) \gtreqqless \Pi_A^S(\omega) \Leftrightarrow \omega \gtreqqless \alpha$.

(II) $\Pi_B^T(\omega) \gtreqqless \Pi_B^S(\omega) \Leftrightarrow \omega \gtreqqless \beta$.

Proof Denote $\sigma := \overline{c} - \underline{c}$ and observe that $\sigma < \tau$. Also for $i \in \{A, B\}$ we denote $\Delta_i(\omega) := \Pi_i^T(\omega) - \Pi_i^S(\omega)$. We prove the lemma by showing that there are constants $\alpha, \beta \in (\underline{c}, \overline{c})$ such that (I) $\Delta_A(\omega) \gtreqqless 0 \Leftrightarrow \omega \gtreqqless \alpha$ and (II) $\Delta_B(\omega) \gtreqqless 0 \Leftrightarrow \omega \gtreqqless \beta$.

(I) Recall that $\Pi_A^T(\omega) = \tau/2$ for all $\omega \in (\underline{c}, \overline{c})$ (Prop 3) and $\Pi_A^S(\omega)$ is strictly decreasing in ω (Prop 2). Hence $\Delta_A(\omega)$ is strictly increasing in ω. To determine $\Pi_A^S(\omega)$, we consider the following possible cases where $\widehat{c} \equiv 4\overline{c}/3 - \underline{c}/3 - \tau$.

Case 1 $\sigma > (3/4)\tau$:

Subcase 1(a) $\omega \in (\underline{c}, \widehat{c})$: For this case, from Prop 2, we have

$$\Pi_A^S(\omega) = (p_A^S - \omega)K(\omega) = (3\tau + \underline{c} - \omega)^2/16\tau, \text{ so that } \Delta_A(\omega) = \tau/2 - (3\tau + \underline{c} - \omega)^2/16\tau$$

Observe that $\Delta_A(\underline{c}) = -\tau/16 < 0$ and $\Delta_A(\widehat{c}) = [2\sigma^2 - (3\tau - 2\sigma)^2]/18\tau$. Hence $\Delta_A(\widehat{c}) \gtreqqless 0 \Leftrightarrow \sigma \gtreqqless 3(2 - \sqrt{2})\tau/2$. We have the following two possibilities.

(i) If $3(2-\sqrt{2})\tau/2 < \sigma < \tau$, then $\Delta_A(\widehat{c}) > 0$. Since $\Delta_A(\underline{c}) < 0$, $\exists\ \widehat{\alpha} \in (\underline{c}, \widehat{c})$ such that $\Delta_A(\omega) \gtreqless 0 \Leftrightarrow \omega \gtreqless \widehat{\alpha}$. Standard computations show that

$$\widehat{\alpha} \equiv (3-2\sqrt{2})\tau + \underline{c} \tag{29}$$

(ii) If $(3/4)\tau < \sigma \leq 3(2-\sqrt{2})\tau/2$, then $\Delta_A(\widehat{c}) \leq 0$. Hence $\Delta_A(\omega) < 0$ for all $\omega \in (\underline{c}, \widehat{c})$.

Subcase 1(b) $\omega \in [\widehat{c}, \overline{c})$: For this case $K(\omega) = D_A(\overline{c}, \underline{c})$ and $\Pi_A^S(\omega) = \Phi_A^0 + (\overline{c} - \omega)D_A^0 = (3\tau - \sigma)^2/18\tau + (\overline{c} - \omega)(3\tau - \sigma)/6\tau$. Hence we have

$$\Delta_A(\omega) = \tau/2 - (3\tau - \sigma)^2/18\tau - (\overline{c} - \omega)(3\tau - \sigma)/6\tau$$

Note that $\Delta_A(\overline{c}) = \sigma(6\tau - \sigma)/18\tau > 0$. Noting that $\Delta_A(\omega)$ is continuous, from the last case we know that $\Delta_A(\widehat{c}) \gtreqless 0 \Leftrightarrow \sigma \gtreqless 3(2-\sqrt{2})\tau/2$. Again we consider two possibilities.

(i) If $3(2-\sqrt{2})\tau/2 < \sigma < \tau$, then $\Delta_A(\widehat{c}) > 0$. Hence $\Delta_A(\omega) > 0$ for all $\omega \in [\widehat{c}, \overline{c})$.

(ii) If $(3/4)\tau < \sigma \leq 3(2-\sqrt{2})\tau/2$, then $\Delta_A(\widehat{c}) \leq 0$. Since $\Delta_A(\overline{c}) > 0$, $\exists\ \widetilde{\alpha} \in (\widehat{c}, \overline{c})$ such that $\Delta_A(\omega) \gtreqless 0 \Leftrightarrow \omega \gtreqless \widetilde{\alpha}$. Standard computations show that

$$\widetilde{\alpha} \equiv 2\underline{c}\tau/(3\tau - \sigma) - \sigma(\underline{c} + \overline{c})/3(3\tau - \sigma) + \overline{c}/3. \tag{30}$$

Case 2 $\sigma \leq (3/4)\tau$: For this case, by Prop 2, $\Pi_A^S(\omega)$ and $\Delta_A(\omega)$ are the same as in Subcase 1(b) for all $\omega \in (\underline{c}, \overline{c})$. From Subcase 1(b), $\Delta_A(\overline{c}) > 0$. Noting that $\Delta_A(\underline{c}) = -\sigma(3\tau - \sigma)/18\tau < 0$, we conclude that $\exists\ \widetilde{\alpha} \in (\underline{c}, \overline{c})$ [given in (30)] such that $\Delta_A(\omega) \gtreqless 0 \Leftrightarrow \omega \gtreqless \widetilde{\alpha}$.

Define

$$\alpha := \begin{cases} \widehat{\alpha} & \text{if } 3(2-\sqrt{2})\tau/2 < \sigma < \tau \\ \widetilde{\alpha} & \text{if } \sigma \leq 3(2-\sqrt{2})\tau/2 \end{cases} \tag{31}$$

Using (31), for $3(2-\sqrt{2})\tau/2 < \sigma < \tau$, the result follows from Subcases [1(a)(i)]-[1(b)(i)], for $(3/4)\tau < \sigma \leq 3(2-\sqrt{2})\tau/2$, it follows from Subcases [1(a)(ii)]-[1(b)(ii)] and for $\sigma \leq (3/4)\tau$, from Case 2.

(II) Recall from Prop 3 that $\Pi_B^T(\omega) = \tau/2 + (\omega - \underline{c})$ for all $\omega \in (\underline{c}, \overline{c})$. To determine $\Pi_B^S(\omega)$, we consider the following possible cases.

Case 1 $\sigma > (3/4)\tau$:

Subcase 1(a) $\omega \in (\underline{c}, \widehat{c})$: For this case, by Prop 2 and (27), we have

$$\Pi_B^S(\omega) = (5\tau - \underline{c} + \omega)^2/32\tau + (\omega - \underline{c})[3/8 - (\omega - \underline{c})/8\tau] \text{ and}$$

$$\Delta_B(\omega) = \tau/2 + (\omega - \underline{c})[5/8 + (\omega - \underline{c})/8\tau] - (5\tau - \underline{c} + \omega)^2/32\tau$$

Note that $\Delta_B(\omega)$ is increasing in ω. Now observe that $\Delta_B(\widehat{c}) = [(\tau + 2\sigma)^2 - 13\tau^2]/24\tau < (9\tau^2 - 13\tau^2)/24\tau < 0$ (since $\sigma < \tau$). Hence $\Delta_B(\omega) < 0$ for all $\omega \in (\underline{c}, \widehat{c})$.

Subcase 1(b) $\omega \in [\widehat{c}, \underline{c})$: For this case, by Prop 2, we have $\Pi_B^S(\omega) = \Phi_B^0 + (\omega - \underline{c})D_B^0 = (3\tau + \sigma)^2/18\tau + (\omega - \underline{c})(3\tau + \sigma)/6\tau$, so that

$$\Delta_B(\omega) = \tau/2 + (\omega - \underline{c})(1/2 + \sigma/6\tau) - (3\tau + \sigma)^2/18\tau$$

Note that $\Delta_B(\omega)$ is increasing in ω. We know from the last case that $\Delta_B(\widehat{c}) < 0$. Observing that $\Delta_B(\overline{c}) = \sigma(3\tau + 2\sigma)/18\tau > 0$, we conclude that $\exists\ \beta \in (\widehat{c}, \overline{c})$ such that $\Delta_B(\omega) \gtreqless 0 \Leftrightarrow \omega \gtreqless \beta$. Standard computations show that

$$\beta \equiv 2\overline{c}\tau/(3\tau + \sigma) + \sigma(\underline{c} + \overline{c})/3(3\tau + \sigma) + \underline{c}/3 \tag{32}$$

Case 2 $\sigma \leq (3/4)\tau$: For this case, by Prop 2, $\Pi_B^S(\omega)$ and $\Delta_B(\omega)$ are the same as in Subcase 1(b) for all $\omega \in (\underline{c}, \overline{c})$. From Subcase 1(b), we know that $\Delta_B(\overline{c}) > 0$. Noting that $\Delta_B(\underline{c}) = -\sigma(6\tau + \sigma)/18\tau < 0$, we conclude that $\exists\ \beta \in (\underline{c}, \overline{c})$ [given in (32)] such that $\Delta_B(\omega) \gtreqless 0 \Leftrightarrow \omega \gtreqless \beta$.

The result for $\sigma > (3/4)\tau$ follows from Subcases 1(a)-(b) and for $\sigma \leq (3/4)\tau$, it follows from Case 2. ■

Proof of Proposition 4 (I) We prove (I) from Lemma A3 by showing that $\alpha < \beta$. Denote $\sigma := \overline{c} - \underline{c}$. First let $\sigma > 3(2 - \sqrt{2})\tau/2 > (3/4)\tau$. Then by Case 1 of the proof Lemma A3(II), $\beta > \widehat{c}$ and by subcases [1(a)(ii)]-[1(b)(ii)] and (31) of the proof of Lemma A3(I), $\alpha = \widehat{\alpha} < \widehat{c}$. Hence $\beta > \alpha$. Next consider $\sigma \leq 3(2 - \sqrt{2})\tau/2$. Then by (31), $\alpha = \widetilde{\alpha}$. By (30) and (32) we have $\beta - \widetilde{\alpha} = \sigma(9\tau^2 + \sigma^2)/3(9\tau^2 - \sigma^2) > 0$.

(II) To prove (II), we consider the following possible cases.

Case 1 $\sigma > (3/4)\tau$:

Subcase 1(a) $\omega \in (\underline{c}, \widehat{c})$: For this case, from Prop 2, the SPNE prices in $\Gamma^S(\omega)$ are

$$p_A^S(\omega) = (3\tau + \underline{c} + \omega)/2 \text{ and } p_B^S(\omega) = (5\tau + 3\underline{c} + \omega)/4.$$

From Prop 3, the SPNE prices in $\Gamma^T(\omega)$ are $p_A^T(\omega) = p_B^T(\omega) = \tau + \omega$. Hence $p_A^S(\omega) - p_A^T(\omega) = (\tau + \underline{c} - \omega)/2 > 0$ and $p_B^S(\omega) - p_B^T(\omega) = (\tau + 3\underline{c} - 3\omega)/4 \gtreqless 0 \Leftrightarrow \omega \lesseqgtr \tau/3 + \underline{c}$. Note from (25) that $\widehat{c} \equiv 4\overline{c}/3 - \underline{c}/3 - \tau$. Hence $(\tau/3 + \underline{c}) - \widehat{c} = (4/3)(\tau + \underline{c} - \overline{c}) > 0$. Therefore, for all $\omega \in (\underline{c}, \widehat{c})$, we have $\omega < (\tau/3 + \underline{c})$ and hence that $p_B^S(\omega) > p_B^T(\omega)$. Consequently for this case all consumers prefer technology transfer over outsourcing.

Subcase 1(b) $\omega \in [\widehat{c}, \overline{c})$: Note from Prop 2 that for this case the SPNE prices in $\Gamma^S(\omega)$ are the same as in the case of no contracts. Therefore, comparing outsourcing and technology transfer for consumers is the same as comparing technology transfer with no contracts and we can use the results of Prop 3 (III)(a).

Since $\underline{\theta} = (2\underline{c} + \overline{c})/3$ and $\widehat{c} = 4\overline{c}/3 - \underline{c}/3 - \tau$, we have $\underline{\theta} - \widehat{c} = \tau + \underline{c} - \overline{c} > 0$, i.e., $\underline{\theta} > \widehat{c}$. From Prop 2(III)(a), it then follows that (i) if $\omega \in [\widehat{c}, \underline{\theta})$, then all consumers prefer technology transfer over outsourcing, (ii) if $\omega \in (\overline{\theta}, \overline{c})$, then all consumers prefer outsourcing over technology transfer and (iii) if $\omega \in [\underline{\theta}, \overline{\theta}]$, there is $\lambda(\omega) \in (0, 1/2]$ such that consumers at $x \in [0, \lambda]$ prefer technology transfer and $x \in (\lambda, 1]$ prefer outsourcing. Combining the conclusions of Subcases 1(a)-(b), the proof for the case of $\sigma > (3/4)\tau$ is complete.

Case 2 $\sigma \leq (3/4)\tau$: For this case, for all $\omega \in (\underline{c}, \overline{c})$, the SPNE prices in $\Gamma^S(\omega)$ are the same as in the case when there are no contracts. The result then follows directly from Prop 3(III)(a).

(III) The result will follow from (I)-(II) if we can show that $\alpha < \underline{\theta} < \beta < \overline{\theta}$. Note from (31) that if $\sigma > 3(2 - \sqrt{2})\tau/2 > (3/4)\tau$, then $\alpha = \widehat{\alpha} < \widehat{c}$. Since $\underline{\theta} > \widehat{c}$, for this case, we have $\underline{\theta} > \alpha$. Next consider $\sigma \leq 3(2-\sqrt{2})\tau/2$. Then by (31), $\alpha = \widetilde{\alpha}$. By (30) we have $\underline{\theta} - \widetilde{\alpha} = \sigma^2/3(3\tau - \sigma) > 0$. From (32) and (28), it follows that $\overline{\theta} - \beta = \sigma^2/3(3\tau + \sigma) > 0$ and $\beta - \underline{\theta} = \tau\sigma/(3\tau + \sigma) > 0$. This completes the proof of Proposition 4. ■

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