Partial Equity Ownership and Knowledge Transfer

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Abstract

When firms form an alliance, it often involves one firm acquiring an equity stake in its alliance partner. Such an alliance lessens the competition, but induces knowledge transfer within the alliance. This paper explores oligopoly models that capture this important link between partial equity ownership (PEO) and knowledge transfer. We consider an industry consisting of three firms, where firm 1 has superior knowledge that other firms in the industry do not have. Firms 1 and 2 have an option of forming an equity strategic alliance in which firm 1 owns a fraction of firm 2's share. The equilibrium level of PEO is endogenously determined in our model. Previous theoretical models of PEO, in which the levels of PEO are exogenously given, have shown that PEO arrangements would decrease welfare by reducing the degree of competition in the industry. We demonstrate that endogenously determined levels of PEO can increase welfare under a range of parameterizations. Our analysis indicates that there are three relevant policy interventions (prohibit PEO, partially permit PEO, or permit PEO) for antitrust authorities to maximize welfare, and shows that any one of the three can be optimal depending on parameterizations.

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1 Introduction

A strategic alliance exists when two or more independent organizations cooperate in the development, manufacturing, or sale of products or services (Barney, 2002). In recent years, the incidence and importance of inter-firm collaborations has substantially increased (Caloghirou, Ioannides and Vonortas, 2003). Strategic alliances are accompanied by partial equity ownership in many cases. Recent examples of such strategic alliances, often called equity strategic alliances, are listed below:[1]

• In March 2007, Citigroup and Nikko Cordial announced the formation of a strategic alliance. Citigroup, after acquiring a 4.9% stake in Nikko, will help its partner develop a strategic solution through transferring considerable know-how and expertise in principal investments and private equity.

• In April 2004, Harvey World Travel announced its plan to take an initial 11% equity holding in Webjet, an internet travel business specialist. Webjet's Managing Director, David Clarke, said that the arrangement would provide Webjet with a strategic development partner which would enhance Webjet's ability to capitalise on opportunities in a rapidly changing travel market in the Australian region.

• In December 2000, Vodafone announced that it would acquire a 15% stake in Japan Telecom for Yen 249 billion. The Chairman of Japan Telecom said that, under this strategic alliance, his company would benefit from Vodafone's global leadership in mobile communications, access to world-wide technology, content and expertise.

It has been widely recognized in the strategic management literature that one of the most fundamental objectives of strategic alliances is the transfer of knowledge and technology between partner firms.[2] Knowledge transfer can be facilitated through licensing and contracting in some cases. However, knowledge is often tacit, and in situations where this is the case licensing and contracting can play, at best, limited roles.[3] Instead, equity ownership

[1]Details are available, respectively, from http://www.citigroup.com/citigroup/press/2007/070306a.htm, http://www.webjet.com.au/about/webjet-to-enter-major-commercial-and-equity-alliance-with-harvey-world-travel-limited/,
http://www.vodafone.com/start/media_relations/news/group_press_releases/2000/press_release20_12.html

[2]See Hamel, 1991; Mowery, Oxley and Silverman, 1996; Gomes-Casseres, Hagedoorn and Jaffe, 2006; Oxley and Wada, 2009. Gomes-Casseres et al. (2006), for example, hypothesized that knowledge flows between alliance partners would be greater than flows between pairs of nonallied firms, and found empirical results that are consistent with this hypothesis.

[3]See, for example, Teece, 1981; Kogut, 1988; Kogut and Zander, 1992; Mowery et al., 1996; Inkpen, 1998.

can play a critical role in facilitating the transfer of tacit knowledge. Using patent citations as a proxy for knowledge flows, Mowery, Oxley and Silverman (1996) and Gomes-Casseres, Hagedoorn and Jaffe (2006) empirically explored effects of equity ownership between alliance partners on the extent of knowledge flow. Empirical results of both studies supported the hypothesis that equity ownership enhances the extent of knowledge flow between alliance partners.[4,5]

Partial equity ownership (PEO) induces knowledge transfer between alliance partners. This paper explores oligopoly models that capture this important link between PEO and knowledge transfer. We consider an industry consisting of three firms, where firm 1 has superior knowledge that other firms in the industry do not have. The knowledge is tacit and not contractible. Firms 1 and 2 have an option of forming an equity strategic alliance in which firm 1 owns a fraction $\theta \in [0, 1]$ of firm 2's share, while firm 3 is assumed to be independent.

Firm 2's profit increases if firm 1 transfers its superior technological knowledge to firm 2. But, a fraction θ of firm 2's profit belongs to firm 1, and this in turn gives firm 1 an incentive to transfer its knowledge. The equilibrium level of PEO, θ^*, is endogenously determined through the following trade-off. On the one hand, a higher θ increases the incentive for firm 1 to transfer its knowledge, and weakens the degree of competition between firms 1 and 2. This works to the alliance partners' advantage. On the other hand, a higher θ reduces the alliance partners' competitive position against other firms outside the alliance. This works to the alliance partners' disadvantage. Given this trade-off, the alliance partners choose the optimal level of θ that maximizes their joint profits.

PEO arrangements among competitors alter their competitive incentives. The competitive effects of PEO have been previously studied in the context of static oligopoly as well

[4]Both studies used Cooperate Agreements and Technology Indicators (CATI) database developed by the Maastricht Economic Research Institute in Technology (MERIT) to identify alliances of firms. Mowery et al. (1996) focused on bilateral alliances that involved at least one U.S. firm and were established during 1985 and 1986, and the patent data were drawn from the Micropatent data base, which contains all information recorded on the front page of every patent granted in the U.S. since 1975. Gomes-Casseres et al. (2006) matched the firms in the CATI database to the NBER Patent Citations Data File. They used only alliance and patent data from information technology sectors, and analyzed citations on an annual basis from 1975 to 1999.

[5]See also Ono, Nakazato, Davis, and Alley (2004) for an empirical evidence from Japanese automobile industry. They also put forth theoretical framework incorporating POA and technology transfer, but they did not derive the equilibrium of the model by solving it.

as repeated oligopoly models, in which the levels of PEO are exogenously given (see Section 2 for details). To the best of our knowledge, however, no previous papers have explicitly analyzed the process in which PEO induces knowledge transfer between competing firms. The present paper fills this important gap in the literature by exploring a model in which the level of PEO is endogenously determined through the link between PEO and knowledge transfer. Focusing on the competitive effect, existing theoretical models of PEO demonstrate that PEO arrangements could decrease welfare by reducing the degree of competition in the industry. This result suggests that antitrust authorities should consider the trade-off between enhanced production efficiency and reduced competition in cases of PEO. Our analysis indicates that endogenously determined levels of PEO may increase or decrease welfare, and identifies a range of parameterizations under which PEO increases (or decreases) welfare. We then consider three relevant policy interventions (prohibit PEO, partially permit PEO, or permit PEO) for antitrust authorities to maximize welfare, and show that any one of the three can be optimal depending on parameterizations.

Cases of PEO in a competitor have gone mostly unchallenged by antitrust agencies (see Gilo, 2000). However, antitrust agencies have recently begun to pay increasing attention to the possible antitrust harms of PEO. For example, Deborah Platt Majoras, the then Deputy Assistant Attorney General of the Antitrust Division of the U.S. Department of Justice, mentioned in her speech given in April 2002 that PEO can raise antitrust issues when the two companies or their subsidiaries are competitors. Also, several legal scholars have argued that PEO, even if it is not accompanied by control/influence rights, results in antitrust harms in oligopolistic industries, by reducing quantities and raising prices (Gilo, 2000; O'Brien and Salop, 2000, 2001). Their arguments are consistent with the previous literature on economic theoretical analyses of PEO, in which the level of PEO is exogenously assumed. In contrast, by exploring the link between PEO and knowledge transfer, our analysis yields richer policy implications as detailed in Section 5.

The remainder of the paper is organized as follows. Section 2 discusses this study's relationship to the literature. Section 3 explores the link between PEO and knowledge transfer under the linear homogeneous demand, and demonstrates that the endogenously determined level of PEO can improve welfare under a range of parameterizations. Section 4 explores the robustness of our findings under differentiated oligopoly models, and Section 5 elaborates on policy implications of our findings. Section 6 offers concluding remarks.

2 Relationship to the literature

PEO arrangements among competitors alter their competitive incentives. The competitive effect of PEO have been previously studied in the context of static oligopoly as well as repeated oligopoly models. Reynolds and Snapp (1986), in their seminal contribution to theoretical analyses of PEO, analyzed a modified Cournot oligopoly model consisting of n firms that produce the homogeneous product with the same constant marginal cost c. The n firms are linked by PEO, where each firm i holds ownership interest v_{ik} in firm k. Ownership interests are not accompanied by any decision making rights in the sense that each firm i determines the amount of its own production under any PEO structures. The levels of PEO (the values of v_{ik}, $i = 1, ..., n$, $k = 1, ..., n$, $i \neq k$) are exogenously given in their model.[6] Under the model outlined above, Reynolds and Snapp showed that, if one or more Cournot competitors increase the level of ownership links with rival firms, equilibrium market output will decline. That is, they demonstrated that, in markets where entry is difficult, PEO could result in less output and higher prices because PEO arrangements reduce the degree of competition among participants by linking their profitability.[7]

Could firms increase their profitability by linking themselves through PEO? Consider PEO between firms 1 and 2 under the modified Cournot oligopoly model analyzed by Reynolds and Snapp (1986), where other $n-2$ firms have no PEO arrangements. As pointed out by Reitman (1994), the equilibrium joint profit of firms 1 and 2 decline under any levels of PEO for all $n \geq 3$, where the result is similar to the finding of Salant, Switzer and Reynolds (1983) for merger.[8] Reitman (1994) showed, using a conjectural variations model, that with conjectures that lead to more rivalrous equilibria than Cournot, there exist individually rational PEO arrangements with any number of firms in the industry.

[6]More precisely, Reynolds and Snapp make a distinction between firms and plants, where firms are profit-maximizing decision-making units that control plants. Each firm i owns the decision-making right of plant i. In addition to its own share (which is $1 - \sum_{k \neq i} v_{ki}$) of plant i's profit, each firm i also receives v_{ik} share of plant k's ($k \neq i$) profit.

[7]Drawing on the work of Reynolds and Snapp (1986), Bresnahan and Salop (1986) devised a Modified Herfindahl-Hirshman Index (MHHI) to quantify the competitive effects of horizontal joint ventures under a number of alternative financial interest and control arrangements. Also, Kwoka (1992) analyzed the output and profit effects of horizontal joint ventures under a conjectural variations model in which a joint venture constitutes a new producer rather than replaces an existing firm.

[8]Salant, Switzer and Reynolds showed, under a Cournot oligopoly model with a linear demand and symmetric constant marginal costs across all n firms, that horizontal mergers can be profitable only if more than 80 percent of the firms merge. Then, mergers between two firms are not profitable for any $n \geq 3$.

Farrell and Shapiro (1990) showed that, under the Cournot oligopoly model with homogeneous goods, PEO arrangements between two firms can increase their equilibrium joint profit if their production efficiency is different. Suppose that firm 1 holds a share, α, of the stock of firm 2, and each firm j (=2, ..., n) holds no PEO in other firms. As firm 1 increases its stake α in firm 2, firm 1 reduces its output while all other firms increase their outputs in the equilibrium. This is because, as α increases, firm 1 is increasingly willing to sacrifice profits at its own facility in order to augment profits at firm 2. Farrell and Shapiro found that, if firm 1 is smaller than firm 2 (that is, if firm 1 is less cost efficient than firm 2), then a certain level of PEO α increases the joint equilibrium profit of firms 1 and 2, because a larger fraction of their output is produced under more cost-efficient production facility, firm 2. Note, however, that in practice, we often see the reverse: a big firm buys part of a smaller firm, as acknowledged by Farrell and Shapiro.[9] They also showed that the PEO α may increase total surplus as well when firm 1 is smaller than firm 2.

How would PEO affect the ability of firms to engage in tacit collusion? Malueg (1992) addressed this question by considering a repeated symmetric Cournot duopoly model in which the firms hold identical stakes in one another (cross ownership), and showed that increasing the degree of cross ownership may decrease the ease or likelihood of collusion. Investigating a family of demand functions, Malueg found that the curvature of the demand function can alter the possibilities for collusion. Gilo, Moshe and Spiegel (2006) addressed this question under more general setup. They considered a repeated Bertrand oligopoly model consisting of n firms in which firms and/or their controllers acquire some of their rivals' nonvoting shares. The n firms need not have similar stakes in one another in their model. Gilo et al. established necessary and sufficient conditions for PEO arrangements to facilitate tacit collusion and also examined how tacit collusion is affected when firms' controllers make direct passive investments in rival firms.

In the literature on theoretical analyses of PEO arrangements, several papers have pointed out the link between PEO and knowledge transfer. For example, Roynolds and Snapp (1986) pointed out that PEO offers a means for appropriating the returns to technology transfer. Also, Reitman (1994) argued that PEO arrangements may be beneficial to society if they encourage firms to exchange expertise or assets that would otherwise not be made available. However, to the best of our knowledge, no previous papers have explicitly analyzed the process in which PEO induces knowledge transfer between competing firms. The present

[9]Farrell and Shapiro pointed out that in their framework, such purchases will be profitable only if firm 1 gains control over firm 2's actions.

paper fills this important gap in the literature by exploring a model in which the level of PEO is endogenously determined through the link between PEO and knowledge transfer.

3 PEO and knowledge transfer

3.1 The model

Consider an industry consisting of three firms that produce a homogenous product. The industry faces a linear inverse demand given by $P(Q) = a - dQ$ $(a > 0,\ d > 0)$ where Q denotes the industry output. Let p_i and q_i denote each firm i's $(i = 1,\ 2,\ 3)$ price and quantity, respectively. Each firm i's cost for producing q_i (> 0) units of the product is $c_i q_i$ where c_i (> 0) denotes firm i's constant marginal cost. Compared to firms 2 and 3, firm 1 has a cost advantage due to its superior knowledge that other firms do not have.

Firms 1 and 2 have an option to form an equity alliance. In particular, they negotiate and jointly choose the level of firm 1's ownership in firm 2's equity, denoted θ $(0 \leq \theta \leq 1)$, and the monetary terms of the equity transfer. Given θ, firm 1 determines whether or not to transfer its superior knowledge to firm 2. Assume that firms' constant marginal costs are given by $c_1 = c - x < c_2 = c_3 = c$ without knowledge transfer, where $c > x > 0$. If firm 1 transfers its knowledge to firm 2, then $c_1 = c_2 = c - x < c_3 = c$. Note that x captures firm 1's cost advantage due to its superior knowledge, and that firm 1 can reduce firm 2's cost from c to $c - x$ by transferring its knowledge. We assume that firm 3 is independent and cannot form alliances.

We consider the three-stage game described below:

Stage 1 [Alliance formation]: Firms 1 and 2 negotiate and jointly choose the level of firm 1's ownership in firm 2's equity, denoted θ $(0 \leq \theta \leq 1)$, and the monetary terms of the equity transfer. The level of θ becomes common knowledge.

Stage 2 [Knowledge transfer]: Firm 1 determines whether or not to transfer its superior knowledge to firm 2. Firms' constant marginal costs are given by $c_1 = c_2 = c - x < c_3 = c$ if knowledge is transferred, and by $c_1 = c - x < c_2 = c_3 = c$ otherwise, where $c > x > 0$.

Stage 3 [Cournot competition]: Whether or not firm 1 transferred its knowledge to firm 2 becomes common knowledge, and hence every firm knows (c_1, c_2, c_3). If $\theta \in [0, \frac{1}{2}]$, each firm i simultaneously and non-cooperatively chooses q_i to maximize its profit. If $\theta \in (\frac{1}{2}, 1]$, firm 1 chooses q_1 and q_2 and firm 3 chooses q_3, simultaneously and non-cooperatively, to maximize their own profits.

3.2 Analysis

We derive Subgame Perfect Nash Equilibria (SPNE) in pure strategies of the model described above. Define variable $k \in \{0, 1\}$ by $k = 1$ if firm 1 transferred knowledge to firm 2 at Stage 2 and $k = 0$ otherwise, and recall that $\theta \in [0, 1]$ denotes the level of firm 1's equity ownership in firm 2. Every Stage 3 subgame can then be represented by (θ, k). Each firm i's $(i = 1, 2, 3)$ profit, denoted by $\pi_i(\theta, k, q_1, q_2, q_3)$, is given by

$$\begin{aligned}
\pi_1(\theta, k, q_1, q_2, q_3) &= [P(Q) - (c - x)]q_1 + \theta[P(Q) - (c - kx)]q_2, \\
\pi_2(\theta, k, q_1, q_2, q_3) &= (1 - \theta)[P(Q) - (c - kx)]q_2, \\
\pi_3(\theta, k, q_1, q_2, q_3) &= [P(Q) - c]q_3.
\end{aligned} \tag{1}$$

Throughout the analysis in this section, we make the following assumption.

Assumption 1: $x < \frac{a-c}{2}$.

This is the necessary and sufficient condition for each firm i to produce a strictly positive amount of the product in the quilibrium of the Stage 3 subgame for any given (θ, k). Note, all proofs are presented in the Appendix.

Consider equilibria of Stage 3 subgames. Let $q_i^*(\theta, k)$ and $\pi_i^*(\theta, k)$ respectively denote firm i's quantity and profit in the equilibrium of the Stage 3 subgame represented by (θ, k). Suppose $\theta \in [0, \frac{1}{2}]$. Then, at Stage 3, each firm i simultaneously and non-cooperatively chooses q_i to maximize $\pi_i(\theta, k, q_1, q_2, q_3)$. Through a standard analysis of Cournot competition, we find that the equilibrium is unique for any given (θ, k), where the equilibrium quantities are given by

$$\begin{aligned}
q_1^*(\theta, k) &= \frac{(1 - \theta)(a - c) + [3 - (1 + 2\theta)k]x}{d(4 - \theta)}, \\
q_2^*(\theta, k) &= \frac{a - c - (1 - 3k)x}{d(4 - \theta)}, \\
q_3^*(\theta, k) &= \frac{a - c - x - (1 - \theta)kx}{d(4 - \theta)},
\end{aligned} \tag{2}$$

and each firm i's equilibrium profit is given by

$$\pi_i^*(\theta, k) = \pi_i(\theta, k, q_1^*(\theta, k), q_2^*(\theta, k), q_3^*(\theta, k)). \tag{3}$$

Next consider Stage 3 subgames with $\theta \in (\frac{1}{2}, 1]$. In this class of Stage 3 subgames, firm 1 chooses q_1 and q_2 to maximize $\pi_1(\theta, k, q_1, q_2, q_3)$. Note that firm 2 cannot be more cost effective than firm 1. Then, since firms 1 and 2 produce a homogeneous product, firm 1 cannot be strictly better off by producing a strictly positive quantity at firm 2. Given this, for expositional simplicity we make a tie-breaking assumption that, if firm 1 is indifferent between shutting down and not shutting down firm 2, firm 1 chooses to shut down firm 2. We then find that the equilibrium of any Stage 3 subgame with $\theta \in (\frac{1}{2}, 1]$ is unique, where the equilibrium quantities are given by $q_1^*(\theta, k) = \frac{a-c+2x}{3d}$, $q_2^*(\theta, k) = 0$, and $q_3^*(\theta, k) = \frac{a-c-x}{3d}$, and each firm i's equilibrium profit is given by (3).

We next consider firm 1's optimal decision at Stage 2 in Stage 2 subgames. Given θ, firm 1 decides whether or not to transfer its knowledge to firm 2 (that is, $k = 1$ or 0) in order to maximize its profit in the subsequent Stage 3 subgame $\pi_1^*(\theta, k)$. If $\theta \in (\frac{1}{2}, 1]$, firm 1 shuts down firm 2 in the equilibrium of the subsequent Stage 3 subgame as mentioned above, and hence firm 1 is indifferent between transferring and not transferring its knowledge at Stage 2. For expositional simplicity, we assume that firm 1 chooses not to transfer its knowledge (i.e., $k = 0$) in this case. Now suppose $\theta \in [0, \frac{1}{2}]$. Firm 1 transfers its knowledge to firm 2 if and only if $\pi_1^*(\theta, 1) - \pi_1^*(\theta, 0) > 0$. We obtain Lemma 1.

Lemma 1: Consider firm 1's decision at Stage 2 in the equilibrium of the Stage 2 subgame.
(i) Suppose $0 < x \leq 0.1875(a - c)$. Then there exists a unique value $\hat{\theta}(x) \in (0, \frac{1}{2}]$ such that firm 1 transfers knowledge to firm 2 if and only if $\theta \in [\hat{\theta}(x), \frac{1}{2}]$, where $\hat{\theta}(x)$ is strictly increasing in x.
(ii) Suppose $0.1875(a - c) < x < \frac{1}{2}(a - c)$. Then firm 1 does not transfer knowledge to firm 2 for any $\theta \in [0, \frac{1}{2}]$.

(**Figure 1 to be inserted here**)

By transferring its knowledge, firm 1 loses its competitive advantage over firm 2, but a fraction θ of firm 2's profit belongs to firm 1. Lemma 1 tells us that firm 1 chooses to transfer its knowledge if θ is sufficiently high so that $\theta \in [\hat{\theta}(x), \frac{1}{2}]$ holds, where $\hat{\theta}(x)$ is the minimum PEO that induces knowledge transfer. As x increases, firm 1's loss of its competitive advantage through knowledge transfer becomes more substantial, and hence a higher level of PEO is necessary for firm 1 to have an incentive to transfer its knowledge to firm 2. That is, $\hat{\theta}(x)$ is increasing in x. And, once x exceeds $0.1875(a - c)$, firm 1 has no incentive to transfer its knowledge for any given $\theta \in [0, \frac{1}{2}]$.

At Stage 1, firms 1 and 2 jointly determine the level of θ to maximize their joint profit in the subsequent equilibrium. They anticipate that firm 1 will transfer knowledge to firm

2 if and only if $\theta \in [\hat{\theta}(x), \frac{1}{2}]$. The following lemma is useful for deriving the equilibrium of the entire game. In what follows, let $\pi^*_{12}(\theta, k) \equiv \pi^*_1(\theta, k) + \pi^*_2(\theta, k)$ denote the joint profit of firms 1 and 2 in the equilibrium of the Stage 3 subgame represented by (θ, k).

Lemma 2: For any given k $(\in \{0, 1\})$, $\pi^*_{12}(\theta, k)$ is strictly decreasing in θ for all $\theta \in [0, \frac{1}{2}]$, and constant for all $\theta \in (\frac{1}{2}, 1]$. Furthermore, for any given $\theta' \in (\frac{1}{2}, 1]$, (i) $\pi^*_{12}(\frac{1}{2}, 1) > \pi^*_{12}(\theta', 1)$ holds for all $x \in (0, \frac{a-c}{2})$, and (ii) $\pi^*_{12}(0, 0) > (=, <)\ \pi^*_{12}(\theta', 0)$ holds if $x < (=, >)\ 0.0769(a-c)$.

First consider $\pi^*_{12}(\theta, 1)$, where $k = 1$ so that $c_1 = c_2 = c - x$. PEO reduces the degree of competition between firms 1 and 2 and eliminates the competition when $\theta \in (\frac{1}{2}, 1]$. This effect works in the direction of increasing the joint profit of firms 1 and 2. At the same time, weaker competition between firms 1 and 2 induces firm 3 to take more aggressive strategy, and this effect works in the direction of decreasing the joint profit of firms 1 and 2. Lemma 2 tells us that the latter effect dominates the former effect for all $\theta \in (0, 1]$, where both effects get stronger as θ increases. See Figure 2-1.

Next consider $\pi^*_{12}(\theta, 0)$, where $k = 0$ so that $c_1 = c - x < c_2 = c$. An increase in θ within the interval $[0, \frac{1}{2}]$ shifts outputs from firm 1 to firm 2. Given $c_1 = c - x < c_2 = c$, this effect works in the direction of reducing the joint profit, and, combined with the two effects mentioned above, yields the same qualitative result as the one for $\pi^*_{12}(\theta, 1)$ in $\theta \in [0, \frac{1}{2}]$. That is, $\pi^*_{12}(\theta, 0)$ is strictly decreasing in θ for all $\theta \in [0, \frac{1}{2}]$. When $\theta \in (\frac{1}{2}, 1]$, firm 1 shuts down the operation of firm 2. Since all output is shifted to the cost efficient firm (firm 1), the joint profit $\pi^*_{12}(\theta, 0)$ discontinuously increases when θ increases from $\frac{1}{2}$ to $\theta \in (\frac{1}{2}, 1]$ (see Figure 2-2). The improvement of cost efficiency becomes more substantial as x increases, and we find that $\pi^*_{12}(\theta', 0) > \pi^*_{12}(0, 0)$ where $\theta' \in (\frac{1}{2}, 1]$ if and only if $x > 0.0769(a - c)$.

(**Figure 2-1 and 2-2 to be inserted here**)

We are now ready to derive the equilibrium of the entire game. First suppose $0.1875(a - c) < x < \frac{1}{2}(a - c)$. Lemma 1 tells us that firm 1 does not transfer knowledge to firm 2 at Stage 2 for any given $\theta \in [0, 1]$ in this case. Anticipating this, at Stage 1 firms 1 and 2 jointly choose θ that maximizes their joint profit without knowledge transfer, $\pi^*_{12}(\theta, 0)$, and Lemma 2 tells us that $\theta = (\frac{1}{2}, 1]$ maximizes the value of $\pi^*_{12}(\theta, 0)$. For expositional simplicity, we assume that firms 1 and 2 choose $\theta = 1$ and interpret this as their merger. That is, merger is the joint optimal decision of firms 1 and 2 in this case.

Next suppose $0 < x \leq 0.1875(a-c)$. In this case, Lemma 1 tells us that firms 1 and 2 can induce knowledge transfer by choosing $\theta \in [\hat{\theta}(x), \frac{1}{2}]$ at Stage 1. Lemma 2 tells us that $\pi_{12}^*(\theta, 1)$ is strictly decreasing in θ for all $\theta \in [\hat{\theta}(x), \frac{1}{2}]$, and hence firms 1 and 2 choose $\theta = \hat{\theta}(x)$ if they intend to induce knowledge transfer from firm 1 to firm 2. Under this option, their joint profit is $\pi_{12}^*(\hat{\theta}(x), 1)$. At the same time, they have an option of not inducing knowledge transfer. Under this option, firms 1 and 2 choose $\theta = 0$ if $x \in (0, 0.0769(a-c)]$ and chooses $\theta \in (\frac{1}{2}, 1]$ otherwise. This leads us to Proposition 1.

Proposition 1 [Equilibrium characterization]: For any given $x \in (0, 0.5(a-c))$, there exists a unique value $\theta^*(x)$ such that actions taken by firms 1 and 2 in the unique equilibrium of the game are described as follows:
(i) Suppose $0 < x \leq 0.00495(a-c)$. Then firms 1 and 2 choose $\theta = \theta^*(x) \equiv 0$ at Stage 1 and firm 1 does not transfer its knowledge to firm 2 at Stage 2.
(ii) Suppose $0.00495(a-c) < x \leq 0.188(a-c)$. Then firms 1 and 2 choose $\theta = \theta^*(x) \equiv \hat{\theta}(x)$ at Stage 1 and firm 1 transfers its knowledge to firm 2 at Stage 2, where $\theta^*(x)$ is strictly positive and strictly increasing in x for all $x \in (0.00495(a-c), 0.188(a-c)]$ with $\theta^*(0.188(a-c)) = \frac{1}{2}$.
(iii) Suppose $0.188(a-c) < x < 0.5(a-c)$. Then firms 1 and 2 choose $\theta = \theta^*(x) \equiv 1$ (that is, they choose to merge) at Stage 1.

The logic behind Proposition 1 can be explained as follows. Suppose firms 1 and 2 choose $\theta = 0$ $(< \hat{\theta}(x))$ at Stage 1. Then, firm 1's knowledge is not transferred to firm 2 (that is, $k = 0$) at Stage 2, and their joint profit is $\pi_{12}^*(0, 0)$ in the subsequent equilibrium. In order to induce knowledge transfer, the level of PEO should be increased from 0 to $\hat{\theta}(x)$. Firms 1 and 2 prefer $\theta = \hat{\theta}(x)$ to $\theta = 0$ if $\pi_{12}^*(\hat{\theta}(x), 1) - \pi_{12}^*(0, 0) \geq 0$, where $\pi_{12}^*(\hat{\theta}(x), 1) - \pi_{12}^*(0, 0)$ can be decomposed into knowledge transfer effect and PEO effect as follows:

$$\pi_{12}^*(\hat{\theta}(x), 1) - \pi_{12}^*(0, 0) = \underbrace{[\pi_{12}^*(\hat{\theta}(x), 1) - \pi_{12}^*(\hat{\theta}(x), 0)]}_{knowledge\ transfer\ effect} + \underbrace{[\pi_{12}^*(\hat{\theta}(x), 0) - \pi_{12}^*(0, 0)]}_{PEO\ effect}.$$

The knowledge transfer effect is positive. That is, holding the level of PEO fixed at $\theta = \hat{\theta}(x)$, knowledge transfer increases the joint profit of firms 1 and 2. The PEO effect can be regarded as the cost that firms 1 and 2 jointly incur in order to induce knowledge transfer, since an increase of θ from 0 to $\hat{\theta}(x)$ holding $k = 0$ fixed decreases their joint profit. That is, the PEO effect is negative. We find that $\lim_{x \to 0} \hat{\theta}(x) > 0$. This implies that the PEO effect does not approach zero as x approach zero, where $\lim_{x \to 0}[\pi_{12}^*(\hat{\theta}(x), 0) - \pi_{12}^*(0, 0)] < 0$. In contrast, the knowledge transfer effect decreases as x decreases, and approaches zero as

x approaches zero. Hence, when x is small enough, we have $\pi_{12}^*(\hat{\theta}(x), 1) - \pi_{12}^*(0, 0) < 0$ and so firms 1 and 2 prefer $\theta = 0$ to $\theta = \hat{\theta}(x)$.

An increase in x increases the knowledge transfer effect as well as the magnitude of the PEO effect. We find that the knowledge transfer effect dominates the PEO effect if x is large enough to satisfy $x \in (0.00495(a-c), 0.1875(a-c)]$, where firms 1 and 2 choose $\theta = \hat{\theta}(x)$ over $\theta = 0$. And, once x exceeds $0.1875(a-c)$, no PEO $\theta \in [0, \frac{1}{2}]$ can induce knowledge transfer. Lemma 2 then tells us that the relevant options for firms 1 and 2 at Stage 1 is $\theta = 0$ or $\theta = \hat{\theta}(x)$ if $0 < x \leq 0.0769(a-c)$, and $\theta = \hat{\theta}(x)$ or $\theta = 1$ if $0.0769(a-c) < x \leq 0.1875(a-c)$. Also, if $x > 0.1875(a-c)$, $\theta = 1$ maximizes their joint profit. This leads us to Proposition 1.

We now turn to welfare consequences of PEO. Let $CS(\theta)$ and $TS(\theta)$ respectively denote consumer surplus and total surplus in the equilibrium of the Stage 2 subgame represented by θ. We first compare $CS(\theta^*(x))$ and $CS(0)$. That is, we compare consumer surplus at the endogenously determined level of PEO $\theta = \theta^*(x)$ with consumer surplus at $\theta = 0$. We then compare $TS(\theta^*(x))$ and $TS(0)$. We have that $CS(\theta^*(x)) = CS(0)$ and $TS(\theta^*(x)) = TS(0)$ for all $x \in (0, 0.00495(a-c)]$, because $\theta^*(x) = 0$ and knowledge is not transferred in the equilibrium for all $x \in (0, 0.00495(a-c)]$. Given this, we focus on the case of $x \in (0.00495(a-c), 0.5(a-c))$ in what follows.

Proposition 2 [Consumer surplus]:
$CS(\theta^*(x)) < CS(0)$ holds for all $x \in (0.00495(a-c), 0.5(a-c))$.

Proposition 3 [Total surplus]:
(i) Suppose $0.00495(a-c) < x \leq 0.026(a-c)$. Then $TS(\theta^*(x)) \leq TS(0)$ holds, where equality holds if and only if $x = 0.026(a-c)$.
(ii) Suppose $0.026(a-c) < x \leq 0.188(a-c)$. Then $TS(\theta^*(x)) > TS(0)$ holds.
(iii) Suppose $0.188(a-c) < x \leq 0.226(a-c)$. Then $TS(\theta^*(x)) \leq TS(0)$ holds, where equality holds if and only if $x = 0.226(a-c)$.
(iv) $0.226(a-c) < x < 0.5(a-c)$. Then $TS(\theta^*(x)) > TS(0)$ holds.

(**Figure 3 to be inserted here**)

PEO decreases welfare by reducing the degree of competition in the industry. At the same time, PEO induces knowledge transfer, which can increase welfare. Proposition 3 tells us that the latter effect dominates the former effect under a range of parameterizations so that PEO can increase total surplus in our model. The standard intuition seems to suggest that an increase in the level of PEO decreases total surplus by weakening the degree of competition in the industry. To the contrary, however, we find that the equilibrium total surplus $TS(\theta^*(x))$ is increasing in the level of PEO. This is because, in our model, an increase in the level of PEO is driven by an increase in x, which works in the direction of increasing total surplus. We find that the endogenously determined level of PEO, $\theta^*(x)$, increases total surplus if and only if $\theta^*(x)$ is relatively high.

Regarding consumer surplus, Proposition 2 tells us that the endogenously determined level of PEO decreases consumer surplus in our model. In the next section, we show that PEO can increase consumer surplus under a differentiated oligopoly model.

4 An extension to differentiated oligopoly

In this section we explore the robustness of our findings under differentiated oligopoly models, and find some new results that did not arise in the previous section.

4.1 The model

In this extension, everything is the same as in the original model except for the demand structure. Consider an economy consisting of an imperfectly competitive sector with three firms, each producing a symmetrically differentiated product, and a competitive numeraire sector whose output is denoted by q_0. Each firm i (=1,2,3) produces product i, and let p_i and q_i denote respectively the price and quantity of product i.

There is a continuum of consumers of the same type, and the representative consumer's preferences are described by the utility function $U(q_1, q_2, q_3) + q_0$, where

$$U(q_1, q_2, q_3) \equiv a(q_1 + q_2 + q_3) - \frac{q_1^2 + q_2^2 + q_3^2}{2} - b(q_1q_2 + q_2q_3 + q_3q_1),$$

$a > 0$ and $b \in (0, 1]$. This yields linear inverse demands:

$$p_i = a - q_i - b(q_j + q_k), \qquad i, j, k \in \{1, 2, 3\}; i \neq j \neq k. \tag{4}$$

This is a standard specification of the representative consumer model, where the consumer prefers product variety (see, for example, Vives, 1999). The term b captures the degree of product differentiation in the market. As b increases, the degree of product differentiation decreases. Note that the case of the linear homogenous demand is nested as a special case of $b = 1$.

4.2 Analysis

We derive Subgame Perfect Nash Equilibria (SPNE) in pure strategies of the model described above. As in the original model, every Stage 3 subgame can be represented by (θ, k), where $k = 1$ if firm 1 transferred knowledge to firm 2 at Stage 2 and $k = 0$ otherwise. Each firm i's $(i = 1, 2, 3)$ profit, denoted by $\pi_i(\theta, k, q_1, q_2, q_3)$, is given by

$$\begin{aligned}\pi_1(\theta, k, q_1, q_2, q_3) &= [a - q_1 - b(q_2 + q_3) - (c - x)]q_1 + \theta[a - q_2 - b(q_3 + q_1) - (c - kx)]q_2, \\ \pi_2(\theta, k, q_1, q_2, q_3) &= (1 - \theta)[a - q_2 - b(q_3 + q_1) - (c - kx)]q_2, \\ \pi_3(\theta, k, q_1, q_2, q_3) &= [a - q_3 - b(q_1 + q_2) - c]q_3.\end{aligned} \tag{5}$$

Analogous to Assumption 1, we make Assumption 1'.

Assumption 1': $x < \frac{2-b}{2b}(a - c)$.

Let $q_i^*(\theta, k)$ and $\pi_i^*(\theta, k)$ respectively denote firm i's quantity and profit in the equilibrium of the Stage 3 subgame represented by (θ, k). Suppose $\theta \in [0, \frac{1}{2}]$. Then the equilibrium quantities are given by

$$\begin{aligned}q_1^*(\theta, k) &= \frac{[2 - b(1 + \theta)](a - c) + [2 + b - (b + \frac{2b}{2-b}\theta)k]x}{4 + 2b - (2 + \theta)b^2}, \\ q_2^*(\theta, k) &= \frac{(2 - b)(a - c) - [b - (2 + b)k]x}{4 + 2b - (2 + \theta)b^2}, \\ q_3^*(\theta, k) &= \frac{(2 - b)(a - c) - [b + \frac{b}{2-b}[2 - (1 + \theta)k]]x}{4 + 2b - (2 + \theta)b^2},\end{aligned} \tag{6}$$

and each firm i's equilibrium profit is given by

$$\pi_i^*(\theta, k) = \pi_i(\theta, k, q_1^*(\theta, k), q_2^*(\theta, k), q_3^*(\theta, k)). \tag{7}$$

Let $\pi_{12}^*(\theta, k) \equiv \pi_1^*(\theta, k) + \pi_2^*(\theta, k)$ as in the previous section.

In what follows, we proceed our analysis under specific values of parameter b, $b = 0.6$ and $b = 0.4$. We believe that the model can be fully analyzed under any given values of b. However, we have been unable to fully analyze the model without specifying the value of b because of algebraic complexity.

4.2.1 The case of $b = 0.6$

Assumption 1 becomes $x < 1.17(a-c)$ when $b = 0.6$. Let $\theta \in [0, \frac{1}{2}]$ be given, and consider firm 1's incentive to transfer its knowledge to firm 2. We obtain Lemma 1', which is qualitatively similar to Lemma 1.

Lemma 1' (b=0.6): Let $\theta \in [0, \frac{1}{2}]$ be given and consider firm 1's decision at Stage 2 in the equilibrium of the Stage 2 subgame. There exists a unique value $\hat{\theta}(x) \in (0, \frac{1}{2}]$ such that firm 1 transfers its knowledge to firm 2 if and only if $\theta \in [\hat{\theta}(x), \frac{1}{2}]$, where $\hat{\theta}(x)$ is strictly increasing in x with $\lim_{x\to 0} \hat{\theta}(x) \approx 0.236$ and $\lim_{x\to 1.17(a-c)} \hat{\theta}(x) \approx 0.446$.

Next we consider the level of θ that firms 1 and 2 choose to maximize their joint profit in the equilibrium.

Lemma 2' (b=0.6): There exists a unique value $\bar{\theta} \approx 0.384$ such that $\pi^*_{12}(\theta, 1)$ is strictly increasing in θ for all $\theta \in [0, \bar{\theta})$ and strictly decreasing in θ for all $\theta \in (\bar{\theta}, \frac{1}{2}]$. Furthermore, $\bar{\theta} \in (\hat{\theta}(x), \frac{1}{2})$ for all $x \in (0, 0.707(a-c))$ and $\bar{\theta} \leq \hat{\theta}(x)$ for all $x \in [0.707(a-c), 1.17(a-c))$.

(**Figure 4 to be inserted here**)

Suppose that firms 1 and 2 are confined to choose $\theta \in [\hat{\theta}(x), \frac{1}{2}]$ at Stage 1. Under the original model, we found that they choose $\theta = \hat{\theta}(x)$, which is the minimum PEO that induces knowledge transfer. Lemma 2' tells us, however, that this is not true when $b = 0.6$ and $x \in (0, 0.707(a-c))$. In this case, by choosing $\theta = \bar{\theta}$ ($> \hat{\theta}(x)$), firms 1 and 2 induce firm 1's knowledge transfer to firm 2 at Stage 2, where $\theta = \bar{\theta}$ is the level of PEO that maximizes their joint profit conditional upon knowledge transfer (see Figure 3). In contrast, if $x \in [0.707(a-c), 1.17(a-c))$, firms 1 and 2 choose $\theta = \hat{\theta}(x)$ as in the original model. This leads us to Proposition 1' below.

Proposition 1' (b=0.6) [Equilibrium characterization]: For any given $x \in (0, 1.17(a-c))$, there exists a unique value $\theta^*(x)$ such that actions taken by firms 1 and 2 in the unique equilibrium of the game are described as follows:
(i) Suppose $0 < x < 0.707(a-c)$. Then firms 1 and 2 choose $\theta = \theta^*(x) \equiv \bar{\theta} \approx 0.383$ at Stage 1 and firm 1 transfers its knowledge to firm 2 at Stage 2.
(ii) Suppose $0.707(a-c) \leq x < 1.17(a-c)$. Then firms 1 and 2 choose $\theta = \theta^*(x) \equiv \hat{\theta}(x)$ at Stage 1 and firm 1 transfers its knowledge to firm 2 at Stage 2, where $\theta^*(x)$ is strictly positive and strictly increasing in x for all $x \in (0.707(a-c), 1.17(a-c))$.

The key difference between $b = 0.6$ case and the original model is captured by (i). That is, when x is small enough satisfying $x \in (0, 0.707(a-c))$, firms 1 and 2 choose $\theta = \bar{\theta}$, which is strictly greater than $\hat{\theta}(x)$, the minimum PEO that induces knowledge transfer. In contrast, under the original model, firms 1 and 2 choose $\theta = \hat{\theta}(x)$ whenever knowledge is transferred in the equilibrium. This difference yields a novel policy implication as we elaborate in the next section.

We now turn to welfare consequences of PEO. As in the previous section, we compare $CS(\theta^*(x))$ and $CS(0)$ in Proposition 2' and compare $TS(\theta^*(x))$ and $TS(0)$ in Proposition 3'.

Proposition 2' (b=0.6) [Consumer surplus]:
(i) Suppose $0 < x \leq 0.083(a-c)$. Then $CS(\theta^*(x)) \leq CS(0)$ holds, where equality holds if and only if $x = 0.083(a-c)$.
(ii) Suppose $0.083(a-c) < x < 1.17(a-c)$. Then $CS(\theta^*(x)) > CS(0)$ holds.

Proposition 3' (b=0.6) [Total surplus]:
(i) Suppose $0 < x \leq 0.0203(a-c)$. Then $TS(\theta^*(x)) \leq TS(0)$ holds, where equality holds if and only if $x = 0.0203(a-c)$.
(ii) Suppose $0.0203(a-c) < x < 1.17(a-c)$. Then $TS(\theta^*(x)) > TS(0)$ holds.

(**Figure 5 to be inserted here**)

Propositions 2' and 3' tell us that, compared to the case of $\theta = 0$, the equilibrium PEO $\theta = \theta^*(x)$ can increase not only total surplus but also consumer surplus under differentiated oligopoly models. That is, the equilibrium PEO $\theta = \theta^*(x)$ decreases consumer suplus when x is relatively small and increases consumer surplus when x is relatively large, and analogous results hold for total surplus. Proposition 3' is qualitatively similar to proposition 3, while Proposition 2' is different from Proposition 2.

4.2.2 The case of $b = 0.4$

Assumption 1 becomes $x < 2(a-c)$ in this case. We find that the equilibrium characterization result is quite simple.

Proposition 1' (b=0.4) [Equilibrium characterization]: For any given $x \in (0, 2(a-c))$, actions taken by firms 1 and 2 in the unique equilibrium of the game are described as follows. Firms 1 and 2 choose $\theta = 1$ (i.e, they choose to merge) at Stage 1, and firm 1 transfers its knowledge to firm 2 at Stage 2.

Merger between firms 1 and 2 eliminates the competition between themselves, but the lack of competition between firms 1 and 2 induces firm 3 to take more aggressive strategy. We find that, when $b = 0.4$, the former effect dominates the latter when the merger is compared to any levels of PEO $\theta \in [0, 1)$, and so firms 1 and 2 are strictly better off by choosing to merge whether or not knowledge is transferred. That is, for any given $k = \{0, 1\}$, $\pi_{12}^*(1, k) > \pi_{12}^*(\theta, k)$ holds for all $\theta \in [0, 1)$. This implies Proposition 1', which tells us that, even if any levels of PEO $\theta \in [0, 1]$ is possible, firms 1 and 2 choose to merge in the equilibrium.

We now turn to welfare consequences of PEO. Given that firms 1 and 2 choose $\theta = 1$ in the equilibrium, we compare $CS(1)$ and $CS(0)$ in Proposition 2' and compare $TS(1)$ and $TS(0)$ in Proposition 3'. The results are qualitatively similar to the results under $b = 0.6$ case.

Proposition 2' (b=0.4) [Consumer surplus]:
(i) Suppose $0 < x \leq 0.395(a - c)$. Then $CS(1) \leq CS(0)$ holds, where equality holds if and only if $x = 0.395(a - c)$.
(ii) Suppose $0.395(a - c) < x < 2(a - c)$. Then $CS(1) > CS(0)$ holds.

Proposition 3' (b=0.4) [Total surplus]:
(i) Suppose $0 < x \leq 0.0858(a - c)$. Then $TS(1) \leq TS(0)$ holds, where equality holds if and only if $x = 0.0858(a - c)$.
(ii) Suppose $0.0858(a - c) < x < 2(a - c)$. Then $TS(1) > TS(0)$ holds.

5 Policy implications

In this section we explore policy implications of PEO that arise from our analysis. In the United States, cases of PEO in a competitor have gone mostly unchallenged by antitrust agencies (see Gilo (2000) for details). The U.S. antitrust agencies, however, have recently begun to pay increasing attention to the possible antitrust harms of PEO. For example, Deborah Platt Majoras, the then Deputy Assistant Attorney General of the Antitrust Division of the U.S. Department of Justice, mentioned in her speech given in April 2002 that PEO can raise antitrust issues when the two companies or their subsidiaries are competitors. Also, several legal scholars have argued that PEO, even if it is not accompanied by control/influence rights, results in antitrust harms in oligopolistic industries, by reducing quantities and raising prices (Gilo, 2000; O'Brien and Salop, 2000, 2001). Their arguments are consistent with the previous literature on economic theoretical analyses of PEO, in which the level of PEO is exogenously assumed.

Our model demonstrates that PEO can improve welfare by inducing knowledge transfer, suggesting that antitrust authorities might allow, rather than prohibit, PEO arrangement between competitors to maximize welfare. To make this idea precise, let us consider an antitrust authority whose objective is to maximize total surplus. Can the antitrust authority increase total surplus by imposing a binding constraint on the level of PEO in our model? We explore this question by considering the following simple extension of the model, in which everything is the same as in the original model except for the following. At Stage 0, the antitrust authority can announce a maximum permissible level of PEO, denoted $\bar{\theta}(x) \in [0, 1]$. Then, when firms 1 and 2 jointly choose θ at Stage 1, $\theta \in [0, \bar{\theta}(x)]$ must be satisfied. Assume, for expositional simplicity, that the antitrust authority announces $\bar{\theta}(x)$ only if the authority can strictly increase the equilibrium total surplus by doing so. Note that qualitatively similar results follow under an alternative assumption that the antitrust authority's objective is to maximize consumer surplus.

Knowledge transfer and PEO work in opposite directions from the welfare standpoint. That is, knowledge transfer increases the equilibrium total surplus by reducing firm 2's production cost, while the PEO decreases the equilibrium total surplus by reducing the overall degree of competition in the industry. Then, from the antitrust's standpoint, knowledge should be transferred at $\theta = \hat{\theta}(x)$, the minimum PEO that induces knowledge transfer. Under the linear homogeneous demand, the antitrust's preference matches with the choice made by firms 1 and 2, since they choose $\theta = \hat{\theta}(x)$ whenever knowledge is transferred in the equilibrium. Hence the antitrust authority's relevant option is either to impose no restrictions on PEO or to prohibit PEO. Proposition 3 tells us that the authority prohibits PEO (i.e., announces $\bar{\theta}(x) = 0$) if $x \in (0, 0.026(a-c))$ or $x \in (0.188(a-c), 0.226(a-c))$ and allows any levels of PEO (i.e., does not announce $\bar{\theta}(x)$) otherwise.

The analysis of $b = 0.6$ case captures a richer policy implication as shown in Proposition 4 below. Let us start from considering a social planner's problem. Suppose that a social planner chooses θ at Stage 1 with the objective of maximizing total surplus. Stages 2 and 3 are the same as in the original model. Let $TS(\theta, k)$ denote total surplus in the equilibrium of the Stage 3 subgame represented by (θ, k). We find that, holding $k \in \{0, 1\}$ fixed, $TS(\theta, k)$ is strictly decreasing in θ for all $\theta \in [0, \frac{1}{2}]$. This implies that at Stage 1 the social planner has two relevant options, $\theta = 0$ or $\hat{\theta}(x)$. That is, the social planner achieves $TS(\hat{\theta}(x), 1)$ by choosing the minimum PEO, $\hat{\theta}(x)$, that induces knowledge transfer (i.e., $k = 1$), or achieves $TS(0,0)$ by choosing $\theta = 0$ that does not induce knowledge transfer (i.e., $k = 0$). We find that $TS(0,0) > (=, <)\ TS(\hat{\theta}(x), 1)$ if and only if $x < (=, >)\ 0.0118(a - c)$.

Now we get back to the extension of the model in which the antitrust authority can impose a restriction on PEO at Stage 0, and firms 1 and 2 choose θ subject to the restriction (if imposed) at Stage 1. The analysis of the social planner's problem mentioned above leads us to the following result.

Proposition 4 (b=0.6) [Policy implications]: In the extension of our model, actions taken by the antitrust authority and firms 1 and 2 in the unique equilibrium of the game are described as follows:
(i) Suppose $0 < x < 0.0118(a - c)$. Then the antitrust authority announces $\bar{\theta}(x) = 0$ at Stage 0, firms 1 and 2 choose $\theta = 0$ at Stage 1, and firm 1 does not transfer its knowledge to firm 2 at Stage 2.
(ii) Suppose $0.0118(a - c) < x < 0.707(a - c)$. Then the antitrust authority announces $\bar{\theta}(x) = \hat{\theta}(x)\ (\in (0, \bar{\theta}))$ at Stage 0, firms 1 and 2 choose $\theta = \hat{\theta}(x)$ at Stage 1, and firm 1 transfers its knowledge to firm 2 at Stage 2.
(iii) Suppose $0.707(a - c) < x < 1.17(a - c)$. Then the antitrust authority makes no announcement at Stage 0, firms 1 and 2 choose $\theta = \hat{\theta}(x)$ at Stage 1, and firm 1 transfers its knowledge to firm 2 at Stage 2.

Proposition 4 tells us that the antitrust authority's optimal policy is to prohibit PEO, or partially permit PEO by imposing a binding constraint on the level of the PEO, or permit any levels of PEO without imposing any restrictions, depending on the value of x. First suppose $x \in (0, 0.0118(a - c))$. The social planner would choose $\theta = 0$, and hence the antitrust authority prohibits PEO by announcing $\bar{\theta}(x) = 0$ in this case. Next suppose $x \in (0.0118(a - c), 0.707(a - c))$. The social planner would induce knowledge transfer by choosing $\theta = \hat{\theta}(x)$ in this case. The antitrust authority can achieve the same outcome by announcing a binding restriction of $\bar{\theta}(x) = \hat{\theta}(x)$ if this restriction induces firms 1 and 2 to choose $\theta = \hat{\theta}(x)$ at Stage 1. We find that $\pi^*_{12}(\hat{\theta}(x), 1) > \pi^*_{12}(\theta, 0)$ for all $\theta \in [0, \hat{\theta}(x)]$, which implies that firms 1 and 2 do choose $\theta = \hat{\theta}(x)$ at Stage 1. This implies (ii). Finally, if $x \in (0.707(a - c), 1.17(a - c))$, firms 1 and 2 would choose $\theta = \hat{\theta}(x)$ if no restriction is imposed, as Proposition 1' (b=0.6) tells us. Then, since $\theta = \hat{\theta}(x)$ is the social planner's optimal choice, the antitrust authority imposes no restrictions in this case.

Next, consider the case of $b = 0.4$. As in other cases considered above, for any given

$x \in (0, 2(a-c))$) there exists the minimum PEO, $\hat{\theta}(x) \in (0, \frac{1}{2})$, that induces firm 1 to transfer its knowledge to firm 2. This leads us to Proposition 4', which is qualitatively similar to Proposition 4 (b=0.6) presented above.

Proposition 4' (b=0.4) [Policy implications]: In the extension of our model, actions taken by the antitrust authority and firms 1 and 2 in the unique equilibrium of the game are described as follows:
(i) Suppose $0 < x < 0.00663(a-c)$. Then the antitrust authority announces $\bar{\theta}(x) = 0$ at Stage 0, firms 1 and 2 choose $\theta = 0$ at Stage 1, and firm 1 does not transfer its knowledge to firm 2 at Stage 2.
(ii) Suppose $0.00663(a-c) < x < 2(a-c)$. Then the antitrust authority announces $\bar{\theta}(x) = \hat{\theta}(x)$ ($\in (0, \bar{\theta})$) at Stage 0, firms 1 and 2 choose $\theta = \hat{\theta}(x)$ at Stage 1, and firm 1 transfers its knowledge to firm 2 at Stage 2.

Proposition 4' tells us that, unless the value of x is very small, the antitrust authority can improve equilibrium total surplus by prohibiting merger and inducing firms 1 and 2 to choose the minimum PEO $\theta = \hat{\theta}(x)$ under which knowledge is still transferred from firm 1 to firm 2.

In summary, in this section we have demonstrated that our analysis yields new policy implications of PEO through exploring the link between PEO and knowledge transfer. Although PEO itself reduces the degree of competition in the industry, the endogenously determined level of PEO could increase welfare under our framework because it induces knowledge transfer. Our analysis indicates that the antitrust authority should allow, rather than prohibit, PEO between competitors under a range of parameterizations. Furthermore, we identify partial permission of PEO as a relevant policy of the antitrust authority. Partial permission becomes the optimal policy when the antitrust authority prefers knowledge transfer at the minimum level of PEO but the collaborating firms would choose a higher level of PEO if no restrictions are imposed. This can never be the case under the linear homogenous model but can be the case under a range of parameterizations under differentiated oligopoly models in our framework.

6 Conclusion

We have explored oligopoly models in which the level of PEO is endogenously determined through the link between PEO and knowledge transfer. Previous theoretical models of

PEO, in which the levels of PEO are exogenously given, have shown that PEO arrangements would decrease welfare by reducing the degree of competition in the industry. We have demonstrated that endogenously determined levels of PEO can increase welfare under a range of parameterizations. Our analysis indicates that there are three relevant policy interventions (prohibit PEO, partially permit PEO, or permit PEO) for antitrust authorities to maximize welfare, and shows that any one of the three can be optimal depending on parameterizations.

Appendix

To be typed up.

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