Transfer Pricing and Offshoring in Global Supply Chains

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Taking advantage of lower foreign tax rates using transfer pricing and taking advantage of lower production costs using offshoring are two strategies that global companies use to increase their profitability. Evidence suggests that firms employ these strategies independently. We study how global firms can jointly leverage tax and cost differences through coordinated transfer pricing and offshoring. We derive a trade-off curve between tax and cost differences that can be used to design sourcing and transfer pricing strategies jointly. However, in a global firm the implementation of such jointly optimal strategies is often hindered by the following incentive problem. The headquarters is more concerned about the consolidated after tax profits than the local divisions. Local divisions, on the other hand, have a better view on the product cost structure and hence, have a better view on the appropriate sourcing strategies. Hence, we need to understand how different transfer price strategies and decentralization of sourcing and/or pricing decisions can be helpful. We find that when the tax differential is large, a fully centralized strategy works best. In other settings, a decentralized sourcing strategy (enabling the global firm to take advantage of the local cost information) should be considered. Finally, we show that when the cost of outsourcing increases, a decentralized company has more flexibility in transfer pricing and hence can achieve higher profits.

Key words: transfer pricing, tax, global supply chain, offshoring

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1. Introduction

Tax-aligned design and management of supply chains is poised to be a new frontier of excellence for global companies. Supply chain activities such as procurement decisions and distribution network design were traditionally done independently of the tax planning activities such as transfer pricing and deferral of taxation. Recently, however, there is ample evidence that companies have recognized that significant savings can be achieved if these two sets of activities are coordinated. A recent global transfer pricing survey conducted by Ernst & Young found that 80% of U.S. based multinationals involve tax directors at the "concept or initiation phase" of business planning and that only 5% of multinationals reported that they do not (Ernst&Young 2007). Deloitte expounds in its strategic tax vision that, at the beginning of any new business project, multinational companies should involve tax departments to assess supply chain strategies that may lead to a reduced structural tax rate and consequently, to an improvement of the after-tax earnings (Deloitte 2008).

The importance of tax strategies and their integration into supply chain modeling has also attracted a lot of attention in the trade journals recently. Irving et al. (2005) claim that "By aligning its tax and global supply chain strategies, a company can establish tax and legal structures that will create significant tax savings – often tens or hundreds of millions of dollars – while ensuring compliance with applicable laws and regulations." They claim that these savings can be achieved by reducing the effective tax rate that a company faces and they specifically see significant opportunities in the areas of procurement and logistics. Murphy and Goodman (1998) mention that "Millions of dollars that could be adding to the value of multinational corporations instead are ending up in the hands of tax authorities and diminishing hard-won savings achieved through supply-chain improvements." They hypothesize that this can be achieved by a careful combination of supply chain and tax planning. Sutton (2008) stresses the importance of tax considerations in supply chain management and identifies procurement and sourcing as the major area that can be enhanced via tax planning and alignment.

These opportunities arise because governmental authorities of various countries are aware of the correlation between tax rates and foreign capital investment and thus often offer tax incentives to global corporations. Mutti (2003) has demonstrated empirically that taxes have a strong impact on the distribution of capital of multinational manufacturing companies, while DeMooij and Ederveen (2003) found that a 1% reduction in a country's tax rate leads to a 3.3% increase (on average) in the country's foreign direct investment. As countries compete with each other in offering different tax incentives, multinational companies are offered a menu of tax incentives and must be able to choose the location whose tax structure works best for them.

In order to make the best decision, global companies' analysis should encompass operational, financial, and tax considerations. In spite of the mounting evidence of the importance of combining tax and operational considerations in design and management of supply chains, there is limited research in operations management that addresses taxation issues. Cohen and Lee (1989) develop a mixed integer non-linear model for analyzing the resource deployment decisions of a global firm by maximizing after-tax profits. Vidal and Goetschalckx (2001) consider a global firm that moves some of its production to foreign facilities and optimize after-tax profit by selecting optimal flows between facilities and by setting transfer prices. Even though these papers use transfer prices and look at after-tax profits, the aim of this stream of literature is to develop a procedure for optimizing large scale supply chains rather than to analyze the impact of taxation and transfer pricing policies on the sourcing decisions, which is a focus of our paper. Transfer price in these papers is considered to be an income-shifting mechanism that determines taxable profit (referred to as the *tax role* of transfer prices), however, in decentralized firms, transfer price is also crucial for determining incentives for divisional managers (referred to as the *incentive role* of transfer prices). The papers mentioned above do not incorporate the incentive role of transfer prices that has a large impact on the decision making process in decentralized supply chains, especially in the presence of information asymmetry, which is an attribute of our model. Kouvelis and Gutierrez (1997) study a global newsvendor network with the aim to optimize production quantities considering the impact of exchange rates and transfer prices. The authors explore the centralized and decentralized decision making structures and find that the centralized model performs better. We will show, however, that if there is information asymmetry between the headquarters and the subdivisions pertaining to outsourcing cost, decentralization of some of the decisions may add value. In addition, our model considers an endogenous selling price and a price-dependent end-customer demand. Shunko and Gavirneni (2007) consider a supply chain in which the only sourcing option is production at a foreign facility; they analyze transfer pricing and selling price decisions in the presence of price-dependant demands with an additive random component. They showed that the benefits of transfer pricing are larger when there is randomness in demand. We allow sourcing to be a decision variable with options covering the whole range from no offshoring to full offshoring. We do this for deterministic, price-dependant demand with randomness in the cost of outsourcing. Huh and Park (2008) analyze the effect of different transfer pricing methods on the performance of a supply chain that sources from a foreign facility and faces random demand on the local market. Their model does not consider offshoring as a decision and also does not optimize over the transfer prices, but rather takes the transfer pricing rules as given.

To summarize, we consider a global supply chain that has an option to offshore some or all of its production, optimize over a continuous spectrum of transfer prices within legal bounds, incorporate information asymmetry about the outsourcing cost, and explore different organizational structures that impact the incentive role of transfer pricing in the firm. This model allows us to answer the following primary research questions: 1) What are the optimal sourcing strategies of global firms that face different tax rates and different production costs at various business locations? 2) How does organizational structure affect the sourcing and transfer pricing strategies of the global firm in the presence of information asymmetry? 3) When should a global firm choose one structure over another?

Before we present the details of our modeling and analysis, we present a brief summary of our results. Through the paper, we use the term outsourcing to indicate sourcing from an external supplier and offshoring to indicate sourcing from a foreign location owned by the firm. We mathematically characterize the optimal sourcing and pricing decisions for a global supply chain with differential tax rates and price-dependant demands under both centralized and decentralized organizational structures. From this analysis, we derive the tradeoff curves between the tax and cost differences among the supply chain members and determine the conditions under which it is optimal to offshore. We find that firms that are fully centralized get the greatest benefit from optimizing transfer prices, because the incentive role of transfer prices in decentralized firms restricts them from getting substantial taxation benefits. In the presence of asymmetric information, the benefit of decentralization depends on the relative size of the tax advantage versus the cost advantage. If the tax advantage is more significant, the global firm is better off centralizing all relevant business decisions and taking full advantage of transfer pricing; if the cost advantage is more significant, the global firm is better off decentralizing and taking advantage of the better cost information at the local divisions of the firm. When choosing between decentralizing sourcing or pricing decision, it is almost always more beneficial to delegate the sourcing decision power to the local division.

The rest of this paper is organized as follows. In the next section (section 2), we introduce the concept of transfer pricing and its potential role in determining the sourcing strategy. In section 3, we describe the supply chain model we use and follow that up, in sections 4 and 5, with analysis and comparison of the centralized and decentralized structures. Section 6 details the results of a numerical study that enables us to draw managerial insights on the role that various supply chain parameters play in determining the best supply chain configuration. We close the paper, in section 7, with some concluding remarks and ideas for future research.

2. Transfer Pricing and its Role in Sourcing

Transfer price is an intrafirm price that is used for transactions between affiliated companies within a multinational enterprise. Transfer pricing is a tool (the most popular one) that a multinational company can use to shift income to a lower-tax jurisdiction to take advantage of the difference in the tax rates. More than 90% of the companies surveyed in the Ernst & Young study indicated that transfer pricing is an important international taxation issue that they face and 31% of the respondents indicated that transfer pricing will be absolutely critical for them over the next few years (Ernst&Young 2007). Even though multinational companies are allowed to use different transfer pricing schemes for managerial versus taxation purposes, there exists empirical evidence that they prefer to use the same transfer price for both purposes to avoid the high cost of setting up alternate systems and to minimize tax disputes with authorities (Czechowicz et al. 1982). This approach has also been accepted for modeling transfer pricing in the economics (Schjelderup and Sørgard 1997, Nielsen et al. 2008) and operations management literature (Huh and Park 2008, Shunko and Gavirneni 2007).

As an example, consider a book seller incorporated in the U.S. that is taxed at 35% and sells 1000 books per year at $10 per unit. The company has an opportunity to buy the books from its subsidiary in Ireland that publishes at a cost of \$3 per unit and has a corporate income tax rate of 12.5%. If the company produces in Ireland and buys the books from the subsidiary at a cost of \$7 per book, its after tax profit would be $1000 * ((10-7) * (1-0.35) + (7-3) * (1-0.125) = \$5,450$. Notice that if the company did not transfer any profits to Ireland (i.e purchased the books at cost), its after tax profit would only be \$4,550. By using a transfer pricing strategy, the firm was able to realize a higher after-tax profit. This seems like a clear choice. But what if the bookseller could produce the books in the U.S. at a cost of \$2 per book versus producing them in Ireland at a cost of \$3 per book? Then, traditional procurement model would clearly suggest that it is optimal to procure them in the U.S. and realize an after tax profit of \$5,200. However, we earlier showed that by producing them in Ireland and using a transfer price of \$7, the book seller can realize an after-tax profit of \$5,450. Thus by incorporating the availability of a transfer pricing strategy into the sourcing decision, the bookseller is able to increase its profit by \$250. There are, of course, issues associated with the legally allowed transfer prices and what happens to the profits accumulated abroad. We will next explain some of the related legal rules and regulations.

Transfer pricing rules in the U.S. Transfer pricing in the U.S. is regulated by the Internal Revenue Service. Federal Income Tax Regulation of the Internal Revenue Code §1.482-1 allows the companies to choose one of the six methods outlined below: (i) the comparable uncontrolled price method, (ii) the resale price method, (iii) the cost plus method, (iv) the comparable profit method, (v) the profit split method, and finally, (vi) unspecified methods. As a result of the variety of rules and the fact that it is often difficult to find similar products sold in the uncontrolled environment, companies often have a large range of transfer prices to choose from (Halperin and Srinidhi 1987). In order to focus our study, we base our modeling choices on the findings from an empirical study on the current trends in corporate transfer pricing conducted by Tang (2002) in 1997-1998. The study was performed using a questionnaire addressed to Fortune 1000 companies and focused on the following issues: transfer pricing methods currently used in practice, environmental variables relevant to the transfer pricing issue and their relative importance as perceived by the management of the interrogated companies, management objectives in setting transfer prices, and other relevant questions. Based on the results of the study, the most widely used methods for transfer pricing for international transfers were cost based (used by 42.7% of the respondents) and market price based (35.5%). Furthermore, the highest percentage of firms (42%) reported maximization of consolidated after-tax profits of the company as their primary objective. This implies that the transfer pricing decision is made at the headquarters level where the management has access to information on consolidated after-tax profit. Thus, we will restrict our attention to the case when the transfer pricing is set in a central manner.

Controlled foreign corporations. Different sourcing strategies such as outsourcing and offshoring of manufacturing to countries like China, India, Ireland, Poland, etc. have been very popular amongst U.S. based multinational companies. As defined in Clausing (2005), outsourcing stands for purchasing from an external (third-party) supplier, which may be located onshore or offshore; and offshoring stands for relocation of the internal production process to a foreign subsidiary. In this paper, we model the sourcing decision as a continuum from outsourcing (i.e. 0% sourced from the foreign subsidiary) to offshoring (i.e. 100% sourced from the foreign subsidiary). Typically, if the company offshores with an intent to take advantage of tax rates, the subsidiary is established as a controlled foreign corporation (CFC, a legal entity that allows the firm to take advantage of tax benefits and that is defined in 26 U.S.C. § 957 as a foreign subsidiary, in which at least 50% is owned by the U.S. firm).

Deferral of taxation. U.S. companies are taxed on a residence basis, i.e. the U.S. government collects taxes on all income earned by U.S. companies regardless of the country the income originated in. However, there is an exception to this rule, which allows U.S. companies to temporarily exclude the unrepatriated portion of income earned by a CFC from U.S. taxation, deferring these tax liabilities until this income returns to the United States in the form of dividends (Hines 1996). Occasionally, U.S. firms get a chance to repatriate profits at a discounted tax rate; for example, the American Job Creation Act of 2004 allowed multinational companies to pay 5.25% on the foreign income repatriated back to the U.S. (Arndt 2005). In practice, we see evidence in current trade journals and corporate annual reports that numerous U.S. companies do not repatriate, and do not intend to repatriate, their foreign earnings. For example, Merck&Co has \$18 billion in the unrepatriated earnings and states that it does not intend to ever pay U.S. taxes on this sum. Hewlett-Packard has indefinitely deferred taxation on \$14.4 billion in foreign earnings for the year 2003 (Weisman 2004). Pfizer Inc. states in its 10-K filing for the year 2003: "As of December 31, 2003, we have not made a U.S. tax provision on approximately \$38 billion of unremitted earnings of our international subsidiaries. These earnings are expected, for the most part, to be reinvested overseas" (Pfizer 2004). In 2004 it was estimated that U.S. multinationals kept about \$639 billion in the unrepatriated foreign earnings (Weisman 2004). Most common uses of unrepatriated funds are (i) reinvesting into CFCs as 'subsidiary retained earnings are typically cheaper than parent equity transfers' and (ii) repayment of debts (Jun 1995). Based on this evidence, we assume that the profits realized in the foreign location remain there for the relevant duration.

3. The Supply Chain Model

We consider a global firm that consists of three entities, namely (i) the headquarters; (ii) a domestic division that sells a single product in the domestic market; and (iii) a foreign subsidiary that can manufacture the product.

Demand Structure. The end-customer demand that the domestic division faces is a deterministic linear function of the selling price, P (all notation is summarized in Table 3 in the Appendix). That is, $D(P) = \xi - bP$, where $\xi \geq 0$ is the total market size and $b \geq 0$ is the demand elasticity. This is a demand model that is commonly used in the operations management literature (Petruzzi and Dada 1999).

Sourcing Options. The company can procure the product from two sources, namely (i) the foreign subsidiary; and (ii) an external third party supplier. It also has the option to simultaneously use both the sources. We denote the proportion of demand sourced from the foreign subsidiary by $\lambda \in [0, 1]$. It is worth noting here that when the product is sourced from the third party supplier (who can be either domestic or foreign), the company does not have the ability to use transfer prices to move profits abroad. For ease of exposition, we refer to the setting when $\lambda = 0$ as *the outsourcing case* and the setting $\lambda = 1$ as *the offshoring case.*

The manufacturing cost in the foreign country is c and at the external supplier, it is $\boldsymbol{c}_E$. For analytical tractability we model $\boldsymbol{c}_E$ as a two-point distribution with $Pr(\boldsymbol{c}_E = \underline{c}_E) = Pr(\boldsymbol{c}_E = \overline{c}_E) = \frac{1}{2}$, where β represents the coefficient of variation, μ is the mean, $\underline{c}_E = \mu(1-\beta)$, and $\overline{c}_E = \mu(1+\beta)$. When $c > \overline{c}_E$, there is a certain cost disadvantage to offshoring and when $c < \underline{c}_E$, there is a certain cost advantage to offshoring. In order to focus on the cases in which the cost advantage is uncertain, we restrict c to be in $[\underline{c}_E, \overline{c}_E]$.

Transfer Pricing. One of the most widely used methods for transfer pricing is the market price based strategy (Tang 2002). Under this approach, the transfer price (T) is calculated as the market price scaled down by an appropriate markdown that would be reasonable in a transaction between unrelated parties. Assuming that the retail price is proportional to the market price, we restrict transfer price to be below αP, where α is an exogenous parameter such that $0 \le \alpha \le 1$. To disallow negative profits at the foreign division and to comply with the basic rules of thumb for setting the transfer price, we also restrict the transfer price to be above the foreign production cost (c). As a result, management is constrained to set the selling price and the transfer price such that $(T, P) \in \mathcal{C}$, where $\mathcal{C} = \{T \ge 0, P \ge 0 : c \le T \le \alpha P\}$. To guarantee positive demands in further analysis, we put a restriction on the parameters: $\xi > \text{Max}(\overline{c}_E, \frac{c}{\alpha})$[1].

Information Asymmetry. Management of the local division has direct contact with the external suppliers and consequently should have better information about the external cost than the headquarters. Hence we assume that the headquarters only know the distribution (i.e. parameters μ and β) of the outsourcing cost, while the local management knows its exact realization, c_E. Another way of justifying this information asymmetry is by recognizing the time lag between the headquarters' decisions and the local management's decisions: there is usually some resolution of uncertainties during this time and the local management can often take advantage of it.

Tax Rates. Tax rates in the two tax jurisdictions differ and we use t to represent tax rate in the local country and τ in the foreign country. When $\tau > t$, it is optimal to report all income at the

[1] Notice that the legal constraints set a lower bound on price: $P \ge \frac{c}{\alpha}$. We make sure that the demand is non-negative at the lowest price value and at the highest cost value.

selling division situated in the local country, which is legally attainable by setting transfer price equal to cost. In order to avoid this trivial solution, we assume that the tax advantage is in the foreign country (i.e. $\tau < t$).

Measures of Performance. The Local Management (LM) is interested in the profit of the local division ($\pi_L(T, P, \lambda, \boldsymbol{c}_E) = D(P)(P - \lambda T - (1-\lambda)\boldsymbol{c}_E)$). The profit of the foreign subsidiary can be computed as $\pi_F(T, P, \lambda) = \lambda D(P)(T - c)$ and this is monitored by the HeadQuarters (HQ) because it plays a role in the after-tax profits of the firm. The objective of HQ is to maximize:

$$\Pi(T, P, \lambda, \boldsymbol{c}_E) = \begin{cases} \pi_L(T, P, \lambda; \boldsymbol{c}_E)(1-t) + \pi_F(T, P, \lambda)(1-\tau), & \lambda > 0 \\ \Pi^o(P, \boldsymbol{c}_E), & \lambda = 0, \end{cases}$$

where $\Pi^o(P, \boldsymbol{c}_E) = \pi_L(T, P, 0, \boldsymbol{c}_E)(1-t)$.

Decision Variables. The firm has three major decisions to make: 1) *the sourcing decision* - the proportion, λ, of sourcing needs to be offshored; 2) *the retail pricing decision* - the selling price, P, at which the product is sold to the end-customer; and 3) *the transfer pricing decision* - the transfer price T to use for shifting income between the domestic and the foreign divisions.

Organizational Structures. We model (based on the empirical evidence from Tang (2002)) that the transfer pricing decision is always made by HQ, but HQ may delegate the selling price decision and/or the sourcing decision to LM. Thus, we examine four different decision-making structures: 1) *centralized* - where all decisions are made by HQ; 2) *decentralized retail pricing* - in which the selling price decision is made locally, which will happen when the marketing division is local and sourcing division is global; 3) *decentralized sourcing* - LM determines λ; this can happen when the sourcing division is local and the marketing department is global; and 4) *decentralized retail pricing and sourcing* - LM determines both P and λ; both the sourcing and marketing divisions are local.

4. Centralized Model

We first formulate the model in which all decisions are made by HQ. This model illustrates the role of taxation and transfer pricing in the sourcing decisions of a centralized global firm. HQ optimizes the expected after-tax profit over all three decisions, making sure that the legal constraints are satisfied:

$$\Pi^C = \max_{(T,P)\in\mathcal{C}, 0\le\lambda\le 1} \mathbb{E}\left[\Pi(T,P,\lambda,\boldsymbol{c}_E)\right].$$

$\Pi(T,P,\lambda,\boldsymbol{c}_E)$ is linear in $\boldsymbol{c}_E$, and thus $\mathbb{E}[\Pi(T,P,\lambda,\boldsymbol{c}_E)] = \Pi(T,P,\lambda,\mu)$. Hence, profit depends only on the expected value of $\boldsymbol{c}_E$ and the problem simplifies to:

$$\Pi^C = \max_{(T,P)\in\mathcal{C}, 0\le\lambda\le 1} \Pi(T,P,\lambda,\mu).$$

Let P^C, λ^C, and T^C denote the optimal solutions for the benchmark model. $P^o(\cdot) = \arg\max_P \Pi^o(P,\cdot)$ denotes the monopoly pricing solution of LM.

Lemma 1. *When $t=\tau$, HQ offshores, $\lambda^C=1$, if and only if $c<\mu$. The optimal price is: $P^C = P^o(\min(\mu,c))$. The transfer price is irrelevant.*

This lemma is very intuitive and acts as a benchmark for the analysis to follow. In the absence of the tax advantage abroad, the firm offshores if and only if there is a cost advantage in the foreign country. Shifting income from one tax jurisdiction to another does not lead to tax savings and thus, the transfer pricing decision becomes irrelevant. When the foreign tax rate is lower than the local tax rate (i.e. $\tau<t$), there is a tax advantage in the foreign country and the sourcing decision is determined as follows (all thresholds are fully defined in the appendix):

Proposition 1. *When $\tau<t$, there exists a threshold $\hat{c}>\mu$ on the foreign cost, such that*

$$\lambda^C = \begin{cases} 1, & c<\hat{c} \\ 0, & c\ge\hat{c}, \end{cases}$$

the optimal price is

$$P^C = \begin{cases} P^o\left(\frac{c(1-\tau)}{1-t+\alpha(t-\tau)}\right), & c<\hat{c} \\ P^o(\mu), & c\ge\hat{c}, \end{cases}$$

and the optimal transfer price is

$$T^C = \begin{cases} \alpha P^C, & c<\hat{c} \\ n/a, & c\ge\hat{c}. \end{cases}$$

Recall from Lemma 1 that when there is no tax advantage and the offshoring cost is higher than the average outsourcing cost, the profit in the offshoring case is necessarily lower than the expected profit in the outsourcing case. In the presence of the tax advantage, however, the tax savings in the offshoring case may compensate for the cost disadvantage and it may not necessarily be optimal to outsource when the local cost realization is lower than the foreign cost, because doing so foregoes the opportunity to capture tax savings. Thus, there exists a threshold $\hat{c} > \mu$, below which it is optimal for the firm to offshore.

We also find that when the firm offshores, it sets the transfer price equal to the legal upper bound, which allows it to shift as much income as possible to the lower tax jurisdiction. Retail price in the offshoring case has the same form as the monopoly solution (P^o), however the cost term accounts for the tax differential.

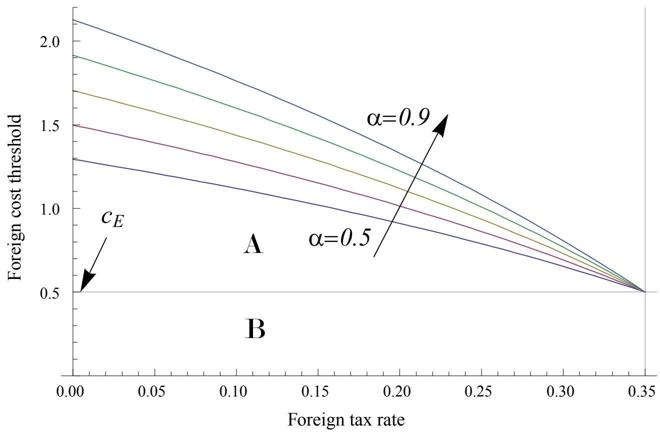


Figure 1 Tradeoff curves between the cost and tax differentials for various values of markdown parameter α. Each curve separates the offshoring region (below the curve) from the outsourcing region (above the curve). Parameters: $\xi = 1$, $b = 0.1$, $t = 0.35$, $c_E = 0.5$, and α varies from 0.5 to 0.9.

The threshold $\hat{c}$ identifies the tradeoff curve between the cost and tax difference between the supply chain members. We illustrate the tradeoff curve with a numerical example depicted in Figure 1, where we plot the threshold on the foreign production cost on the vertical axis and the foreign tax rate on the horizontal axis. Each line represents a tradeoff curve for different values of the markdown parameter α. For each curve, in the area above the line the optimal solution is to outsource and in the area below the line, the optimal solution is to offshore. The area in region B is self-explanatory: when there is a cost advantage *and* a tax advantage in the foreign country the firm offshores. In region A, even though the firm has a cost *disadvantage* in the foreign country, the tax savings from the low tax rate still make it beneficial for the firm to offshore.

LEMMA 2. *Threshold $\hat{c}$ is increasing in markdown parameter (α), increasing in market size (ξ), and decreasing in price elasticity (b).*

As a consequence of Lemma 2, the area of region A in Figure 1 increases in markdown parameter (α). Intuitively, if the legal bound on the transfer price is looser (high α), the firm can increase the transfer price and enjoy greater tax savings. Consequently, the foreign production cost may be higher and yet the tax savings will be enough to outweigh the cost disadvantage. This effect is greater when the tax differential is low (e.g. $\tau = 0$ versus $\tau = 0.35$). We can observe similar effects with respect to the demand parameters ξ and b. An increase in market size (ξ) means that the firm can reap more tax benefits from a larger total profit, hence, it can tolerate a higher production cost. An increase in elasticity (b) decreases profits and thus, decreases tax savings. In addition, since customers are more sensitive to price, it is essential to lower cost. Consequently, the foreign production cost that the firm can tolerate decreases as well.

5. Decentralized Models

In the presence of asymmetric information between HQ and LM, the decentralized structure may be beneficial for the firm because LM will base their decisions on the actual realization of the outsourcing cost rather than only on the probability distribution of the cost. On the other hand, decentralization of the pricing and/or sourcing decisions has the disadvantage that LM maximizes only the local profit without taking into consideration consolidated after-tax profit. In the next three subsections, we analyze this tension and determine the corresponding optimal solution.

5.1. Decentralized Retail Pricing Decision

When the retail pricing decision is decentralized, LM sets the retail price by maximizing local profit given the sourcing decision and transfer price set by HQ. HQ sets the offshoring proportion and the transfer price by maximizing consolidated after-tax profit, taking into account the optimal reaction of LM. Furthermore, HQ ensures that the selling price and the transfer price stay within the constraint set $\mathcal{C}$:

$$\Pi^P = \max_{T, 0\le\lambda\le 1} \mathbb{E}\left[\Pi(T, P^P(T,\lambda,\boldsymbol{c}_E),\lambda,\boldsymbol{c}_E)\right] \tag{1}$$

$$\text{s.t. } \left(T, P^P(T,\lambda,c_E)\right) \in \mathcal{C},\ \forall\ c_E \in \{\underline{c}_E, \bar{c}_E\}, \tag{2}$$

$$\text{where } P^P(T,\lambda,c_E) = \arg\max_{P\ge 0} \pi_L(T,P,\lambda,c_E).$$

LM finds optimal price by maximizing local profit and the cost that LM faces is a linear combination of external cost and transfer price $\lambda T + (1-\lambda)c_E$. Hence, we can think of $\pi_L(T,P,\lambda,c_E)$ as of $\Pi^o(P, \lambda T + (1-\lambda)c_E)$ and the optimal pricing solution for LM is equal to $P^o(\lambda T + (1-\lambda)c_E)$. Notice that when the firm offshores a positive portion of its sourcing needs, the selling price $P^P(T,\lambda,c_E)$ increases in the transfer price T. But, due to the downward sloping form of the demand function $D(P)$, a high selling price may not be ideal for the firm. Hence, in the organizational structure with decentralized retail pricing, there is a force that pushes the transfer price down. If the optimal transfer price that takes into account these incentive issues (we refer to it as *incentive upper bound*) is less than the legal upper bound, the legal restriction ($T < \alpha P$) is no longer binding. Hence, the solution is substantially different from that of the centralized model (in which $T = \alpha P$). If the incentive upper bound is greater than or equal to the legal upper bound, the results of the centralized model carry over to the model with decentralized retail pricing decision. Based on our numerical results (detailed in Section 6), incentive upper bound is tight in 79.49% of the cases in our study.

Before formally presenting the solution to (1), to gain further insight we study a relaxation of Π^P (denoted by $\overline{\Pi}^P$) by ignoring the legal constraints (2) and present the results in Lemma 3.

$$\overline{\Pi}^P = \max_{T, \lambda\in\{0\}\cup[\epsilon,1]} \mathbb{E}[\Pi(T, P^P(T,\lambda,\boldsymbol{c}_E),\lambda,\boldsymbol{c}_E)]. \tag{3}$$

Since the firm cannot practically offshore an infinitesimal amount of production, we introduce ϵ as a lower bound on the offshoring proportion. Although this observation is true for all models, we omit it for clarity of exposition in other models as it is not relevant.

Let $\left(\overline{\lambda}^P, \overline{T}^P\right)$ be the solution for $\overline{\Pi}^P$:

$$\left(\overline{\lambda}^P, \overline{T}^P\right) = \arg \max_{T, \lambda \in \{0\} \cup [\epsilon, 1]} \mathbb{E}[\Pi(T, P^P(T, \lambda, \boldsymbol{c}_E), \lambda, \boldsymbol{c}_E)]$$

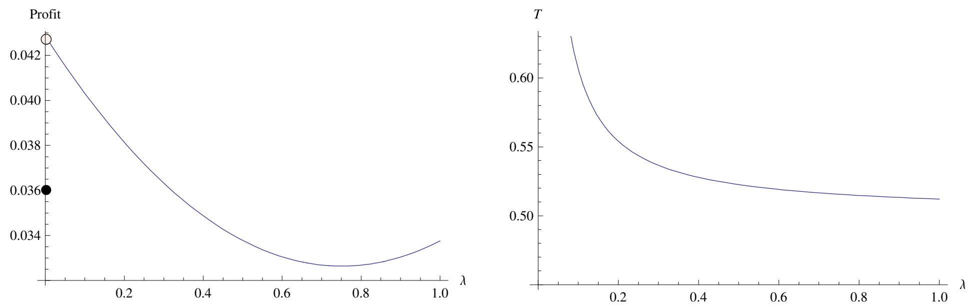
We define an interim function

$$\hat{T}^P(\lambda) = \arg \max_T \mathbb{E}[\Pi(T, P^P(T, \lambda, \boldsymbol{c}_E), \lambda, \boldsymbol{c}_E)]$$

Lemma 3. *The relaxed problem 3 is convex in λ with a discontinuity at $\lambda = 0$. There exists a threshold on the offshoring cost, $\bar{c}$, such that:*

1. *If $c < \bar{c}$, then $\overline{\lambda}^P = 1$ and $\overline{T}^P = \hat{T}^P(1)$;*
2. *Otherwise, $\overline{\lambda}^P = \epsilon$ and $\overline{T}^P = \hat{T}^P(\epsilon)$, where $\lim_{\epsilon \to 0} \hat{T}^P(\epsilon) = \infty$.*

When ignoring legal constraints, Lemma 3 suggests that the firm always offshores at least some portion of its sourcing needs. When the cost of foreign production is low, the firm offshores all the demand. When the foreign cost is high, it is optimal for the firm to offshore a small amount ϵ but to set the transfer price very high. Recall that we are temporarily ignoring the legal constraints on the transfer price. Thus, the firm may source all but one unit from the external supplier at a low cost, and offshore just a single unit at a transfer price that *shifts all profit to the low tax jurisdiction.* With this strategy, the firm enjoys *both* tax savings and cost savings. At $\lambda = 0$, such a solution is not feasible since if there is no product to transfer, the transfer price does not exist in practice and thus, the profit function is discontinuous at zero. Notice that the discontinuity at $\lambda = 0$ is not due to the introduced lower bound ϵ (see Figure 2). Also notice that in the absence of legal constraints, the profit function is convex in λ. Since the firm can always take full advantage of taxes (even when we set $\lambda = \epsilon$, because we can set T as large as needed), the sourcing decision is based solely on the cost differential. If the cost in one tax jurisdiction outperforms the other, it should always be optimal to shift all production to this tax jurisdiction as this does not reduce the tax benefit. Failing to do so, i.e. a fractional λ, would increase cost, which leads to an increased price and a decreased demand (given the form of the demand function). Therefore, the profit is convex in λ.



(a) Profit (b) Transfer price

Figure 2 Illustrate discontinuity of profit at $\lambda = 0$

Now, we re-introduce the legal constraints. Since $P^P(T, \lambda, c_E)$ is increasing in c_E, we replace (2) with $(T, P^P(T, \lambda, \underline{c}_E)) \in \mathcal{C}$. When the transfer price is bounded from above, the company is limited on how much tax advantage it can obtain from offshoring. In Proposition 2, we characterize the optimal strategy that complies with these legal bounds on the transfer price.

Proposition 2. 1. *For some parameter settings, there exists an interior optimal solution* $(\lambda^P \in (0,1))$ *and in such cases,* $T^P = \alpha P^P$.

2. *When* $\alpha = 1$*, there exists a unique* $\hat{\lambda}$ *that defines an upper bound on* λ^P.

In Proposition 2, the sourcing decision no longer has an all-or-nothing structure. In order to build up intuition for Proposition 2 we revisit the main result of Lemma 3. In the absence of legal constraints the firm may always take full advantage of the favorable tax rate either by offshoring and setting the transfer price at its legal upper bound, or by outsourcing everything but a small volume and using the remaining volume to shift all profit to the low tax jurisdiction by means of a very high transfer price. Hence, when λ is small, the firm wants to set the transfer price high, but the legal constraint becomes binding and the firm cannot take full advantage of the favorable tax rate. As a result, instead of outsourcing one unit at a very high transfer price, it will be optimal for the firm to transfer more units at the highest allowed transfer price to take advantage of tax benefits.

We show the existence of partial solution, however, we do not have a full characterization of

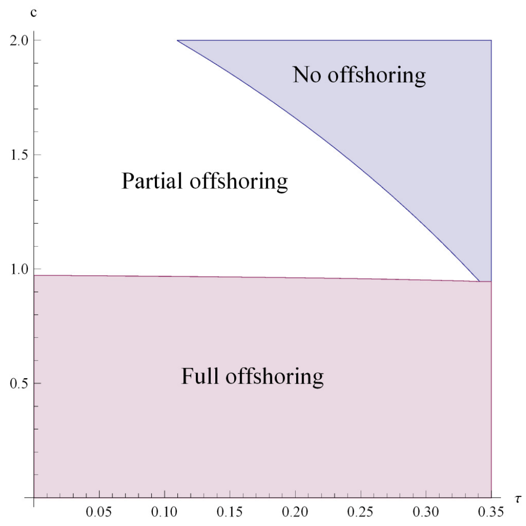


Figure 3 **Optimal sourcing strategy. Parameters:** $\xi = 10$, $b = 1$, $\mu = 1$, $\beta = 1$, $t = 0.35$, **and** $\alpha = 1$

the conditions under which the partial solution holds. Instead, we demonstrate its behavior with a numerical example in Figure 3. When the foreign cost is lower than the average external cost and there is a tax advantage in the foreign country, the firm fully offshores ($\lambda = 1$). When the costs are equal, it may seem intuitive that the firm would want to fully offshore, because the costs are equal on average and offshoring provides tax benefits. However, when $\lambda = 1$, LM's price decision is highly dependant on the transfer price and hence, HQ has to keep the transfer price low. In the case of partial offshoring, LM's price decision depends on the transfer price to a lesser degree and hence, HQ can offer a higher transfer price and obtain higher after-tax profits. When foreign cost is larger than the outsourcing cost, the firm wants to procure from a cheaper source and take advantage of taxes - hence, the solution is to partially offshore and get tax savings from the offshored amount and cost savings from the outsourced amount. But, when the tax differential is small, partial offshoring is not worth it because the lower outsourcing cost will result in a lower retail price, which will consequently create a tight upper bound on the transfer price. Hence, the firm will not be able to take substantial advantage of the favorable tax rate in the foreign country.

5.2. Decentralized Sourcing Decision

In this subsection we study delegating the sourcing decision to LM while keeping the retail and transfer pricing decisions at the HQ level. The sourcing decision is made by LM based on the actual realization of the outsourcing cost rather than on its probability distribution. It is worth noting that the tax rates do not play a role in the LM's sourcing decision. For a given pricing and transfer pricing decisions from HQ, LM finds the sourcing strategy that optimizes its local profit. HQ finds the best pricing and transfer pricing policy by optimizing the consolidated after-tax profit taking into consideration the optimal reaction of LM and the legal constraints:

$$\begin{aligned} \Pi^S = \max_{P,T} \quad & \mathbb{E}\left[\Pi\left(T, P, \lambda^S\left(T, P, \boldsymbol{c}_E\right), \boldsymbol{c}_E\right)\right] \\ \text{s.t.} \quad & (T, P) \in \mathcal{C} \end{aligned} \tag{4}$$

$$\text{where } \lambda^S\left(T, P, c_E\right) = \arg\max_{0 \le \lambda \le 1} \pi_L\left(T, P, \lambda, c_E\right)$$

Define now

$$\lambda^o\left(T, c_E\right) \doteq \begin{cases} 1, \ T < c_E, \\ 0, \ T > c_E. \end{cases}$$

LEMMA 4. *The optimal strategy of the local management is as follows:*

$$\lambda^S\left(T, P, c_E\right) = \lambda^o\left(T, c_E\right), \forall\left(T, P\right) \in \mathcal{C}$$

Since LM is focused solely on the local profit, the offshoring decision is rather straightforward. LM will choose the cheapest supply source. The cheapest source for the local manager is influenced by T. To study this, we define an interim function $\hat{P}^S(T)$ and characterize the optimal transfer pricing policy as a function of $\hat{P}^S(T)$ in Proposition 3.

$$\hat{P}^S(T) = \arg\max_P \mathbb{E}\left[\Pi\left(T, P, \lambda^o\left(T, \boldsymbol{c}_E\right), \boldsymbol{c}_E\right)\right]$$

PROPOSITION 3. $T^S = \min\left(\hat{T}^S, \bar{c}_E\right)$*, where* $\hat{T}^S$ *solves* $T = \alpha \hat{P}^S(T)$*.*

Proposition 3 says that it is never optimal for HQ to offer a transfer price above the highest realization of cost to ensure outsourcing. First, consider the case without the tax advantage: if the tax rates are equal, the sourcing decision will be made purely based on the cost advantage; thus, it is always better to give the party that has better information an opportunity to choose the sourcing strategy rather than to restrict it to a single option. If there is a tax advantage in the foreign country, it is impractical for the company to set the transfer price so high that LM would never offshore, because HQ will lose the opportunity to take advantage of the favorable tax rate. Hence, $\bar{c}_E$ represents the *incentive upper bound* on T. As was the case in the centralized structure, the profit increases in the transfer price because of the opportunity to shift income to the low-tax jurisdiction; however, there are two upper bounds that the firm has to comply with: the legal upper bound and the incentive upper bound. As a result, the optimal transfer price is set at the least upper bound, which is the lowest value of $\hat{T}^S$ or $\bar{c}_E$. In our numerical study, the incentive upper bound $\bar{c}_E$ is tight in the vast majority of cases, 98.5%, of the cases.

Next, we discuss how HQ profit changes when the average cost increases.

PROPOSITION 4. *When $\bar{c}_E < \hat{T}^S$, there exists a $\hat{\beta}$, such that Π^S increases in μ when $\beta > \hat{\beta}$.*

Proposition 4 suggests that when the outsourcing decision is decentralized, but HQ controls the retail price and transfer price, the global firm may benefit from outsourcing opportunities with higher average cost. This seems counterintuitive at first glance. However, as the average outsourcing cost increases, in the two-point distribution, the highest realization of cost ($\bar{c}_E$) increases as well. Since LM bases its offshoring decision on the comparison of the cost realization and transfer price, HQ needs to keep T below $\bar{c}_E$ (Proposition 3). When $\bar{c}_E$ increases, HQ can set a higher transfer price and still comply with the incentive upper bound. Since this higher transfer price allows the firm to shift more income to the lower-tax jurisdiction, the after-tax profit will increase [2]. We conjecture that this behavior will be observed for all distributions in which the highest and the lowest realizations increase with the mean of the distribution. When cost variability is low ($\beta < \hat{\beta}$), the above logic does not hold because the value of information at the local level is low; or, mathematically speaking, the incentive upper bound is never tight.

[2] This result is not just an artifact of the two-point distribution. Based on our numerical experiments, this result continues to hold when the outsourcing cost follows a uniform distribution over $[\underline{c}_E, \bar{c}_E]$ instead of a two-point distribution

5.3. Decentralized Retail Pricing and Sourcing Decisions

So far we have discussed how sourcing and pricing decisions may be decentralized individually. In this subsection we study the case in which both the decisions are delegated to the local level simultaneously. In this case LM jointly sets the optimal selling price and the sourcing strategy for a given transfer price. HQ optimizes the consolidated after-tax profit over transfer price after taking into account the optimal reaction of LM and the legal constraints:

$$\begin{aligned} \Pi^{PS} &= \max_T \mathbb{E}[\Pi(T, P^{PS}(T, \boldsymbol{c}_E), \lambda^{PS}(T, \boldsymbol{c}_E), \boldsymbol{c}_E)] \qquad (5) \\ \text{s.t. } \big(T, P^{PS}(T, c_E)\big) &\in \mathcal{C} \ \forall \ c_E \in \{\underline{c}_E, \overline{c}_E\} \\ \text{where } \big(P^{PS}(T, c_E), \lambda^{PS}(T, c_E)\big) &= \arg \max_{P \geq 0, 0 \leq \lambda \leq 1} \pi_L(T, P, \lambda, c_E) \ \forall \ c_E \in \{\underline{c}_E, \overline{c}_E\} \end{aligned}$$

Now HQ has only one instrument, the transfer price, to induce LM to make the appropriate sourcing and retail pricing decisions and to try to leverage tax benefits at the same time. Lemma 5 provides insight into the solution of (5).

Lemma 5. *The optimal strategy of LM is as follows:* $\lambda^{PS}(T, c_E) = \lambda^o(T, c_E)$ *and the optimal price is:* $P^{PS}(T, c_E) = P^o(\min(T, c_E))$

Similar to the result in the case of decentralized sourcing and centralized retail pricing, LM chooses the cheapest supply source. The retail price is set at the optimal monopoly price since LM considers only the local profit. We now specify the optimal transfer price.

Proposition 5. *The optimal transfer pricing policy is as follows:* $T^{PS} = \min\left(\overline{T}^{PS}, \hat{T}^{PS}, \overline{c}_E\right)$, *where* $\hat{T}^{PS} = \alpha P^o(\underline{c}_E)$ *and* $\overline{T}^{PS} = \arg\max_T \mathbb{E}\left[\Pi\left(T, P^{PS}\left(T, \boldsymbol{c}_E\right), \lambda^{PS}\left(T, \boldsymbol{c}_E\right), \boldsymbol{c}_E\right)\right]$.

In this case, in addition to having a legal upper bound on the transfer price ($\hat{T}^{PS}$), there are two incentive upper bounds on the transfer price: one is determined by the pricing decision of LM ($\overline{T}^{PS}$) and the other by the sourcing decision of LM ($\overline{c}_E$). The optimal transfer price will be set to the smallest of the three. In our numerical study, the legal constraint is never binding and in 33.5% of the cases, the pricing incentive binds.

Proposition 6. *When* $\overline{c}_E < \min(\hat{T}^{PS}, \overline{T}^{PS})$, Π^{PS} *increases in* μ *when* $\mu < \hat{\mu}$.

This result is similar to Proposition 4. The profit increases in the average outsourcing cost, because the increased average cost allows HQ to set the transfer price higher to enjoy more tax savings on the shifted income. However, the profit starts to decrease once the average cost increases beyond the threshold $\hat{\mu}$, which was not true for the firm with a decentralized sourcing decision and a centralized pricing decision. This is caused by the fact that LM uses the transfer price to set the selling price in addition to using it for the sourcing decision. Since the firm faces downward sloping demand, a high transfer price causes the selling price to be high, which drives the demand down and results in decreased profit. Hence, when the average outsourcing cost is very high ($\mu > \hat{\mu}$), the profit will start to decrease in the average cost. Notice that there is no such effect in the structure with decentralized sourcing and centralized retail pricing because in that case the firm has centralized control over the retail price, and hence, a high transfer price does not decrease profit as long as it is in compliance with the incentive upper bound.

5.4. Summary of Results

In Table 1, we summarize the structural results obtained in the previous sections. In the analytical

	Centralized	Decentralized P	Decentralized S	Decentralized PS
P	$P^o(\mu)$ $P^o(\frac{c(1-\tau)}{1-t+\alpha(t-\tau)})$	$P^o(\lambda^P T + (1-\lambda^P)\boldsymbol{c}_E)$	$P^o(\frac{\underline{c}_E(1-t)+c(1-\tau)+T^S(\tau-t)}{4(1-t)})$	$P^o(\min(T, c_E))$
λ	$\lambda^C \in \{0,1\}$	$\lambda^P \in [0,1]$	$\lambda^S \in \{0,1\}$	$\lambda^{PS} \in \{0,1\}$
T	Legal UB	The lowest of: legal UB incentive UB for pricing	The lowest of: legal UB incentive UB for sourcing	The lowest of: legal UB incentive UB for sourcing incentive UB for pricing
$\Pi(\mu)$	$\downarrow$	$\downarrow$	$\updownarrow$	$\updownarrow$

Table 1 Summary of structural results

part of our study, we examine the impact of tax differences and cost differences on the sourcing and transfer pricing strategies of a global firm. For fully centralized firms, we identify a tradeoff curve between foreign cost and foreign tax rate that can be used by managers of global firms to determine what production cost they can accept in a foreign country where they face a certain tax advantage, or vice versa. We show further that the dual role of transfer prices, tax purpose and incentives purpose, has a nontrivial impact on the sourcing decisions of the firm. Namely, we characterize the following results.

First, we notice the difference in retail prices. Even though the retail pricing follows the same structure as the standard monopoly pricing solution, it incorporates taxes via the cost term. The impact of taxes on price is different for various organizational structures. Second, we highlight the difference in the sourcing strategy among organizational structures. The only case in which the optimal sourcing strategy differs from the all-or-nothing solution is the case when the retail pricing decision is decentralized. This phenomenon is driven by the legal constraint on the transfer price that forces the transfer price to be no larger than the retail price marked down by a fixed percentage. Third, we highlight the dual role of transfer pricing that forces the transfer price to be at the least upper bound provided by legal and incentive restrictions. Finally, we summarize the profit behavior with respect to changes in the average external cost. Here we notice the surprising managerial insight in the cases with decentralized sourcing that if the manager faces a choice of two suppliers in the global setting, it may be beneficial to pick the more expensive one for incentives/tax reasons.

6. Numerical study

In our numerical study summarized below (Table 2), we study 1) what is the best organizational structure for a global firm that wants to take advantage of tax differentials using transfer pricing and sourcing strategies and 2) what is the value of optimizing the transfer price.

	Low value	**High value**	**Increment**	**Number**
b, ξ is fixed at 10	1	3	2	2
τ, t is fixed at 0.35	0.15	0.35	0.05	5
μ	0.2	0.5	0.1	4
β	0.4	1	0.2	4
α	0.7	1	0.1	4
c	$\mu(1-\beta)$	$\mu(1+\beta)$	$\frac{2\mu\beta}{3}$	4
Total number of experiments:				**2560**

Table 2 Setup for the numerical study

What is the best organizational structure?

We have analyzed different decentralization options for global firms and showed the impact of these structures on the optimal decisions and profitability of the firm. There are two major drivers in our model that affect the optimal solutions: cost variability that determines the scope of information asymmetry and tax differential that creates an opportunity for tax savings. Now, with the next sequence of plots (Figures 4-7), we compare after-tax profits of global firms with four different organizational structures and demonstrate the impact of these two drivers on the selection of the best structure. We start our analysis with Figure 4 that focuses on one of the drivers - high cost variability ($\beta = 1$), while the tax differential is set to 0 ($t = \tau$).

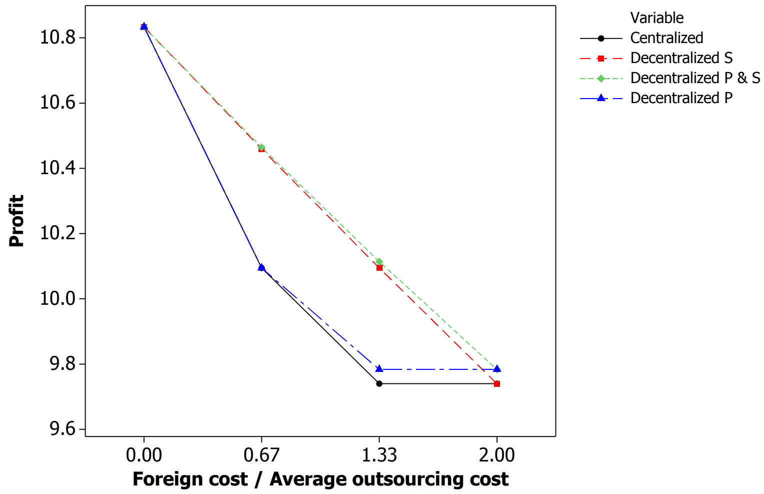


Figure 4 Average profit for each organizational structure as a function of the foreign cost relative to the average outsourcing cost when the coefficient of variation is high ($\beta = 1$) and the foreign tax rate is equal to the local tax rate ($\tau \in \{0.35\}$).

When cost is variable, but there is no tax advantage, any decentralized solution, in which the better informed party makes one or more decisions, is at least as good as the centralized. Hence, the best structure is when both decisions are delegated to the party that has better information. It is not surprising that decentralization of the sourcing decision is almost always more valuable than decentralization of the pricing decision: since the firm is facing a downward sloping demand curve, selecting the most economical production source (regardless of who sets the price) is more important than pricing the product appropriately after HQ has chosen a non-efficient supply source.

This observation is not valid at the extreme points because when the foreign cost is equal to the highest realization of the external cost $\frac{c}{\mu} = \frac{\bar{c}_E}{\mu} = \frac{\mu(1+\beta)}{\mu} = 1 + \beta = 2$ (or to the lowest realization of the external cost $\frac{c}{\mu} = \frac{\underline{c}_E}{\mu} = \frac{\mu(1-\beta)}{\mu} = 1 - \beta = 0$), the sourcing decision is trivial - always outsource (or always offshore), and hence, decentralization of the sourcing decision does not bring any additional value.

In Figure 5, we focus on the second driver: we set tax differential high $(t - \tau \geq 0.15)$ and cost variability very low $(\beta = 0.4)$.

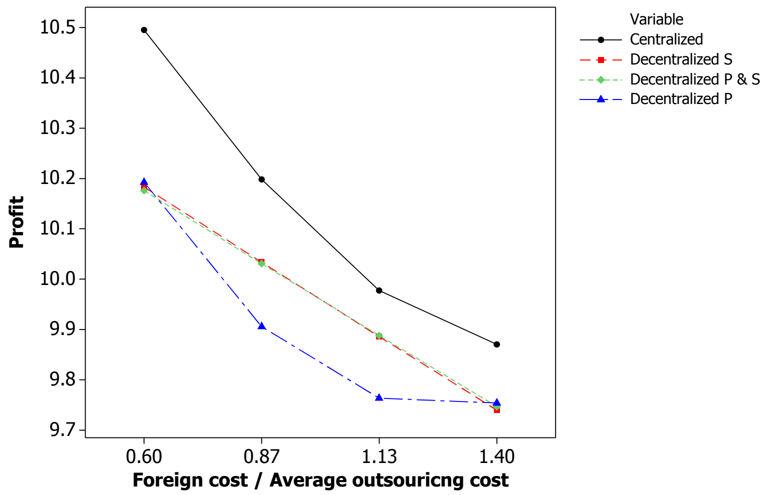


Figure 5 Average profit for each organizational structure as a function of the foreign cost relative to the average outsourcing cost when the coefficient of variation is low ($\beta = 0.4$) and the foreign tax rate is low ($\tau \in \{0.15, 0.20\}$).

Now, we can see that when the coefficient of variation is low, the centralized structure outperforms the decentralized structures, because when the variability of cost is low, better information about the cost has little value, but an opportunity to take advantage of high tax differential has high value. Notice that when the foreign cost is close to the extreme values of the average outsourcing cost ($\frac{c_F}{\mu} = 0.6$ or $\frac{c_F}{\mu} = 1.4$), the second best solution is to decentralize only the pricing decision. Decentralization of sourcing has little value at the extremes because the sourcing decision is rather straightforward: offshore everything when the foreign cost is low or outsource everything when the foreign cost is high. However, when the foreign cost is in the middle, the sourcing decision is less trivial and therefore, decentralization of sourcing becomes the second best.

It is more interesting to see what happens when we combine the effects of these two drivers. In Figure 6, we consider a case when the cost variability is high and the tax differential exists, but it is small ($t - \tau \leq 0.05$).

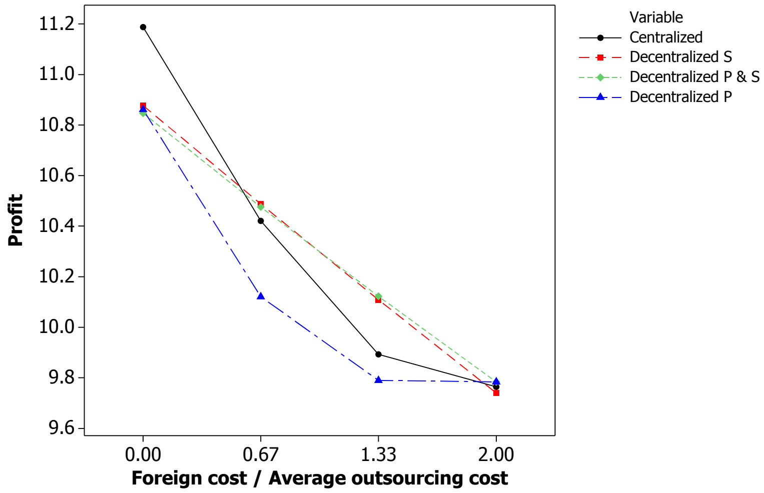


Figure 6 Average profit for each organizational structure as a function of the foreign cost relative to the average outsourcing cost when the coefficient of variation is high ($\beta = 1$) and the foreign tax rate is high ($\tau \in \{0.30, 0.35\}$).

The best organizational structure in this scenario is highly dependent on the ratio of the foreign cost to the average outsourcing cost. When the foreign cost is substantially lower than the average outsourcing cost ($c_F < 0.62$), the centralized structure performs better than any decentralized arrangement. This is intuitive because when the foreign supply source is cheap, it is very likely that the best sourcing strategy is to offshore and thus, knowledge about external cost has little value. As the foreign cost increases (e.g. $\frac{c_F}{\mu} = 0.67$), the sourcing decision is less obvious, and it becomes worthwhile to delegate the sourcing decision to LM who has additional information about the external sourcing cost. Now, we discuss a more subtle result: when $\frac{c_F}{\mu}$ is low (e.g. $\frac{c_F}{\mu} = 0.67$), decentralization of the pricing decision is not beneficial. It may seem intuitive that if LM has better information about cost and there is no cost of decentralization, delegating the pricing decision to the better informed party should be always beneficial. However, for the global firm that faces tax differences and that wants to take advantage of transfer pricing, retail price is a constraining factor for setting the transfer price, and hence, it affects the firm's ability to use transfer pricing. As a result, decentralization of the pricing decision is not always beneficial and in particular, it is not beneficial when the foreign supply source is relatively cheaper than outsourcing and it is more likely that the firm will offshore. As $\frac{c_F}{\mu}$ increases and it becomes more profitable to outsource, cost information becomes more valuable for the pricing decision and transfer pricing is not useful (because there is no transfer price when the firm outsources). Consequently, decentralization of pricing on top of decentralization of sourcing becomes beneficial. When $\frac{c_F}{\mu}$ reaches its maximum ($\frac{c_F}{\mu} = 2$ in Figure 6), the sourcing decision is trivial (it is always better to outsource), therefore decentralization of pricing performs as well as decentralization of both pricing and sourcing decisions.

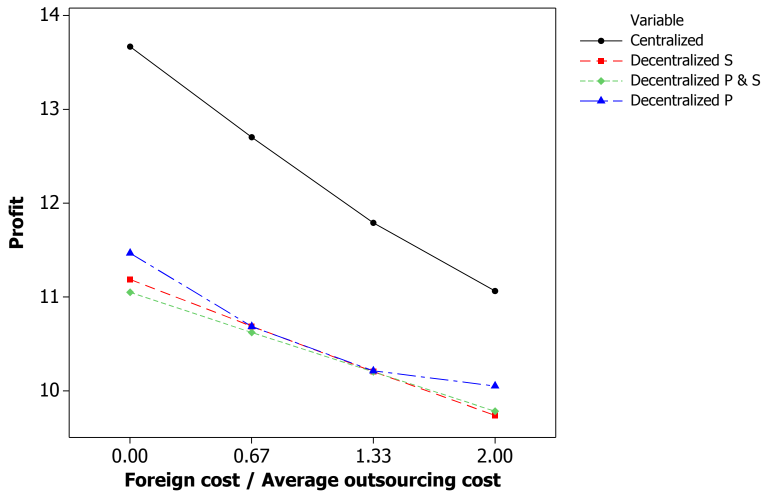


Figure 7 Average profit for each organizational structure as a function of the foreign cost relative to the average outsourcing cost when the coefficient of variation is high ($\beta = 1$) and the foreign tax rate is low ($\tau \in \{0.15, 0.20\}$).

Finally, we notice that when the cost variability is high and tax differential is high (Figure 7), profit improvement from tax benefits always dominates the value of better information and it is always optimal for the firm to maintain fully centralized structure. The relative comparison of the decentralized structures in Figure 7 differs from the scenario discussed above when the tax differential was low. Now, the second best structure is to decentralize only the pricing decision for the same reason: it is better for the firm to keep the control over the sourcing decision because they have high interest in using the transfer price.

In summary, when the tax differential is large, it is best to centralize all decisions even in the presence of information asymmetry. If the tax differential is small, it may be better to decentralize the pricing and/or sourcing decision in order to take advantage of information asymmetry. If a company has to choose between decentralizing pricing or decentralizing sourcing, it is almost always better to decentralize the sourcing decision as this allows a direct application of LM's information and also influences pricing.

What is the value of optimizing transfer price?

One of the simplest transfer pricing solutions commonly used in practice is transferring products at cost. In this subsection, we assess the value of transferring goods at an optimized transfer price rather than at cost and also investigate how this value is affected by various business parameters. First, we show the value of optimizing the transfer price for the centralized case when the cost variability is high (Figure 8).

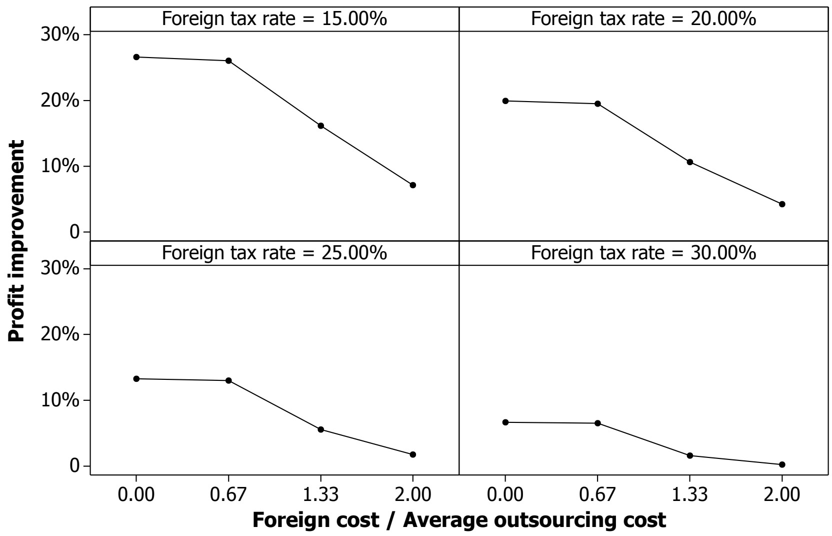


Figure 8 Percentage improvement in profit from using optimal transfer price as opposed to transferring items at cost in the fully centralized organizational structure when the coefficient of variation is high ($\beta = 1$).

When the foreign cost is low relative to the average outsourcing cost and the tax differential is high, it is often optimal for the company to offshore, hence the value of optimizing the transfer price is high. As either the foreign cost differential decreases or the foreign tax rate increases, the firm will offshore more rarely and the value of optimizing the transfer price decreases.

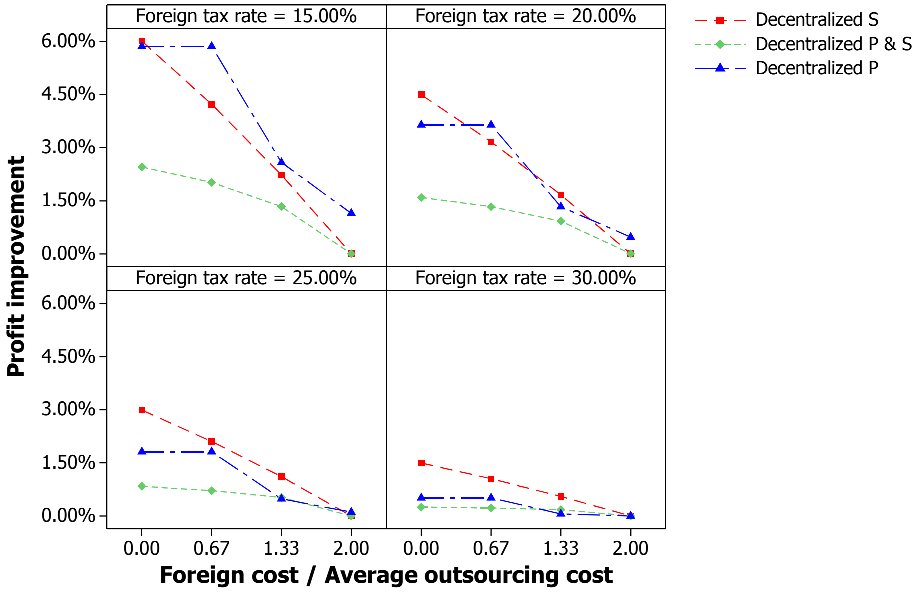


Figure 9 **Percentage improvement in profit from using optimal transfer price as opposed to transferring items at cost when the coefficient of variation is high ($\beta = 1$)**

Now, we look at the value of optimizing transfer prices in the decentralized structures (Figure 9). In the decentralized structures, the transfer price plays an additional role as an incentive mechanism, which puts an additional constraint on the transfer price. Decentralization of two decisions (pricing and sourcing) adds tighter bounds than decentralization of one (pricing or sourcing) and thus, the fully decentralized structure gets the least value from optimized transfer pricing.

When the tax differential is high ($t = 0.15$), HQ has strong desire to motivate LM to offshore, thus, the incentive constraint on the transfer price is very tight and the organizational structure with decentralized sourcing gets the second worst improvement from optimizing transfer price. When the tax differential is small ($t = 0.3$), HQ has less need to motivate offshoring behavior from LM, the incentive constraint on transfer price becomes less strict and the value of optimizing transfer price becomes higher in the structure with decentralized sourcing.

7. Conclusion and Further Research

This study contributes to the supply chain management literature by incorporating international taxation considerations into global sourcing and pricing decisions of multinational firms. We quantify the advantage of using transfer pricing to take advantage of tax differentials and observe that profit improvement can be as large as 30%.

One of the existing literature streams on global supply chain management that addresses international taxation and transfer pricing (such as Vidal and Goetschalckx (2001), Cohen and Lee (1989)) focuses on creating comprehensive mathematical programs and solution methods for optimizing large supply chains. These methods are practical, however, they do not provide theoretical insights in the interaction of taxation and operational decisions. Our stylized model allows obtaining more fundamental insights in the cost/tax advantage trade-off and provide important managerial guidelines summarized below. In addition, our model explicitly addresses the dual role of transfer pricing (the incentive and the tax role) and analyzes the impact of the incentive role of transfer prices in the presence of cost information asymmetry, which adds on to the second stream of related literature (Kouvelis and Gutierrez 1997, Huh and Park 2008).

Our results can be summarized as follows. First, we analytically derive a tradeoff curve between the cost and tax advantages that drives the global firms' choice of sourcing strategy. The curve demonstrates that the offshoring option with a significant tax advantage should be considered even if it does not have a cost advantage. Managers can use the tradeoff curve provided by our model to determine the cost increase that the firm can tolerate for a given tax advantage; or vice versa, for a given cost structure at a foreign facility, determine what tax rate should be negotiated with the government. Further, we show that the decentralization structure of the firm determines the form of the sourcing solution. For example, partial offshoring solution can be optimal only for firms that decentralize pricing decision but keep sourcing decision at the central level. This finding immediately limits the sourcing options to be considered by management of firms with other organizational structures. We also show that the fully centralized firms benefit more from optimizing transfer pricing and consequently, centralized firms should offshore more often. In the presence of information asymmetry, it is better to decentralize the pricing and/or sourcing decision especially if the tax differential is small. If a company has to choose between decentralizing pricing or decentralizing sourcing, it is almost always better to decentralize the sourcing decision. Finally, we explain the taxation and incentive reasons behind a counterintuitive finding that if the cost of a sourcing option increases, the company can make larger profits. With this knowledge in hand, the managers of global firms may consider choosing more expensive suppliers as this may lead to increased profits.

There are a number of ways in which this research can be extended. Our model currently assumes that there is unlimited capacity available in the foreign country if the firm decides to offshore. When this capacity is restricted, full offshoring may not be feasible and the threshold for transfer price that makes it worthwhile for the firm to offshore would increase. As a consequence, it would be interesting to incorporate a capacity investment decision into the offshoring options and derive a new tradeoff curves between the tax and cost advantages.

Another possible extension would be to consider the availability of a market in the offshoring location for the product. In such a case, there are more business decisions to be made in the model: (i) what is the retail price in the foreign market? and (ii) how should the available capacity be allocated between the two markets? The foreign division could become an active player and HQ could delegate these decisions to the foreign management. Since the foreign division is situated closer to the foreign market, it may have better information about the demand parameters than HQ, adding another layer of information asymmetry to the model.

Finally, considering random demand at the local and/or foreign market could lead us to a more realistic problem setting and practicable guidelines. Shunko and Gavirneni (2007) show that transfer pricing adds more value in supply chains facing random demand, deterministic costs and without an option to outsource. It would be interesting to see whether this result continues to hold in the presence of information asymmetry and an endogenous sourcing decision.

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8. Appendix

Parameters	
ξ	Market size
b	Price elasticity
t and τ	Tax rates in the local and foreign countries respectively
c	Offshoring cost
α	Markdown on retail price
Random variable and associated parameters	
$\boldsymbol{c}_E$	Outsourcing cost: $\Pr(\boldsymbol{c}_E = \underline{c}_E) = \Pr(\boldsymbol{c}_E = \overline{c}_E) = \frac{1}{2}$
μ and β	Mean and coefficient of variation of the outsourcing cost
Decision variables	
P	Price
λ	Offshoring proportion
T	Transfer price
Superscripts identifying organizational structures	
C	Centralized decision making with information asymmetry
P	Decentralized retail pricing
S	Decentralized sourcing
PS	Decentralized retail pricing and sourcing
Subscripts	
L and F	Refer to the Local and Foreign divisions
Functions	
$D(P)$	Demand function
$\pi_L(T,P,\lambda,\boldsymbol{c}_E)$ and $\pi_F(T,P,\lambda,\boldsymbol{c}_E)$	Pre-tax profits of the Local and Foreign divisions
$\Pi(T,P,\lambda,\boldsymbol{c}_E)$	Consolidated after-tax profit of the firm
$\Pi^o(P,\boldsymbol{c}_E)$	Is equal to $\Pi(T,P,0,\boldsymbol{c}_E)$ which is independent of T
$\lambda^o(T,c_E)$	Is equal to 1 if $T < c_E$ and 0 if $T > c_E$
Set	
$\mathcal{C}$	Legal bounds on the transfer price
Thresholds	
$\hat{c}$,$\overline{c}$,$\hat{\beta}$,$\hat{\mu}$	Thresholds on corresponding parameters

Table 3 Summary of notation

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Proofs of Statements

EC.0.1. Summary of parameter restrictions

Tax rates: $0 < t < 1$, $0 < \tau < 1$, and $t > \tau$.

Markdown parameter: $0 < \alpha < 1$.

Cost parameters: $0 < \beta < 1$, $\underline{c}_E < c < \overline{c}_E$, and $\mu = \frac{\underline{c}_E + \overline{c}_E}{2}$.

Positive demand: $\xi > \max(\frac{c}{\alpha}, \overline{c}_E)$, which implies $\xi > \underline{c}_E$, $\xi > c$, and $\xi > \mu$.

EC.0.2. Proofs

Proof of Lemma 1 In this lemma we derive the optimal strategy of the global firm when there is no tax differential. We present the proof in the following steps. First, we show that $\Pi^C(T, P, \lambda, \mu | t = \tau)$ is independent of T (Step 1). Second, we find λ^C by using the envelope theorem to show that $\Pi^C(T, P, \lambda, \mu | t = \tau)$ increases (decreases) in λ when $\mu > (<) c$ (Step 2). Finally, we find optimal price using first order conditions (Step 3).

Step 1: $\Pi^C(T, P, \lambda, \mu | t = \tau)$ *is independent of* T. When $t = \tau$, $\Pi^C(T, P, \lambda, \mu | t = \tau)$ simplifies to $\hat{\Pi}^C(P, \lambda, \mu) = (\xi - bP)(P - (1-\lambda)\mu - \lambda c)(1-t)$ and hence, is independent of T.

Step 2: Find λ^C. By envelope theorem, $\frac{d\hat{\Pi}^C(P,\lambda,\mu)}{d\lambda} = \frac{\partial \hat{\Pi}^C(P,\lambda,\mu)}{\partial \lambda}\Big|_{P=\hat{P}^C(\lambda)} = (\xi - b\hat{P}^C(\lambda))(1-t)(\mu - c)$, where $\hat{P}^C(\lambda)$ is the solution to $\frac{\partial \hat{\Pi}^C(P,\lambda,\mu)}{\partial P} = 0$. Given our parameter restrictions, $\xi - b\hat{P}^C(\lambda) > 0$, hence, if $\mu > c$, profit increases in λ, thus, set $\lambda^C = 1$ and vice versa.

Step 3: Find P^C. When $\lambda^C = 0$, $\hat{\Pi}^C(P, \lambda, \mu) = \Pi^o(P, \mu)$. Hence, the solution is $P^C = P^o(\mu)$. When $\lambda^C = 1$, $\hat{\Pi}^C(P, \lambda, \mu)$ is analogous to $\Pi^o(P, c)$. Hence, the solution is $P^C = P^o(c)$. $\square$

Proof of Proposition 1 In Proposition 1, we characterize optimal offshoring policy, optimal transfer prices, and optimal retail prices for the firm that faces a tax differential. As part of the optimal solution, we characterize the threshold that separates offshoring from outsourcing solution and claim that the threshold is greater than the average outsourcing cost. We present this proof in the following steps. First, we find optimal transfer price (T^C) and plug it into the profit function (Step 1). Then, we find the optimal price as a function of λ ($\hat{P}^C(\lambda)$) and plug it into the profit function (Step 2). Next, we show that $\Pi(\hat{P}^C(\lambda), \lambda, \mu)$ is convex in λ and hence, there are two candidate solutions (Step 3). Next, derive the threshold on c that determines which candidate solution for λ is optimal (Step 4). And finally, we demonstrate that $\hat{c} > \mu$ (Step 5).

Step 1: Find optimal transfer price. By a direct application of envelope theorem, we notice that when $\lambda \neq 0$ and $t > \tau$, $\Pi(T, P, \lambda, \mu)$ increases in T for all P and λ; hence, we set $T^C = \alpha P$ and look for optimal price.

Step 2: Find optimal price. The profit function is concave in P ($\frac{\partial^2 \Pi(\alpha P, P, \lambda, \mu)}{\partial P^2} = -2b(1 - t + \alpha\lambda(t - \tau)) < 0$). Thus, we look at first order condition with respect to P:

$$\frac{\partial \Pi(\alpha P, P, \lambda, \mu)}{\partial P} = (\xi - 2bP)(1 - t + \alpha\lambda(t - \tau)) + b\mu(t-1)(\lambda - 1) - b\lambda(\tau - 1)c = 0$$

Which leads to the following solution:

$$\hat{P}^C(\lambda) = \frac{b\mu(t-1)(\lambda-1) + \xi(1 - t + \alpha\lambda(t-\tau)) - b\lambda(\tau-1)c}{2b(1 - t + \alpha\lambda(t-\tau))}$$

Step 3: Show that there are two candidate solutions for λ. Since $\frac{d^2 \Pi(\alpha \hat{P}^C(\lambda), \hat{P}^C(\lambda), \lambda, \mu)}{d\lambda^2} = \frac{b(1-t)^2(\mu(1-t+\alpha(t-\tau)) - (1-\tau)c)^2}{2(1-t+\alpha\lambda(t-\tau))^3} > 0$, the function is convex in λ. Two candidate solutions for the firm can be fully characterized as following:

1. Outsource all needs ($\lambda^C = 0$) and set $P^C = \frac{\mu}{2} + \frac{\xi}{2b}$, which results in $\Pi^o(P^C, \mu) = \frac{(\xi - b\mu)^2}{4b}(1-t)$.
2. Otherwise, offshore all production ($\lambda^C = 1$), set transfer price as high as possible ($T^C = \alpha P^C$), and set $P^C = \frac{\xi}{2b} + \frac{(1-\tau)c}{2(1-t)+2\alpha(t-\tau)}$, which results in $\Pi^C(\alpha P^C, P^C, 1, \mu) = \frac{(\xi(1-t+\alpha\lambda(t-\tau)) + b(\tau-1)c)^2}{4b(1-t+\alpha\lambda(t-\tau))}$.

Step 4: Find threshold $\hat{c}$. Now we compare two solutions above. We will outsource when $\Pi^o(P^C, \mu) > \Pi^C(\alpha P^C, P^C, 1)$:

$$(\xi - b\mu)^2 > \frac{(\xi(1 - t + \alpha(t-\tau)) - b(1-\tau)c)^2}{(1 - t + \alpha(t-\tau))(1-t)}$$

The condition is quadratic in c and there is only one root that satisfies the parameter restriction on c:

$$\hat{c} = \frac{\xi(1 - t + \alpha(t-\tau)) - (\xi - b\mu)\sqrt{(1-t)(1-t+\alpha(t-\tau))}}{b(1-\tau)}$$

Step 5: Show that $\hat{c} > \mu$.

$$\hat{c} = \frac{\mu\sqrt{(1-t)(1-t+\alpha(t-\tau))}}{(1-\tau)} + \frac{\xi(1-t+\alpha(t-\tau)) - \xi\sqrt{(1-t)(1-t+\alpha(t-\tau))}}{b(1-\tau)}$$

We can view $\hat{c}$ as $\mu A + B$, where

$$A = \frac{\sqrt{(1-t)(1-t+\alpha(t-\tau))}}{(1-\tau)} = \frac{\sqrt{(1-t)^2+\alpha(t-\tau)(1-t)}}{(1-\tau)} \geq \frac{1-t}{1-\tau} \geq 1$$

$$B = \frac{\xi\sqrt{1-t+\alpha(t-\tau)}(\sqrt{1-t+\alpha(t-\tau)}-\sqrt{(1-t)})}{b(1-\tau)} \geq 0$$

Therefore, $\mu A + B > \mu$. $\square$

Proof of Lemma 2 We find comparative statics (CS) of the threshold $\hat{c}$ by taking partial derivatives with respect to relevant parameters α, ξ, and b and evaluating their signs:

Step 1: CS with respect to α.

$$\frac{\partial \hat{c}}{\partial \alpha} = \frac{(t-\tau)\left((1-t)(b\mu-\xi)+2\xi\sqrt{(1-t)(1-t+\alpha(t-\tau))}\right)}{2b(1-\tau)\sqrt{(1-t)(1-t+\alpha(t-\tau))}}$$

To show that $\frac{\partial \hat{c}}{\partial \alpha}$ is positive, we first claim that $\frac{\partial \hat{c}}{\partial \alpha}$ evaluated at $\alpha = 0$ is positive and then claim that $\frac{\partial \hat{c}}{\partial \alpha}$ is increasing in α by showing that $\frac{\partial^2 \hat{c}}{\partial \alpha^2}$ is positive $\forall \alpha \in [0,1]$:

$$\left.\frac{\partial \hat{c}}{\partial \alpha}\right|_{\alpha=0} = \frac{(b\mu+\xi)(t-\tau)}{2b(1-\tau)} > 0 \text{ and } \frac{\partial^2 \hat{c}}{\partial \alpha^2} = \frac{\sqrt{1-t}(\xi-b\mu)(t-\tau)^2}{4b(1-\tau)(1-t+\alpha(t-\tau))^{3/2}} > 0 \Rightarrow \frac{\partial \hat{c}}{\partial \alpha} > 0$$

Step 2: CS with respect to ξ.

$$\frac{\partial \hat{c}}{\partial \xi} = \frac{\left(\sqrt{1-t+\alpha(t-\tau)}-\sqrt{1-t}\right)\sqrt{1-t+\alpha(t-\tau)}}{b(1-\tau)} > 0, \text{ since } t > \tau$$

Step 3: CS with respect to b.

$$\frac{\partial \hat{c}}{\partial b} = -\frac{\xi\left(\sqrt{1-t+\alpha(t-\tau)}-\sqrt{1-t}\right)\sqrt{1-t+\alpha(t-\tau)}}{b^2(1-\tau)} < 0, \text{ since } t > \tau$$

$\square$

Proof of Lemma 3 In Lemma 3, we solve a relaxed problem that ignores the legal constraints. We present the optimal pricing policy for LM and then, the optimal sourcing decision and transfer price for HQ. First, we find $P^P(T, \lambda, c_E)$ by solving LM's problem and plug it into HQ's profit function (Step 1). Next, we optimize HQ's profit by first finding optimal transfer price as a function of λ ($\hat{T}^P(\lambda)$) (Step 2), and then, show that HQ's profit is convex in λ, is discontinuous at $\lambda = 0$, $\lim_{\lambda\to 0} \mathbb{E}[\Pi(\hat{T}^P(\lambda), P^P(\hat{T}^P(\lambda), \lambda, \boldsymbol{c}_E), \lambda)] > \mathbb{E}[\Pi^P(\lambda = 0, P^o(\boldsymbol{c}_E))]$, and hence, there are two candidate sourcing solutions: full offshoring and ϵ-offshoring, where ϵ represents a smallest unit that the company can offshore (Step 3). Finally, we derive the threshold that determines whether the full or ϵ-offshoring solution is optimal (Step 4).

Step 1: Solve LM's problem. Since local profit is concave in P ($\frac{d^2\pi_L(T,P,\lambda,c_E)}{dP^2} = -2b < 0$), LM finds the optimal price using the first order condition:

$$\frac{d\pi_L(T,P,\lambda,c_E)}{dP} = \xi - 2bP + bc_E(1-\lambda) + bT\lambda = 0$$
$$P^P(T,\lambda,c_E) = \frac{\xi + bc_E(1-\lambda) + bT\lambda}{2b}$$

Thus, the total profit for the headquarters is:

$$\Pi(T, P^P(T,\lambda,\boldsymbol{c}_E),\lambda,\boldsymbol{c}_E) = \frac{(\xi - b\boldsymbol{c}_E(1-\lambda) - bT\lambda)\left((1-t)(\xi - b\boldsymbol{c}_E(1-\lambda)) + bT\lambda(t-2\tau+1) - 2b\lambda(1-\tau)c\right)}{4b}$$

Step 2: Find $\hat{T}^P(\lambda)$. Since $\mathbb{E}[\Pi(T,P^P(T,\lambda,\boldsymbol{c}_E),\lambda)]$ is concave in T for all $\lambda \neq 0$ ($\frac{\partial^2\mathbb{E}[\Pi^P(T,P^P(T,\lambda,\boldsymbol{c}_E),\lambda,\boldsymbol{c}_E)]}{\partial T^2} = -\frac{1}{2}b\lambda^2(1+t-2\tau) < 0$), we will first optimize over T using the first order condition:

$$\frac{\partial\mathbb{E}[\Pi(T,P^P(T,\lambda,\boldsymbol{c}_E),\lambda,\boldsymbol{c}_E)]}{\partial T} = \frac{1}{2}\lambda\left((t-\tau)(\xi-b\mu) + b\lambda\mu(t-\tau) - Tb\lambda(t-2\tau+1) + b\lambda c(1-\tau)\right)$$
$$\hat{T}^P(\lambda) = \frac{b\lambda(\tau-1)c + (\xi + b(\lambda-1)\mu)(\tau-t)}{b\lambda(2\tau-t-1)} = c\frac{(1-\tau)}{(1-2\tau+t)} + \frac{(\xi - b(1-\lambda)\mu)(t-\tau)}{b\lambda(1-2\tau+t)}$$

Step 3: Show convexity and discontinuity. The total expected profit at optimal transfer price is:

$$\begin{aligned}&\mathbb{E}[\Pi(\hat{T}^P(\lambda),P^P(\hat{T}^P(\lambda),\lambda,\boldsymbol{c}_E),\lambda)] =\\ &\frac{1}{4}b\lambda^2((1-\tau)^2\frac{(\mu-c)^2}{t-2\tau+1} + \sigma^2(1-t)) + \frac{1}{2}\lambda((\tau-1)^2(\xi-b\mu)\frac{\mu-c}{t-2\tau+1} + b\sigma^2(t-1)) +\\ &\frac{1}{4b}(\tau-1)^2\frac{(\xi-b\mu)^2}{t-2\tau+1} - \frac{1}{4}b\sigma^2(t-1)\end{aligned}$$

$\mathbb{E}[\Pi(\hat{T}^P(\lambda),P^P(\hat{T}^P(\lambda),\lambda,\boldsymbol{c}_E),\lambda)]$ is quadratic in λ and the quadratic coefficient is positive, therefore the function is convex in λ and the optimum is at an extreme point. $\lim_{\lambda\to 0}\mathbb{E}[\Pi(\hat{T}^P(\lambda),P^P(\hat{T}^P(\lambda),\lambda,\boldsymbol{c}_E),\lambda)] = \frac{(\xi-b\mu)^2}{4b}\frac{(1-\tau)^2}{t-2\tau+1} + \frac{1}{4}b\sigma^2(1-t)$ and $\mathbb{E}[\Pi^P(\lambda=0,P^o(\boldsymbol{c}_E))] = \frac{(\xi-b\mu)^2}{4b}(1-t)$, the function is discontinuous at $\lambda=0$ and since $\frac{(1-\tau)^2}{t-2\tau+1} > (1-t)$, $\lim_{\lambda\to 0}\mathbb{E}[\Pi(\hat{T}^P(\lambda),P^P(\hat{T}^P(\lambda),\lambda,\boldsymbol{c}_E),\lambda)] > \mathbb{E}[\Pi^P(\lambda=0,P^o(\boldsymbol{c}_E))]$ and $\lambda=0$ is not a candidate solution. When $\lambda=1$, optimal profit is $\mathbb{E}[\Pi^P(\hat{T}^P(1),P^o(\hat{T}^P(1)),1)] = \frac{(\xi-bc)^2}{4b}\frac{(1-\tau)^2}{(t-2\tau+1)}$.

Step 4: Find threshold on c that determines between full offshoring or ϵ-offshoring. We compare $\lim_{\lambda\to 0}\mathbb{E}[\Pi(\hat{T}^P(\lambda), P^P(\hat{T}^P(\lambda),\lambda,\boldsymbol{c}_E),\lambda)]$ with $\mathbb{E}[\Pi^P(\hat{T}^P(1), P^o(\hat{T}^P(1)),1)]$ to find threshold $\bar{c}$:

$$\frac{(\xi-b\mu)^2}{4b}\frac{(1-\tau)^2}{t-2\tau+1}+\frac{1}{4}b\sigma^2(1-t)-\frac{(\xi-bc)^2}{4b}\frac{(1-\tau)^2}{(t-2\tau+1)}=0$$
$$c=\frac{\xi}{b}\pm\frac{1}{b(1-\tau)}\sqrt{(\tau-1)^2(\xi-b\mu)^2-b^2\sigma^2(t-1)(t-2\tau+1)}$$

Since $c\le\frac{\xi}{b}$ by assumption, only one solution is feasible: $\bar{c}=\frac{\xi}{b}-\frac{1}{b(1-\tau)}\sqrt{(\tau-1)^2(\xi-b\mu)^2-b^2\sigma^2(t-1)(t-2\tau+1)}$. □

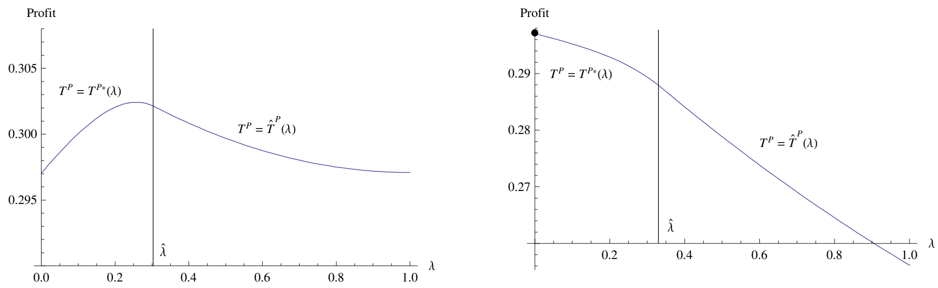
Proof of Proposition 2 In Proposition 2, we add the legal constraint to the result from Lemma 3 and demonstrate that there may exist a partial sourcing solution and derive an upper bound on this partial solution. Notice that optimal transfer price $\hat{T}^P(\lambda)$ from Lemma 3 may not be feasible as it has to satisfy the legal constraint $\mathcal{B}(\lambda)$: $\hat{T}^P(\lambda)-\alpha P^P(\hat{T}^P(\lambda),\lambda,\underline{c}_E)\le 0$. In the proof we first demonstrate using a numerical example that there may exist an interior solution for λ that implies partial offshoring (Step 1). Then, for a special case when $\alpha=1$, we derive an upper bound $\hat{\lambda}$ on the partial solution by showing that the bound $\mathcal{B}(\lambda)$ is violated only for $\lambda<\hat{\lambda}$ (Step 2).

Step 1: Existence of an interior solution. We use $T^{P*}(\lambda)$ to denote the solution to $T=\alpha P^P(T,\lambda,\underline{c}_E)\Rightarrow T^{P*}(\lambda)=\frac{\alpha(\xi+b\underline{c}_E(1-\lambda))}{b(2-\alpha\lambda)}$. For all λ, such that $\mathcal{B}(\lambda)>0$, optimal profit as a function of λ is $\mathbb{E}[\Pi(T^{P*}(\lambda),P^P(T^{P*}(\lambda),\lambda,c_E),\lambda)]$. Notice that $\mathbb{E}[\Pi](T,P,\lambda,\mu)$ is a function of $P\times T\times\lambda$. Hence, given the form of $T^{P*}(\lambda)$, $\mathbb{E}[\Pi(T^{P*}(\lambda),P^P(T^{P*}(\lambda),\lambda,c_E),\lambda)]$ is a division of 4th degree polynomial by a 2nd degree polynomial. Analyzing this function involves evaluating the derivative that involves a 5th degree polynomial with parameterized coefficients. We were unable to obtain an analytical result and therefore, we show that there exists an interior solution using a numerical example (Figure 1(a)).

Step 2: Upper bound on the interior solution. We show the next result for the special case when $\alpha=1$:

$$\mathcal{B}(\lambda):\frac{2bc\lambda(\tau-1)+(2b(\lambda-1)\mu+2\xi)(\tau-t)}{2b\lambda(-t+2\tau-1)}+\frac{\xi+b(1-\lambda)\underline{c}_E}{b(\lambda-2)}\le 0$$

We show that there exists a unique $\hat{\lambda}$, such that $\forall\lambda<\hat{\lambda}$, $\mathcal{B}$ does not hold. $\lim_{\lambda\to 0}\mathcal{B}(\lambda)=\infty$, $\mathcal{B}(1)=-\frac{(\xi-bc)(1-\tau)}{b(t-2\tau+1)}\le 0$. $\frac{d\mathcal{B}(\lambda)}{d\lambda}=\frac{b\mu(t-\tau)(\lambda-2)^2-\xi\left(-3\tau\lambda^2+\lambda^2+4\tau\lambda+2t\left(\lambda^2-2\lambda+2\right)-4\tau\right)+b\lambda^2(t-2\tau+1)\underline{c}_E}{b(\lambda-2)^2\lambda^2(t-2\tau+1)}$, the numerator of



(a) Interior solution, $c = 0.4$. (b) Boundary solution, $c = 0.55$.

Figure EC.1 Illustrate possible solutions for a numerical example (Common parameters: $\mu = 0.4$**,** $\xi = 1$**,** $b = 0.4$**,** $t = 0.35$**,** $\tau = 0.2$**,** $\alpha = 1$**,** $\beta = 1$**)**

$\frac{d\ \mathcal{B}(\lambda)}{d\lambda}$ is quadratic in λ, and the discriminant is less than zero $(-16(\xi - b\mu)(t - 2\tau + 1)(t - \tau)(\xi - b\underline{c}) < 0)$, thus, $\frac{d\mathcal{B}(\lambda)}{d\lambda} = 0$ does not have real roots, the derivative does not change its sign, and the function is always decreasing. Therefore, $\mathcal{B}(\lambda) = 0$ has a unique root $\hat{\lambda}$.

We can rewrite the numerator of $\mathcal{B}(\lambda)$ in quadratic form: $\text{num}(\mathcal{B}(\lambda)) = K\lambda^2 + L\lambda + M$, where $K = b\left(c(1-\tau) + \mu(t-\tau) - (t - 2\tau + 1)\underline{c}_E\right)$, $L = (\xi(2t - 3\tau + 1) + b(2c(\tau - 1) + 3\mu(\tau - t)) + b(t - 2\tau + 1)\underline{c}_E)$, and $M = 2(b\mu - \xi)(t - \tau)$. Thus, $\hat{\lambda} = \frac{-L \pm \sqrt{L^2 - 4KM}}{2K}$, where only one root is less than equal to one. $\square$

Proof of Lemma 4 Local management finds optimal λ by analyzing first derivative of the local profit: $\frac{d\pi_L(T,P,\lambda,c_E)}{d\lambda} = (\xi - bP)(c_E - T)$; thus, $\lambda^o = 0$ when $T > c_E$ and $\lambda^o = 1$ when $T < c_E$. $\square$

Proof of Proposition 3 In Proposition 3, we derive optimal transfer pricing policy for a firm that decentralizes sourcing decisions. Given the optimal sourcing reaction from Lemma 4, we optimize total profit over T and P. If T is above $\overline{c}_E$, local division will never offshore, thus, the expected total profit is independent of T. First, we break the analysis into two cases ($T > \overline{c}_E$ and $c < T < \overline{c}_E$) and derive optimal strategy for each case (Step 1). Next, we compare the solutions for two cases, and demonstrate that Case 1 is always dominated by Case 2 (Step 2).

Step 1: Derive optimal strategies for 2 cases. ***Case 1****:* $T > \overline{c}_E$*.*

$$\mathbb{E}[\Pi(T, P, \lambda^o | T > \overline{c}_E)] = \Pi^o(P, \mu) = (\xi - bP)(1 - t)(P - \mu).$$

Thus, $P^S = P^o(\mu) = \frac{\xi + b\mu}{2b}$ and the optimal profit is:

$$\Pi^o(P^S,\mu) = \frac{1}{4b}(\xi - b\mu)^2(1-t)$$

Case 2: $c < T < \overline{c}_E$. Since $\underline{c}_E < c$, $c < T$ implies $\underline{c}_E < T$. Hence the cost advantage is always random. Expected profit in this case is:

$$\mathbb{E}[\Pi(T,P,\lambda^o|c<T<\overline{c}_E)] = \frac{1}{2}(\xi-bP)(P-\underline{c}_E)(1-t)+\frac{1}{2}(\xi-bP)(P-T)(1-t)+\frac{1}{2}(\xi-bP)(T-c)(1-\tau)$$

Since the expected profit is concave in P for a given T ($\frac{\partial^2\mathbb{E}[\Pi(T,P,\lambda^o)]}{\partial P^2} = -2b\,(1-t) < 0$), we will first optimize over P:

$$\begin{aligned}&\frac{\partial \mathbb{E}[\Pi(T,P,\lambda^o|c<T<\overline{c}_E)]}{\partial P}\\ &= (\xi - 2Pb)(1-t) + \frac{1}{2}b(\underline{c}_E(1-t) + c(1-\tau) + T(\tau - t))\end{aligned}$$

The optimal price is: $\hat{P}^S(T) = \frac{(2\xi+b\underline{c}_E)(1-t)+bc(1-\tau)+Tb(\tau-t)}{4b(1-t)}$. Define $\hat{T}^S$ as the solution to $T = \alpha\hat{P}^S(T)$ ($\hat{T}^S = \frac{\alpha\left(bc(1-\tau)+(1-t)\left(2\xi+b\underline{c}_E\right)\right)}{b(t(\alpha-4)-\alpha\tau+4)}$).

Using envelope theorem, $\frac{d\mathbb{E}[\Pi(T,P,\lambda^o|c<T<\overline{c}_E)]}{dT} = \left.\frac{\partial\mathbb{E}[\Pi(T,P,\lambda^o|c<T<\overline{c}_E)]}{\partial T}\right|_{P=\hat{P}^S(T)} = \frac{1}{2}(\xi - b\hat{P}^S(T))(t-\tau) > 0$, hence, profit is increasing in T; the solution for T is $\text{Min}[\overline{c}_E, \hat{T}^S]$.

Step 2: Compare solutions from two cases. Next, we show that Case 2 always dominates Case 1 and hence, the optimal transfer price is indeed $\text{Min}[\overline{c}_E, \hat{T}^S]$. Given the form of the solution for transfer price, we perform the following analysis also by separating the problem into two settings ($\overline{c}_E < \hat{T}^S$ and $\overline{c}_E > \hat{T}^S$):

Setting 1: $\overline{c}_E < \hat{T}^S$. Expected profit from Case 2:

$$\begin{aligned}\mathbb{E}[\Pi(T,\hat{P}^S(T),\lambda^o|c<T<\overline{c}_E \text{ and } \overline{c}_E<\hat{T}^S)] &= \frac{\left((2\xi-b\underline{c}_E)(1-t)-bc\,(1-\tau)+bT(t-\tau)\right)^2}{16b(1-t)}\\ &= \frac{\left((2\xi-b\underline{c}_E)(1-t)-bc\,(1-\tau)-b\overline{c}_E(1-t)+b\overline{c}_E(1-\tau)\right)^2}{16b(1-t)}\\ &= \frac{\left((2\xi-b\underline{c}_E-b\overline{c}_E)(1-t)+(b\overline{c}_E-bc)\,(1-\tau)\right)^2}{16b(1-t)}\\ &= \frac{\left((2\xi-b(\underline{c}_E+\overline{c}_E))(1-t)+(b\overline{c}_E-bc)\,(1-\tau)\right)^2}{16b(1-t)}\\ &= \frac{\left(2(\xi-b\mu)(1-t)+(b\overline{c}_E-bc)\,(1-\tau)\right)^2}{16b(1-t)}\end{aligned}$$

$$= \frac{(\xi - b\mu)^2(1-t)}{4b} + b(\overline{c}_E - c)\,(1-\tau)\,(\frac{4(\xi - b\mu)(1-t)}{16b(1-t)} + \frac{b(\overline{c}_E - c)\,(1-\tau)}{16b(1-t)})$$

We compare expected profit from Case 2 with the profit from Case 1. Thus, we need to sign: $\text{diff}_1 = 4(\xi - b\mu)(1-t) + b(\overline{c}_E - c)\,(1-\tau)$; since $c < \overline{c}_E$ and $\xi - b\mu > 0$ by assumption $\Rightarrow$ $\mathbb{E}[\Pi(T, \hat{P}^S(T), \lambda^o | c < T < \overline{c}_E \text{ and } \overline{c}_E < \hat{T}^S)] > \Pi^o(P, \lambda)$.

Setting 2: $\overline{c}_E > \hat{T}^S$. $\hat{T}^S = \frac{\alpha\left(bc(1-\tau)+(1-t)\left(2\xi+b\underline{c}_E\right)\right)}{b(t(\alpha-4)-\alpha\tau+4)}$, c is at most $\hat{T}^S$, therefore the upper bound on c is $\frac{\alpha\left(2\xi+\underline{c}_E b\right)}{b(4-\alpha)}$. We evaluate the difference between the expected profit in Case 2 and the profit in Case 1:

$$\mathbb{E}[\Pi(\hat{T}^S, \hat{P}^S(\hat{T}^S), \lambda^o | c < T < \overline{c}_E \text{ and } \overline{c}_E > \hat{T}^S)] - \Pi^o(P, \lambda^o)$$
$$= \frac{(1-t)\left(\frac{4\left(bc(t-1)+b\underline{c}_E(t-1)+\xi(t(\alpha-2)-\alpha\tau+2)\right)^2}{(t(\alpha-4)-\alpha\tau+4)^2} - \left(\xi - \frac{1}{2}b\left(\overline{c}_E + \underline{c}_E\right)\right)^2\right)}{4b}$$

Thus, we need to sign $\text{diff}_2 = \left(\frac{4\left(bc(t-1)+b\underline{c}_E(t-1)+\xi(t(\alpha-2)-\alpha\tau+2)\right)^2}{(t(\alpha-4)-\alpha\tau+4)^2} - \left(\xi - \frac{1}{2}b\left(\overline{c}_E + \underline{c}_E\right)\right)^2\right)$. We first calculate the value of diff_2 when $\tau = t$: $\frac{1}{4}b\left(\overline{c}_E - c\right)\left(4\xi - bc - b\overline{c}_E - 2b\underline{c}_E\right)$ and observe that it is always positive. Next, we evaluate $\frac{d\text{diff}_2}{dt} = \frac{8(1-\tau)\left(bc(\tau-1)+\xi(t(\alpha-2)-\alpha\tau+2)+b(t-1)\underline{c}_E\right)\left(bc(\alpha-4)+2\alpha\xi+b\alpha\underline{c}_E\right)}{(t(\alpha-4)-\alpha\tau+4)^3}$ and observe that it is positive when $c < \frac{\alpha\left(2\xi+\underline{c}_E b\right)}{b(4-\alpha)}$, which is a necessary restriction for ensuring that $\mathcal{C}$ is nonempty. Therefore $\text{diff}_2 > 0$, $\mathbb{E}[\Pi(\hat{T}^S, \hat{P}^S(\hat{T}^S), \lambda^o | c < T < \overline{c}_E \text{ and } \overline{c}_E > \overline{T})] > \Pi^o(P, \lambda^o)$ and $T^S = \text{Min}[\overline{c}_E, \hat{T}^S]$. $\square$

Proof of Proposition 4 In Proposition 4, we show that when the incentive upper bound on transfer price is tight, HQ's profit increases in the average outsourcing cost. For the proof we evaluate the derivative of $\mathbb{E}[\Pi(T, \hat{P}^S(T), \lambda^o | c < T < \overline{c}_E \text{ and } \overline{c}_E < \hat{T}^S)]$ with respect to μ and show when it is positive.

$$\frac{\partial \mathbb{E}[\Pi(T, \hat{P}^S(T), \lambda^o | c < T < \overline{c}_E \text{ and } \overline{c}_E < \hat{T}^S)]}{\partial \mu}$$
$$= \frac{(-2t - \beta + (\beta+1)\tau + 1)((1-t)(b\mu - 2\xi) + bc(1-\tau) + b\mu(-t - \beta + (\beta+1)\tau))}{8(1-t)}$$

Since $c \leq \mu(1+\beta)$ by assumption, the second factor is always less than or equal to $-2(\xi - b\mu)(1-t)$, which is negative; and the first factor is negative when $\beta > \hat{\beta} = \frac{-2t+\tau+1}{1-\tau}$. Thus, the function is increasing in μ when $\beta > \hat{\beta}$.

Proof of Lemma 5 We find optimal strategy for LM by first order analysis of $\pi_L(T,P,\lambda,c_E)$ in two steps. In Step 1, we identify optimal offshoring strategy ($\lambda^{PS}(T,c_E)$), and in Step 2, we determine optimal pricing strategy ($P^{PS}(T,c_E)$).

Step 1: Find $\lambda^{PS}(T,c_E)$. We first optimize local profit with respect to λ by applying envelope theorem:

$$\frac{d\pi_L(T,P,\lambda,c_E)}{d\lambda} = \left.\frac{\partial\pi_L(T,P,\lambda,c_E)}{\partial\lambda}\right|_{P=\hat{P}^{PS}(\lambda)} = D(\hat{P}^{PS}(\lambda))(T-c_E)$$

Thus, for a P within reasonable range (i.e. $D(\hat{P}^{PS}(\lambda))>0$), sign of the derivative depends only on the relationship between T and c_E: $\lambda^o=0$ when $T>c_E$ and $\lambda^o=1$ when $T<c_E$.

Step 2: Find $P^{PS}(T,c_E)$. We now find $P^{PS}(T,c_E)$ for each scenario.

1. $T>c_E \Rightarrow \frac{\partial\pi_L(T,P,\lambda^o,c_E)}{\partial P} = -2bP+\xi+bc_E$ and $\frac{\partial^2\pi_L(T,P,\lambda^o,c_E)}{\partial P^2} = -2b$. Thus, $P^{PS}(T,c_E) = \frac{bc_E+\xi}{2b} = P^o(\min(T,c_E))$;
2. $T<c_E \Rightarrow \frac{\partial\pi_L(T,P,\lambda^o,c_E)}{\partial P} = -2bP+\xi+bT$ and $\frac{\partial^2\pi_L(T,P,\lambda^o,c_E)}{\partial P^2} = -2b$. Thus, $P^{PS}(T,c_E) = \frac{bT+\xi}{2b} = P^o(\min(T,c_E))$. $\square$

Proof of Proposition 5 In Proposition 5, we find optimal transfer price for the firm that decentralizes retail pricing and sourcing decisions. We break the problem into two cases similarly to the proof of Proposition 3: $T>\bar{c}_E$ and $c<T<\bar{c}_E$. In Step 1, we derive the profit for Case 1. In Step 2, we plug the LM's reaction into the HQ's profit function and optimize over transfer price without considering any constraints. In Step 3, we show that Case 2 always dominates Case 1, notice that in Case 2, we have three upper bounds on the transfer price: legal upper bound, incentive upper bound for sourcing, incentive upper bound for pricing; hence, we will look at 3 sub-cases enumerated below.

Step 1: Profit in Case 1 ($T>\bar{c}_E$). When $T>\bar{c}_E$, LM never offshores and the solution is identical to the result in Lemma 4. Hence, $\Pi^{PS}(T,P,\lambda^o|T>\bar{c}_E)=\pi^o(P,\lambda^o)$.

Step 2: Find unconstrained optimal transfer price for Case 2. Since $\mathbb{E}[\Pi(T,P^PS(T,c_E),\lambda^o|c<T<\bar{c}_E)]$ is concave in T ($\frac{d^2\mathbb{E}[\Pi(T,P^PS(T,c_E),\lambda^o|c<T<\bar{c}_E)]}{dT^2} = -\frac{1}{4}b(t-2\tau+1)$), we find unconstrained optimal transfer price $\overline{T}^{PS}$ using first order condition: $\frac{d\mathbb{E}[\Pi(T,P^PS(T,c_E),\lambda^o|c<T<\bar{c}_E)]}{dT} = -\frac{(T(t-2\tau+1)+2c(\tau-1))b^2+T(t-2\tau+1)b^2-2\xi(t-\tau)b}{8b}=0$. Hence, $\overline{T}^{PS} = \frac{\xi(t-\tau)-b(\tau-1)c}{b(t-2\tau+1)}$.

Step 3: Show that Case 2 always dominates Case 1. Notice that the transfer price also has to comply with the legal constraints, hence we derive a legal upper bound $\hat{T}^{PS} = \frac{\alpha(b\underline{c}_E+\xi)}{2b}$ that makes the legal constraint binding. Now we need to show that $\bar{c}_E$ determines another upper bound on T^{PS} by showing that $\Pi^{PS}(T,P,\lambda^o|c<T<\bar{c}_E] \geq \Pi^{PS}(T,P,\lambda^o|T>\bar{c}_E)$. Since there are 3 upper bounds on T: $\hat{T}^{PS},\overline{T}^{PS},\bar{c}_E$, we need to look at 3 sub-cases where either of the bounds may be minimum.

1. $\mathbf{min}(\hat{T}^{PS},\overline{T}^{PS},\bar{c}_E)=\bar{c}_E$

$$\begin{aligned}
&\mathbb{E}[\Pi(T,P,\lambda^o|c<T<\bar{c}_E)]-\Pi^o(P,\lambda^o)=\\
&\frac{1}{2}\Pi(P^o(\underline{c}_E),\lambda^o)+\frac{1}{2}\Pi(T,P^o(T),\lambda^o)-\frac{1}{2}\Pi^o(P^o(\underline{c}_E),\lambda^o)-\frac{1}{2}\Pi^o(P^o(\bar{c}_E),\lambda^o)=\\
&\frac{1}{2}(\Pi(\min(\overline{T}^{PS},\bar{c}_E),P^o(\min(\overline{T}^{PS},\bar{c}_E)),\lambda^o)-\Pi^o(P^o(\bar{c}_E),\lambda^o))=\\
&\frac{1}{2}(D(P^o(\bar{c}_E))(P^o(\bar{c}_E)-\bar{c}_E)(1-t)+D(P^o(\bar{c}_E))(\bar{c}_E-c)(1-\tau)-D(P^o(\bar{c}_E))(P^o(\bar{c}_E)-\bar{c}_E)(1-t))=\\
&\frac{1}{2}D(P^o(\bar{c}_E))(\bar{c}_E-c)(1-\tau)\geq 0
\end{aligned}$$

$\mathbb{E}[\Pi(T,P,\lambda^o|c<T<\bar{c}_E]>\Pi^o(P,\lambda^o)\Rightarrow$offer $T^{PS}=\bar{c}_E$

2. $\mathbf{min}(\hat{T}^{PS},\overline{T}^{PS},\bar{c}_E)=\overline{T}^{PS}$

$$\begin{aligned}
&\mathbb{E}[\Pi(T,P,\lambda^o|c<T<\bar{c}_E]-\mathbb{E}[\Pi(T,P,\lambda^o|T>\bar{c}_E)]=\\
&D(P^o(T^{PS}))(P^o(T^{PS})-T^{PS})(1-t)+D(P^o(T^{PS}))(T^{PS}-c)(1-\tau)-D(P^o(\bar{c}_E))(P^o(\bar{c}_E)-\bar{c}_E)(1-t)=\\
&D(P^o(\overline{T}^{PS}))(P^o(\overline{T}^{PS})-\overline{T}^{PS})(1-t)+D(P^o(\overline{T}^{PS}))(\overline{T}^{PS}-c)(1-\tau)-D(P^o(\bar{c}_E))(P^o(\bar{c}_E)-\bar{c}_E)(1-t)=\\
&\frac{(\xi-bc)^2(\tau-1)^2+(t-1)(t-2\tau+1)\left(\xi-b\bar{c}_E\right)^2}{8b(t-2\tau+1)}
\end{aligned}$$

So, we need to sign diff $=(\xi-bc)^2(\tau-1)^2+(t-1)(t-2\tau+1)\left(\xi-b\bar{c}_E\right)^2$. First we evaluate diff at $t=\tau$: diff $=b(\tau-1)^2\left(c-\bar{c}_E\right)\left(bc-2\xi+b\bar{c}_E\right)>0$. Then we notice that diff increases in t ($\frac{d\text{diff}}{dt}=2(t-\tau)\left(\xi-b\bar{c}_E\right)^2>0$). The difference is always positive, thus offer $T^{PS}=\overline{T}^{PS}$

3. $\mathbf{min}(\hat{T}^{PS},\overline{T}^{PS},\bar{c}_E)=\hat{T}^{PS}$

$$\mathbb{E}[\Pi(T,P,\lambda^o|c<T<\bar{c}_E]-\mathbb{E}[\Pi(T,P,\lambda^o|T>\bar{c}_E)]=$$

$$=D(P^o(\hat{T}^{PS}))(P^o(\hat{T}^{PS})-\hat{T}^{PS})(1-t)+D(P^o(\hat{T}^{PS}))(\hat{T}^{PS}-c)(1-\tau)-D(P^o(\bar{c}_E))(P^o(\bar{c}_E)-\bar{c}_E)(1-t)$$

$$= \left(4(t-1)\bar{c}_E^2 - \alpha \underline{c}_E \left(4c(\tau-1) + \alpha(t-2\tau+1)\underline{c}_E\right)\right) b^2 -$$

$$-2\xi \left(2c(\alpha-2)(\tau-1) + 4(t-1)\bar{c}_E + \alpha(t(\alpha-2) + \alpha - 2\alpha\tau + 2\tau)\underline{c}_E\right)^2 b - \alpha\xi^2(t(\alpha-4) + \alpha - 2\alpha\tau + 4\tau)$$

The expression above decreases in c and since we've put the restrictions on the parameters such that $c < \alpha P$ is not empty, we can treat $\hat{T}^{PS}$ as an upper bound on c and we substitute it into the expression above. We obtain:

$$(1-t)\left(\alpha\xi - 2b\bar{c}_E + b\alpha\underline{c}_E\right)\left(\alpha\xi - 4\xi + 2b\bar{c}_E + b\alpha\underline{c}_E\right)$$

Therefore, $\mathbb{E}[\Pi(T, P, \lambda^o | c < T < \bar{c}_E] \geq \Pi^o(P, \lambda^o)$, and the optimal transfer price is $\hat{T}^{PS}$.

Hence, $T^{PS} = min(\hat{T}^{PS}, \overline{T}^{PS}, \bar{c}_E)$. $\square$

Proof of Proposition 6 In Proposition 6, we show that when the incentive upper bound for sourcing is binding, HQ's profit is concave in the average outsourcing cost and for values of $\mu < \hat{\mu}$, profit increases in the average outsourcing cost. In Step 1, we show concavity by simply showing that the second derivative with respect to μ is positive, and in Step 2, we show that profit increases in μ by showing that the first derivative is positive when $\mu < \hat{\mu}$ and derive $\hat{\mu}$.

Step 1: Show concavity.

$$\mathbb{E}[\Pi(\bar{c}_E, P^o(\min(c_E, \bar{c}_E)), \lambda^o)] =$$
$$\frac{2\xi(-t\xi + \xi + bc(\tau-1)) - b\left(b(t-2\tau+1)\bar{c}_E^2 + 2(bc(\tau-1) - \xi(t-\tau))\bar{c}_E - (1-t)\underline{c}_E\left(b\underline{c}_E - 2\xi\right)\right)}{8b}$$

In our bi-value cost distribution, $\underline{c}_E = \mu(1-\beta)$ and $\bar{c}_E = \mu(1+\beta)$. We replace $\underline{c}_E$ and $\bar{c}_E$ in the expression above and take derivatives with respect to μ:

$$\frac{\partial^2 \mathbb{E}[\Pi(\bar{c}_E, P^o(\min(c_E, \bar{c}_E)), \lambda^o)]}{\partial \mu^2} = -\frac{1}{2}b(t-\tau)\beta^2 - b(1-\tau)\beta - \frac{1}{2}b(t-\tau) < 0$$

Thus, $\mathbb{E}[\Pi(\bar{c}_E, P^o(\min(c_E, \bar{c}_E)), \lambda^o)]$ is concave in μ.

Step 2: Show that profit increases in μ.

$$\frac{\partial \mathbb{E}[\Pi(\bar{c}_E, P^o(\min(c_E, \bar{c}_E)), \lambda^o)]}{\partial \mu} =$$
$$\frac{1}{4}\left(\xi(2t + \beta - \beta\tau - \tau - 1) + b\left(2\mu\left(\tau\beta^2 + 2(\tau-1)\beta - t\left(\beta^2+1\right) + \tau\right) - c(\beta+1)(\tau-1)\right)\right)$$

The expression above is linear in μ. Solving for μ we obtain the threshold $\hat{\mu}$:

$$\hat{\mu} = \frac{\xi(2t + \beta - (\beta+1)\tau - 1) - bc(\beta+1)(\tau-1)}{2b\left(t\beta^2 + 2\beta + t - (\beta+1)^2\tau\right)}$$

Such that when $\mu < \hat{\mu}$, $\frac{\partial \Pi^{P,S}}{\partial \mu} > 0$ and vice versa. $\square$