GLOBAL SUPPLY CHAIN PLANNING: IMPACT OF INTERNATIONAL TAXATION AND TRANSFER PRICING

by

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Chapter 1

Introduction

Global supply chains make their strategic design decisions with tax considerations in mind (Ernst & Young 2007). However, taxation issues, such as varying tax rates across the supply chain or the use of transfer pricing strategies to optimize after-tax profitability, are typically omitted in the supply chain management literature. One of the strategies of incorporating tax benefits into supply chain operations is income shifting to favorable tax jurisdictions; hence, global companies design their supply chains in a way that facilitates such income shifting possibilities. One of the tools widely used in practice for income-shifting purposes is transfer pricing. For example, the U.S. Treasury estimates that in the year 2008, global companies incorporated in the U.S. saved $60 billion in taxes by using transfer pricing strategies (Drucker 2010). There exists empirical evidence that many multinational corporations use the same transfer price for tax and for managerial reporting purposes (Czechowicz et al. 1982). Hence, transfer prices have a dual role in global supply chain management: They are used to (i) determine taxable income in different parts of the supply chain; and (ii) determine divisional income used for managerial compensation, and consequently affect the decisions made by the managers. Transfer pricing for income-shifting purposes has been addressed in economics and accounting research multiple times (Horst 1972, Hirshleifer 1956; Dawson and Miller 2000) recognized the dual role of transfer
prices and modeled the decentralized global supply chain in which transfer prices have dual role. All theses studies, however, have been done in deterministic settings. In my thesis I study the effect of the dual role of transfer prices on the optimal strategies of global firms operating under uncertainty and use a combination of comparative statics analysis and computational experiments to find global strategies of such firms and to understand the impact of various supply chain parameters on these strategies.

In the first essay, “Role of Transfer Prices in Global Supply Chains with Random Demands”, I analyze the impact of optimizing transfer prices on the global supply chain performance of a price-setting firm facing random demand. It is well-established in the economics and accounting literature that optimization of transfer prices is beneficial for firms operating in a deterministic environment. In this work we find that the benefit of optimizing transfer pricing is even greater for supply chains facing random demands. The basic dynamics of the result are as following. The supply chain sets the transfer price above the manufacturing cost in order to shift income to the low tax jurisdiction. As a result, the selling price set by the retailer who views transfer price as his cost is set higher than in the absence of transfer price. The presence of randomness in demand, however, counter-balances this effect by reducing the selling price and bringing it closer to the globally optimal selling price. As a result, the supply chain facing random demand gets more benefit from transfer pricing than its deterministic counterpart. Using a detailed computational study, we show that this effect is the greatest when the customer base is small, price elasticity is high, and the ratio of underage cost to overage cost is high.

In the second essay, “Transfer Pricing and Offshoring in Global Supply Chains with Cost Uncertainty”, I focus on the cost uncertainty as a source of randomness in the supply chain while keeping the demand deterministic. We also make the sourcing decision endogenous as opposed to the first essay. We study how global firms can design coordinated transfer pricing and sourcing strategies to leverage tax and cost differences. We derive a trade-off curve between tax and cost differences that determines the optimal sourcing strategy. Such
curve can be used by companies in order to find the optimal strategy and also by policy makers in order to find the tax rate that should be offered to multinationals to attract their business. Global firms, however, also face 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, many global supply chains operate in a decentralized manner and we need to understand how different transfer price strategies and different decentralization strategies can help global supply chains exploit tax and cost benefits. 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. In comparing decentralized structures, we find that the optimal sourcing strategy has an “all-or-nothing” structure only if pricing decision is kept at the headquarters level. However, when the pricing decision is decentralized, partial offshoring solution is optimal because of the transfer pricing regulations imposed by the Internal Revenue Code. Finally, we show that when the cost of outsourcing increases, a decentralized company has more flexibility in setting transfer prices and hence can achieve higher profits.

Finally, in the third essay, “Optimal Sourcing and Transfer Pricing Strategies for Global Supply Chains facing Cost and Exchange Rate Uncertainty”, I add a second source of uncertainty to the supply chain, namely exchange rate uncertainty. However, we now consider a price-taking firm rather than a price-setting firm as in previous two essays. We again derive a trade-off curve between tax and cost differences that can be useful for both global firms and for policy makers. Similarly to the previous essay, we study how decentralization of the sourcing decision can be used by firms to take advantage of better cost information that the local divisions have. We find that the incentive conflict in the supply chain forces the headquarters to set transfer prices below the level that would be optimal for tax purposes. We propose that supply chain flexibility, namely postponement of the sourcing decision, can be
used to loosen this conflict and to set the transfer prices closer to the globally optimal level. Hence, we show that supply chain flexibility has a dual impact on the after-tax profitability of a tax optimized supply chain: (i) it helps the firm cope with uncertainty and (ii) it allows the firm to get higher tax benefits.
Chapter 2

Role of Transfer Prices in Global Supply Chains with Random Demands

2.1. Introduction

The recent trend of corporate globalization (Mataloni 2003) has presented new opportunities to improve the after-tax profits of corporations by taking advantage of differences in tax rates between countries where the parent company and its subsidiaries operate. A number of researchers (Bond 1980, Dawson and Miller 2000, Smith 2002, Horst 1972) in economics and accounting have addressed this issue, but little attention has been given to this topic in the operations management literature. In addition, to the best of our knowledge, the existing research has only focused on supply chains in which there is no randomness. We wish to bridge this gap by analyzing the impact of transfer prices on supply chains operating in a random environment. We specifically consider a two-stage supply chain (a domestic retailer and a foreign manufacturer) in which the end-customer demand is stochastic. Our

\[^1\text{This chapter has been published at Shunko and Gavirneni (2007).}\]
objective is to determine whether the impact of transfer prices is increased or diminished when there is some randomness in the supply chain.

Transfer pricing is a powerful tool for shifting income to subsidiaries in lower-tax countries and consequently increasing after-tax profit of the supply chain (Gordon and MacKie-Mason 1995). Consider the following example to illustrate how corporations can benefit from transfer pricing: A company in the U.S. (the retailer) can sell a product for $100 per unit and manufactures the product (at a cost of $20 per unit) at a controlled foreign corporation (CFC) in Hungary. The effective tax rate is 35% in the U.S., while Hungary has a tax rate of only 16%. If the company transfers the product from Hungary to the U.S. at cost, after-tax profit in the U.S. would equal $(100 - 20) \times (1 - 0.35) = 52$; and after-tax profit in Hungary would equal $(20 - 20) \times (1 - 0.16) = 0$, resulting in a total supply chain profit of $52$.

If the company decides to take advantage of transfer pricing and associated tax deferral (explained below), it may set the transfer price at $80$, so that the after-tax profit in the U.S. would equal $(100 - 80) \times (1 - 0.35) = 13$, and after-tax profit in Hungary would equal $(80 - 20) \times (1 - 0.16) = 50.4$. If the parent company in the U.S. decided not to repatriate any of the profit earned in Hungary back to the U.S., then the resulting supply chain profit would equal $63.4$, which is a 22% improvement over the $52$ profit when the supply chain does not take advantage of transfer prices. It is worth noting that although transfer prices are regulated, there is significant flexibility allowed by the Internal Revenue Service (IRS). As a result, companies are able to determine a range (see section 2 for details) of legitimate transfer prices, called arm-length prices (Dawson and Miller 2000).

An important issue that significantly affects transfer pricing practices is deferral of taxation. Although U.S. companies are taxed on their total income, regardless of the country in which the income originated, there is an exception to this rule. This exception allows U.S. companies to temporarily exclude the unrepatriated portion of income earned by CFCs from U.S. taxation and defer these tax liabilities until this income returns to the
United States (Hines 1996). This issue of repatriation of foreign profits attracted a lot of attention during the 2004 presidential campaign, as it is estimated that U.S. multinationals have about $639 billion in 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” (Jun 1995), and (ii) repayment of debts. In fact, we can see evidence in current trade journals and corporate annual reports that numerous U.S. companies do not intend to repatriate their foreign earnings. Merck&Co has $18 billion in unrepatriated earnings and states that it does not intend to 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).

Given that corporations engage in transfer pricing strategies, it is interesting to see whether this behavior is driven by the desire to avoid high taxation. Empirical evidence tabulated in Clausing (2003) shows that transfer prices are likely influenced by the tax-minimization strategies of multinational firms. In particular, a statistically significant relationship has been found between a country’s tax rate and the prices of intra-firm imports and exports traded with that country (Clausing 2003).

Transfer pricing has been frequently addressed by researchers in economics, accounting, and taxation (Bond 1980, Dawson and Miller 2000, Smith 2002, Horst 1972). Economists usually approach this problem from the perspective of general equilibrium theory (Horst 1972), assuming that demand is determined by the intersection of supply and demand curves, and that optimality is obtained where marginal cost equals marginal revenue. There are various deterministic demand models evaluating optimal transfer price behavior and showing that companies can benefit significantly from choosing them optimally. We study this problem from a stochastic perspective and analyze the transfer pricing problem in
2.2. The Supply Chain Setup

supply chains with some randomness. Evaluating the use of transfer prices in the stochastic environment addresses operational aspects of the problem, enabling us to extend transfer pricing research along a new dimension.

Before presenting details of our model and analysis, we would like to briefly summarize our findings. We conjecture, using a detailed computational study, that if a multinational corporation (MNC) uses the optimal transfer price, the optimal selling price in the supply chain facing stochastic demand is lower than the corresponding optimal selling price in the deterministic setting. As a consequence, a supply chain that faces random demand for its products benefits more from the use of transfer pricing than a similar supply chain facing deterministic demand. This reduction in the selling price results in even larger improvements in profit when the demand elasticity is high. Using a detailed computational study, we conclude that significantly higher profits are possible in supply chains with one or more of the following characteristics: (i) low customer base, (ii) high price elasticity, (iii) demand variability; or (iv) high overage cost to underage cost ratio.

The rest of the paper is organized as follows. We present our supply chain setup and the associated assumptions in section 2. Section 3 describes the extant research and presents a deterministic model that will be used for comparison purposes. In section 4 we incorporate randomness into the model and present the associated mathematical analysis. Section 5 describes experimental setup, and section 6 details the results from that study. We conclude in section 7 with a discussion of future research ideas including a brief analysis of the issues associated with the repatriation of profits.

2.2. The Supply Chain Setup

We consider a two-stage serial supply chain with a parent company in Country $R$ (the retailer) and its CFC in Country $M$ (the manufacturer). Where needed in the notation, ‘$R$’ and ‘$M$’ will be used as subscripts to represent the retailer’s and manufacturer’s entities.
Since the manufacturer is established as a CFC, the retailer has the ability to defer taxation on the profits earned by the manufacturer until the profits are repatriated back to Country $R$ (cfc 2000). The retailer sells the product only in Country $R$, and Country $M$ is the only supplier of the product offered by the retailer. The manufacturer has enough capacity to meet any demand of the retailer. In spite of its simplicity, such a supply chain structure has been widely used in supply chain management research.

We introduce the following parameters that will be used to formulate the model:

- $T$: Transfer price
- $P$: Selling price
- $a$: Customer base
- $b$: Price elasticity
- $\mu$: Mean demand which will be computed as $a - bP$
- $Q$: Order Quantity
- $C_o$: Cost of overage ($/unit) for leftover inventory
- $C_u$: Cost of underage ($/unit) for unsatisfied customers
- $C_M$: Manufacturing cost ($/unit)
- $v$: Parameter for capturing demand variability
- $t_R$: Tax rate in Country $R$
- $t_M$: Tax rate in Country $M$
- $\Pi$: Total expected profit of the supply chain
- $\pi_R$: Retailer’s expected profit
- $\pi_M$: Manufacturer’s profit

The decisions in the supply chain are made in the following order (our model is solved in the reverse order):

1. **Problem T** - The supply chain makes a centralized decision about the intra-firm transfer price ($T$) it should use in order to maximize total profit.
2. Problems P and Q - The parent company (the retailer) makes decentralized decisions of stocking level ($Q$) and selling price ($P$) that maximize its local profit. As was shown in \cite{Petruzzi1999} these problems may be solved in either order.

Note that the supply chain has some leeway in determining the intra-firm transfer price. This is especially true in the U.S. as the Internal Revenue Service (IRS) allows for different methods for calculating transfer prices and also leaves room for interpretation of these methods. To illustrate the flexibility associated with the transfer pricing legislation, we summarize below a few methods that are recommended by the IRS. More details can be found in \cite{Halperin1987}.

- **Comparable uncontrolled price:** This is the price at which comparable products are sold in the open market. It is often hard to find products that are very similar and are sold in an uncontrolled environment.

- **Resale price:** Under this method, transfer price is set equal to the final selling price minus appropriate markdown, where this markdown equals the gross margin (gross profit/sales) earned by companies selling similar items in uncontrolled environments.

- **Cost plus:** Transfer price should equal the production cost plus appropriate markup (gross profit/cost of goods sold) earned by companies selling similar items in an uncontrolled environment.

- **The Alternate Method:** If methods described above cannot be reasonably applied, an alternate method should be implemented. The alternate method can be a combination of the previous three, a profit-based method, or any other method that is reasonable under the given circumstances.

We will not focus on any of the aforementioned rules and will only assume that there is significant flexibility in determining transfer prices. As an extension, in section 2.6.5 we will study the impact of different limits on cost markup.
Along the lines of existing research on transfer prices and to make the problem analytically tractable, we make the following assumptions:

1. The supply chain leaves all profit indefinitely in the country in which the profit originated. We relax this assumption in section 7, where we briefly analyze the setting in which profits are repatriated after a few years.

2. Randomness in demand is modeled as $\mu + \epsilon$, where $\mu = a - bP$ and $\epsilon$ is a Uniformly distributed random error. The additive demand form is common in the economics and operations management literatures (Mills 1959, Federgruen and Heching 1999, Petruzzi and Dada 1999). In our computational experiments, we also consider the situations in which $\epsilon$ is Normally distributed.

3. Unsatisfied demand at the retailer is lost and results in a per unit cost, $C_u$, associated with loss of goodwill. The retailer faces a linear overage cost, $C_o$, on every unit of excess inventory.

4. This is a single-period static model along the lines of research in economics (Dawson and Miller 2000, Horst 1972) and in operations management (Kassicieh 1981).

5. There is only one product exchanged between the two supply chain members.

6. Without loss of generality we assume manufacturing cost to be equal to zero. An exception is in section 2.6.5 where we study the impact of different markups on cost allowed by the IRS.

### 2.3. Deterministic Model

One of the first studies on optimal transfer pricing policies (Horst 1972) evaluated optimal behavior of multinational corporations that are taxed under different rates in different countries, and concluded that a subsidiary which exports from a lower tax-rate country
should set the transfer price as high as possible. It considered corporations where all
decision making was performed centrally. In order to facilitate a better understanding of
our analysis, we briefly summarize the analysis from Horst (1972).

The profit of the supply chain ($\Pi$) may be represented as the sum of the retailer’s ($\pi_R$)
and manufacturer’s ($\pi_M$) profits:

$$\pi_R(Q,P,T) = Q(P-T)(1-t_R),$$

$$\pi_M(Q,P,T) = Q(T-C_M)(1-t_M),$$

$$\Pi(Q,P,T) = \pi_R(Q,P,T) + \pi_M(Q,P,T)$$

$$= Q(P-T)(1-t_R) + Q(T-C_M)(1-t_M). \quad (2.1)$$

By taking the first derivative of the total supply chain profit (1) with respect to $T$
and observing that it is positive for all $t_R > t_M$ ($\frac{\partial \Pi}{\partial T} = Q(1-t_M) - Q(1-t_R)$),
we conclude that for a supply chain where the tax rate in Country $R$ is greater than the tax rate in
Country $M$, total profit increases as the transfer price increases. In the centralized supply
chain with $t_R > t_M$, the transfer price should be set as high as possible (boundary solution)
in order to shift the largest possible income to Country $M$.

A number of further studies (Bond 1980, Dawson and Miller 2000, Hines 1996, Jun
1995) in this area have looked at different variations of this basic model. In particular Bond
(1980) looked at organizations in which transfer pricing decisions are made centrally but the
intra-firm trade quantity decisions are made by the local managements. This is very similar
to the setting of our model, but the analysis in Bond (1980) was restricted to deterministic
settings.

In order to create a baseline for our stochastic model, we next present our version (based
on Bond (1980)) of the deterministic model that captures the supply chain setup described
above.

**Proposition 2.3.1** In the deterministic setting, the maximum supply chain profit equals
2.3. Deterministic Model

\[ \frac{a^2(t_M-1)^2}{4b(t_R+1-t_M)}, \text{ and this is achieved when } P^* = \frac{a+bT}{2b}, \ Q^* = \frac{a-bT}{2b}, \text{ and } T^* = \frac{a(t_M-t_R)}{b(t_M-t_R-1)}. \]

Figure 2.1: A plot of transfer price as a function of selling price for the setting in which \( a = 1000, b = 50, t_R = 40\%, t_M = 0\%, C_u = 9, C_o = 1, \) and \( v = 150. \) Notice that in the stochastic scenario (see section 4) the increase in sales price is not as steep as in the deterministic case.

As a preview of our findings, let us examine Figures 2.1 and 2.2 to evaluate the behavior of the selling price and after-tax profit in response to changes in transfer price, in both deterministic and stochastic settings. Figure 2.1 illustrates the increase in selling price as transfer price grows for the supply chain in which the demand is determined by the linear function \( 1000-50P, \) the tax rate in Country \( R \) equals 40\%, and the tax rate in Country \( M \) is 0\%. For the stochastic scenario, the demand varied uniformly between 150 units above and below the mean demand, the cost of underage was $9 and the cost of overage was $1. Notice that the growth of the selling price in the stochastic setting (dashed line) is not as steep as in the deterministic (solid line) setting.

As a result of the lower selling price in conjunction with inherent price elasticity, in terms of the after-tax profit improvement (Figure 2.2), a supply chain facing random demand will benefit more from transfer pricing than a similar supply chain with deterministic demand.
2.4. Stochastic model

In order to evaluate the impact of transfer pricing policy in the stochastic environment, we incorporate randomness into the demand model described above. Since the observed demand is not known a priori, it is possible the retailer will incur overage (or underage) costs, if the realized demand is less than (or greater than) quantity received from Country $M$. Introducing these costs into the model (see Nahmias (1993) for details on the formulation of the newsvendor problem) transforms the profit function to the following:

$$
\Pi(T, P, Q) = \left[ \int_0^Q (xP - C_o(Q - x))f(x, P)dx + \int_Q^\infty (QP - C_u(x - Q))f(x, P)dx - TQ \right] \ast (1 - t_R) + TQ(1 - t_M),
$$

where $f(x, P)$ is the probability density function of demand distribution. If actual demand is less than or equal to the quantity $Q$ ordered, the retailer profit equals $xP - C_o(Q - x)$, where $x$ represents actual demand. On the other hand, if actual demand exceeds $Q$, the
profit equals $QP - C_u(x - Q)$. Since we assume that the retailer makes its decisions in a decentralized manner, we focus on and optimize its portion of the profit before tax (labeled $\pi_{RB}(Q)$), to find the optimal $P$ and $Q$:

$$
\pi_{RB}(P,Q) = \int_0^Q (xP - C_o(Q - x)) f(x, P) dx + \int_Q^\infty (QP - C_u(x - Q)) f(x, P) dx - TQ.
$$

We use analytical methods to solve Problem $Q$ for the optimal $Q^*$ and to evaluate behavior of the $P^*$. We then use a computational approach to solve Problems $P$ and $T$ and find the best selling price and transfer price.

An alternative solution approach (presented in the Appendix) would be to define $z = Q - \mu$ (along the lines of Petruzzi and Dada [1999]) and rearrange (2.2) as the following:

$$
\pi_{RB}(P, z) = \int_{-\infty}^z ((\mu + x)P - (z - x)C_o) f(x, P) dx + \int_z^\infty ((\mu + z)P - (x - z)C_u) f(x, P) dx - T(\mu + z).
$$

### 2.4.1 Problem Q

We assume that the random error, $\epsilon$, in demand, $D = \mu + \epsilon$, is Uniformly distributed with the mean of 0 and varies from $-v$ to $v$. In order to guarantee the non-negativity of demand, we further assume that $\mu - v \geq 0$. Note that we do not need additional assumptions of non-negativity of $P$ since maximizing the profit function ensures that $P \not< 0$. The probability density function (which is independent of the selling price) of the demand is the following:

$$
f(x) = \frac{1}{2v}.
$$

Substituting (2.4) into (2.2) results in the following retailer profit function for a given
2.4. Stochastic model

solving price $P$:

$$
\pi_{RB}(Q) = \int_{Q-a}^{Q-b} (xP - C_o(Q - x)) \frac{1}{\pi_0} dx + \int_{Q}^{a-bP+v} (QP - C_u(x - Q)) \frac{1}{\pi_0} dx - TQ.
$$

Proposition 2.4.1 The optimal order quantity $Q^*$ can be computed as $Q^* = a - bP - v + 2v \frac{(P-T+C_u)}{(P+C_o+C_u)}$.

Proposition 2.4.2 The optimal profit of the retailer can be represented as $\pi_{RB}(Q^*) = (a - bP)(P - T) - v \frac{(C_o+T)(P-T+C_u)}{(P+C_o+C_u)}$.

2.4.2 Problem P

Since we are unable to obtain the optimal selling price ($P^*$) in closed form, we evaluate the following relationship:

Proposition 2.4.3 For the supply chain that faces Uniformly distributed demand, the optimal selling price in the stochastic setting ($P^*_s$) is less than the optimal selling price in the deterministic scenario ($P^*_d$) for a given transfer price, $T$.

This relationship in prices is a special case of the result in Petruzzi and Dada (1999) and is consistent with the result in Mills (1959). As we shall see later, it lays the foundation for our main result that transfer prices are indeed more beneficial in supply chains with random demands. The usage of a transfer price that is greater than the cost of production has the tendency to increase the eventual selling price at the retailer, thus introducing inefficiency when compared to the globally optimized supply chain. The presence of randomness partially counter-balances this effect by reducing the selling price and bringing it closer to the globally optimal selling price. We believe that this impact of randomness eventually makes transfer prices more attractive for supply chains that face random demand.

We were able to show that $P^*_s < P^*_d$ holds under the restriction that $T_s = T_d$. However in most cases the optimal transfer prices in both cases may not be equal. While we are
2.5. Experimental Design

not able to prove this relationship when equality in transfer prices is not imposed, we have computational evidence to believe that the result of Proposition 2.4.3 would hold when $T_s \neq T_d$. We conjecture that the optimal selling price in the stochastic setting will be lower than the optimal selling price in the deterministic setting ($P^*_s(T^*_s) < P^*_d(T^*_d)$).

2.4.3 Problem T

We solve Problem $T$ for the Uniformly distributed demand using a numerical study. For each $T$ within the allowed range, we evaluate the seller’s profit at each pair ($P$ and $Q$) in the acceptable range and select the pair with the maximum expected profit. We take note of the best profit value when $T = C_M = 0$ for further comparison. Then we select the best transfer price, $T^*$, that gives the maximum expected total supply chain profit. For the case with Uniformly distributed demand we use equation A.6 to find $Q^*_s$.

We use these results to compute the relative profit improvement due to introducing transfer price into the supply chain. See section 2.5 for details on selecting parameters for each experiment. For each experiment, we find corresponding profits and the profit improvement ratio for the deterministic case using the formulae from Proposition 2.3.1. Our objective is to compare the magnitude of profit improvement in the stochastic setting with the magnitude of profit improvement in the corresponding deterministic setting.

2.5. Experimental Design

We know that the use of transfer pricing in supply chains facing random demand may lead to an improvement in profits. We want to establish that this increase will differ from the improvement seen by earlier researchers in the deterministic models. Based on our conjecture that the optimal selling price in the stochastic setting is lower than the optimal selling price in the deterministic setting, we expect supply chains with higher price elasticity to experience higher profit improvement. The objective of our computational study is
to identify the difference in profit improvement between the stochastic and deterministic settings, and to evaluate the relationship between the percentage increase in profit and the various supply chain parameters.

In order to capture a wide spectrum of supply chain structures, we designed the following set of experiments. The factors that characterize important aspects of supply chains are, (i) customer base \((a)\), (ii) price elasticity \((b)\), (iii) the degree of variability \((v)\); and (iv) the ratio of cost of underage to cost of overage \(\left(\frac{C_u}{C_o}\right)\). We determined five levels for each of these parameters in order to capture low and high values. For example, a low customer base \((a = 200)\) represents a supply chain that sells specialized products that have small markets, whereas a high customer base \((a = 1000)\) represents a supply chain engaged in business with a much larger market. Some of the combinations in which the customer base \((a)\) was too small to accommodate the randomness \((v)\) were dropped from the study. Based on our analysis of the experimental setup and in order to ensure non-negativity of demand, we dropped 225 of the cases in which \(\frac{a-v}{b} \leq 2.75\) from the study. Table 2.1 contains a summary of our experimental setup.

<table>
<thead>
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<td>5</td>
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Table 2.1: Summary of the experimental design

2.6. Computational Results

We summarized our findings by presenting the plots of the average profit improvement ratios from using transfer pricing across various treatment levels for all factors. For each treatment level of each factor, we computed (over all scenarios with that parameter setting) the average profit both with transfer price and without transfer price. Then we computed
the ratio of relative increase in the average profit as:

$$\text{Profit Ratio} = \frac{\text{Average Profit (Transfer Price)} - \text{Average Profit (no Transfer Price)}}{\text{Average Profit (no Transfer Price)}}.$$  

We compared the average profit ratio in the stochastic scenario to the profit ratio in the deterministic setting, to answer our primary research question of whether transfer pricing is more attractive for supply chains that face random demands than for supply chains with deterministic demand. We also analyzed the trends in the profit ratios with respect to different business parameters, as presented in section 5, to identify how these parameters of the supply chains affect profit improvement.

### 2.6.1 Customer Base

![Figure 2.3: A plot of the impact of transfer pricing schemes as a function of the customer base. In the stochastic setting as the customer base increases the percentage impact of transfer prices decreases.](image-url)
2.6. Computational Results

As one can see from Figure 2.3, the profit improvement ratio is larger for the stochastic scenario than for the deterministic setting, and also there is a downward trend in the profit ratio with the increase of the customer base. On the other hand, for the deterministic case the profit improvement ratio is constant, and this is analytically established in Proposition 2.6.1 below.

**Proposition 2.6.1** Profit ratio in the deterministic scenario is independent of customer base and price elasticity and equals:

\[
\text{Profit Ratio} = \frac{(t_R - t_M)^2}{(2t_M - t_R - 1)(t_R - 1)}.
\]

For the stochastic case, we observe (Figure 2.3) a decreasing trend in the percentage improvement. For the deterministic supply chain, as was established in Proposition 2.3.1, the optimal transfer price increases linearly with the customer base and as a result the selling price will increase as well. The randomness in the stochastic supply chain will reduce the selling price, but this reduction will be almost independent of the customer base since the variability is independent of the customer base. For example, when the customer base was 200, the optimal selling price in the stochastic setting averaged $4.12 (a 27.6% reduction from the deterministic average optimal selling price of $5.83) while it was $27.86 (only a 4.5% reduction from deterministic average optimal selling price of $29.18) when the customer base was 1000. The difference between optimal prices in the deterministic and stochastic settings remains almost the same as the customer base changes. However, since the selling prices increase as the customer base increases, the percentage change in selling price is decreasing. As a result of the lower percentage drop in selling price, the impact of the transfer pricing strategies is lower when the customer base is larger.
2.6. Computational Results

Figure 2.4: A plot of the impact of transfer pricing strategies as a function of price elasticity. Observe that, as the price elasticity increases, supply chains in the stochastic scenario will gain more advantage.

2.6.2 Price Elasticity of Demand

For the deterministic case, the profit improvement ratio is constant (as expected from Proposition 2.6.1), but for the stochastic scenario we observe an upward trend in Figure 2.4. Supply chains that face high price elasticity of demand for their products (e.g. sellers of products with a large number of relatively similar substitutes) will gain more advantage from the use of transfer price, in terms of profit increase, than supply chains with lower price elasticity of demand. There are two main reasons for this behavior. Because the optimal selling price is lower in the stochastic setting, higher price elasticity leads to a higher mean demand. For example when \( b = 10 \), the increase in mean demand is 12.5%, while the increase in mean demand is 14.6% when \( b = 50 \). The randomness in demand is independent of price and as a consequence independent of mean demand. As a result of the increase in mean demand with no change in the demand variance, the benefits from transfer prices are higher when the price elasticity is larger.
2.6.3 Degree of Variability in Demand

Now we would like to compare overall benefit of the stochastic model over the model without variability of demand, by comparing corresponding profit improvements with respect to the variability of demand.

![Figure 2.5: A plot of the impact of transfer prices as a function of demand variability when price elasticity is low. Observe that the supply chain’s profit improvement from the usage of transfer price in the stochastic setting is not significantly different from the profit improvement in the deterministic scenario.](image)

We can see from Figures 2.5 and 2.6 that for the supply chains with high price elasticity (the horizontal axis represents parameter \(v\)), the average profit increase in the stochastic case is consistently larger than the profit increase in the deterministic model. From these charts, we also observe that, while the profit improvement ratio is not invariant to the presence of variability, it is relatively invariant to changes in degree of variability. The fact that stochastic supply chains with higher price elasticity perform much better is due to the fact they record a larger volume of sales due to the reduction (when compared to supply chains with no transfer price) in selling price. We believe that the invariance of percentage improvement due to changes in variability is due to two opposing forces associated with selling price and stocking level. When the variability parameter \(v\) increased from 30 to
Figure 2.6: A plot of the impact of transfer prices as a function of demand variability when price elasticity is high. A supply chain that experiences random demand is better off with the introduction of transfer price than is a supply chain with deterministic demand.

150, the average selling price decreased from $16.9 to $15.4 while the average stocking level increased from 238.2 units to 325.4 units. As the degree of variability increases, the decreasing selling price counteracts the increasing stocking level and stabilizes the profit improvement.

2.6.4 Ratio of Cost of Underage to Cost of Overage

Another characteristic of supply chains is the ratio of the cost of underage to the cost of overage. As we can see from the corresponding chart (Figure 2.7), the profit increase in the deterministic case is constant, as there are no such costs involved in the deterministic setting. In the stochastic case the profit improvement ratio increases almost linearly as the ratio of the underage cost to the overage cost increases. For the supply chain with relatively low underage cost as compared to overage cost, the profit improvement is not as good as it is for the supply chain with very high underage cost relative to the overage cost. This behavior occurs because, as the ratio of the cost of underage to the cost of overage goes up, the retailer will want to stock much more than the mean demand. For instance, when the
2.6. Computational Results

Figure 2.7: A plot of the impact of transfer prices as a function of the ratio of underage cost to overage cost. As this ratio increases supply chain facing random demand benefits more from transfer pricing as compared to the deterministic case.

underage cost to overage cost ratio was 1, the average stocking level was 270 and increased to 285 when this ratio was increased to 9. Since a supply chain using transfer pricing has the ability to easily absorb such increases in inventory, we observe an increasing trend in the impact of transfer prices as the underage cost to the overage cost ratio increases.

2.6.5 Effect of different cost markups

Recall that one of the methods allowed by IRS for determining transfer prices is the cost plus method. This method is very popular among American corporations [Halperin and Srinidhi (1987)]. We would like to see how our results respond to imposing limits on transfer price that may be necessitated by these rules.

We evaluate the impact of increasing the maximum allowed markup in both the stochastic and deterministic settings. For the setting where $a = 400$, $b = 30$, $v = 30$, $t_R = 20\%$, $t_M = 0\%$ and $C_u/C_o = 5$, we varied the markup limit from 0\% to 200\% of the manufacturing cost. To facilitate such a markup, we set the manufacturing cost equal to 1. The resulting profit improvements are displayed in Figure 2.8.
2.7. Summary and Future Research

Figure 2.8: A plot of the impact of transfer prices as a function of the allowed markup limit for the setting in which $a = 400, b = 30, v = 30, t_R = 20\%, t_M = 0\%, \text{ and } \frac{C_u}{C_o} = 5$. As this limit increases, the profit ratio improves faster for the stochastic setting.

Figure 2.8 illustrates that as the maximum allowed markup increased, the profit improvements increased, for both the deterministic and stochastic settings. Along the lines of our earlier observations, the profit improvement in the stochastic setting was larger than the profit improvement in the deterministic setting. However as the maximum allowed markup increased, the difference between these stochastic and deterministic scenarios increased. This indicates that when there is significant flexibility in setting transfer prices, the supply chains facing random demand have a significant reason to pursue them.

We repeated all of these experiments for the case where $\epsilon$ was normally distributed with mean 0 and standard deviation $\frac{1}{3}v$ for the values of $v$ chosen in Table 1. The observations from that set of experiments were very similar to the ones from the Uniform distribution. As a result we decided not to report them separately.

2.7. Summary and Future Research

This study contributes to the supply chain management literature by merging two very important aspects of business, namely operations management and taxation. We show
that findings from existing deterministic models analyzed by economists may be extended from the operations management perspective, to obtain important managerial insights. Our major conclusion is that global supply chains facing random demand benefit more from engaging in transfer pricing practices than supply chains facing deterministic demand. Another interesting finding is that the optimal selling price for the stochastic supply chain is lower than the optimal selling price for the corresponding deterministic supply chain. We also found that certain business characteristics (such as high price elasticity of demand, high cost of underage as compared to cost of overage) of the global supply chains contribute to the magnitude of their profit improvement experienced from transfer pricing strategies. This is only a starting point, and we identify several directions for future research.

As of now our model mostly focuses on the scenario where the MNC does not repatriate foreign profits back to the U.S. If profits are repatriated back to the U.S., the parent company has to pay the U.S. tax on the income, minus foreign tax credits for the amount that has already been paid to the foreign government [Froot and Hines (1995)]. For example, if MNC earned $100 abroad and paid 15% in taxes to the foreign government, resulting in $85 in the after-tax foreign income, it should pay the remaining $20 in taxes to the U.S. government ($100 \times (35\% - 15\%)$). There are numerous strategies that multinational corporations can engage in (see Altshuler et al. (2001)) that “have the effect of achieving the equivalent of repatriation without incurring the home country tax on direct repatriations of low-tax income”. An example of such a strategy may be investing in passive assets, such as Eurodollar deposits, and then borrowing in the U.S. against these passive assets held at the CFC. In fact, empirical results from Altshuler et al. (2001) suggest that CFC’s actually invest in these alternatives when they face high repatriation taxes. Note that if the MNC uses such strategies, then the results of our main model are applicable.

If the MNC decides to repatriate profits back to the U.S. after a certain number of years, our model needs some modifications, because the profit function will change. Assuming that the company does not pay dividends, does not make tax provisions, and repatriates foreign
income after \( n \) years, the supply chain’s profit will change to \( \Pi_{rep} \), defined below. Notice that, although we pay tax on \( \pi_M \) twice, the total amount of taxes paid sums up (percentage wise) to \( t_R \). We earn interest in country \( M \) on the after tax profit \( (\pi_M(1-t_M)) \):

\[
\Pi_{rep} = \pi_R(1-t_R)(1+g_R)^n + \pi_M(1-t_R) + \pi_M(1-t_M) [(1+g_M)^n - 1] (1-t_R),
\]

where:

- \( \Pi_{rep} \) : Supply chain’s expected profit with repatriation after \( n \) years
- \( \pi_M \) : Manufacturer’s profit
- \( \pi_R \) : Retailer’s expected profit
- \( t_M \) : Manufacturer’s tax rate
- \( t_R \) : Retailer’s tax rate
- \( g_R \) : The return rate of the retailer
- \( g_M \) : The return rate for the manufacturer

We used this profit function in a new computational study to see if our observations are still valid for the situation in which the profit is repatriated after a few years. The results reveal that, when the return rate in the foreign country is higher (20%) than the return rate in the U.S. (10%), and the profit will be retained in the foreign country for 10 years, the company will experience a profit improvement from using transfer pricing. This is due to the fact that it can earn interest on the deferred taxes in addition to the interest earned on the after-tax profit. Along the lines of our earlier observations, these profit improvements were larger when the end-customer demands were random. As this analysis considers only simplest use of unrepatriated funds (reinvestment), more thorough research is needed in this area, to fully address repatriation of profits and assess the profit improvement behavior when MNCs use unremitted earnings in various ways.

Other possible extensions to our research that we have not yet explored, but would like to investigate in the future include the following:

1. Incorporating a capacity constraint and the presence of a local market for the products
made by the manufacturer. In such a case the manufacturer would need to decide how much of its production (bounded by the capacity limit) would be sold in the local market (based on random demand that it faces there) and how much would be supplied to the parent company in the U.S. In this case, the answer to “Problem Q” will be the minimum of the quantity desired by the retailer, determined by the retailer’s maximum profit and the quantity that the manufacturer desires to supply, based on its maximum profit. The list of business parameters of the supply chains to be evaluated should include customer base, price elasticity of demand, and variability of the demand that the manufacturer faces from its local market.

2. Considering multiple products and/or multiple suppliers. The result of this extension may be creation of a decision making tool for multinational corporations that would help choose suppliers or products to pursue.

3. Turning our static model into a dynamic model will give an opportunity to consider
2.7 Summary and Future Research

lead times and may give some interesting insights on the profitability’s response to the changes in average duration and variability of the lead times. Another possible aspect that may be considered in the dynamic model is exchange rate fluctuations.

4. Interesting observations may arise from a study that would add risk preference issues to the current model. For example a risk averse supply chain may want to use transfer pricing to shift income to the countries where the exchange rate risk and return risk are lower.

5. In our model we assume that the demand randomness is of the additive type. It would be interesting to see how the results would, or would not, change if the randomness in demand were modeled in a multiplicative fashion.
Chapter 3

Transfer Pricing and Offshoring in Price-Setting Global Supply Chains Facing Cost Uncertainty

3.1. 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

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1This chapter is joint work with Laurens Debo and Srinagesh Gavirneni.
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 im-
portance 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
3.2. 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 $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
3.2. Transfer Pricing and its Role in Sourcing

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 (Geis 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.
3.3. 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 B.1 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 $c_E$. For analytical tractability we model $c_E$ as a two-point distribution with $Pr(c_E = \underline{c}_E) = Pr(c_E = \bar{c}_E) = \frac{1}{2}$, where $\beta$ represents the coefficient of variation, $\mu$ is the mean, $\underline{c}_E = \mu(1 - \beta)$, and $\bar{c}_E = \mu(1 + \beta)$. When $c > \bar{c}_E$, 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 $[\underline{c}_E, \bar{c}_E]$.

**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 $\alpha P$, where $\alpha$ is an exogenous parameter such that $0 \leq \alpha \leq 1$. 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 $\mathcal{C} = \{T \geq 0, P \geq 0 : c \leq T \leq \alpha P\}$. To guarantee positive demands in further analysis, we put a restriction on the parameters: $\xi > \text{Max}(\tau_E, \frac{\alpha}{\alpha})$.

**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 $\mu$ and $\beta$) 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 $\tau$ in the foreign country. When $\tau > t$, it is optimal to report all income at the 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 ($\pi_L(T, P, \lambda, c_E) = D(P)(P - \lambda T - (1 - \lambda)c_E)$). 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

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

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

where $\Pi^o(P, c_E) = \pi_L(T, P, 0; c_E)(1 - t)$.

### Decision Variables

The firm has three major decisions to make: 1) the sourcing decision - the proportion, $\lambda$, 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 $\lambda$; 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 $\lambda$; both the sourcing and marketing divisions are local.

### 3.4. 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:

$$\Pi^C = \max_{(T,P) \in \mathcal{C},0 \leq \lambda \leq 1} \mathbb{E}[\Pi(T, P, \lambda, c_E)].$$

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

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

Let $$P^C$$, $$\lambda^C$$, 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 3.4.1** 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 3.4.1** When $$\tau < t$$, there exists a threshold $$\hat{c} > \mu$$ on the foreign cost, such that

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

the optimal price is

$$P^C = \begin{cases} P^o(\frac{c(1-\tau)}{1-t+\alpha(t-\tau)}), & c < \hat{c} \\ P^o(\mu), & c \geq \hat{c}, \end{cases}$$
and the optimal transfer price is

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

Recall from Lemma 3.4.1 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.

![Tradeoff curves](image)

Figure 3.1: Tradeoff curves between the cost and tax differentials for various values of markdown parameter \( \alpha \). Each curve separates the offshoring region (below the curve) from the outsourcing region (above the curve). Parameters: \( \xi = 1, b = 0.1, t = 0.35, \mu = 0.5 \), and \( \alpha \) varies from 0.5 to 0.9.
3.4. Centralized Model

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 3.1, 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 \( \alpha \). 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 3.4.2** Threshold \( \hat{c} \) is increasing in markdown parameter \( (\alpha) \), increasing in market size \( (\xi) \), and decreasing in price elasticity \( (b) \).

As a consequence of Lemma 3.4.2, the area of region A in Figure 3.1 increases in markdown parameter \( (\alpha) \). Intuitively, if the legal bound on the transfer price is looser (high \( \alpha \)), 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 \( \xi \) and \( b \). An increase in market size \( (\xi) \) 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.
3.5. 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.

3.5.1 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 $\mathcal{C}$:

\[ \Pi^P = \max_{T, 0 \leq \lambda \leq 1} \mathbb{E} \left[ \Pi(T, P^P(T, \lambda, c_E), \lambda, c_E) \right] \quad (3.1) \]

s.t. \( (T, P^P(T, \lambda, c_E)) \in \mathcal{C}, \forall c_E \in \{c_L, c_E\} \),

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

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 3.6), incentive upper bound is tight in 79.49% of the cases in our study.

Before formally presenting the solution to (3.1), to gain further insight we study a relaxation of \( \Pi^P \) (denoted by \( \Pi^P_{\text{relax}} \)) by ignoring the legal constraints (3.2) and present the results in Lemma 3.5.1.

\[
\Pi^P = \max_{T, \lambda \in \{0\} \cup [\epsilon, 1]} \mathbb{E}[\Pi(T, P^P(T, \lambda, c_E), \lambda, c_E)]. \tag{3.3}
\]

Since the firm cannot practically offshore an infinitesimal amount of production, we introduce \( \epsilon \) 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 \( (\lambda^P, T^P) \) be the solution for \( \Pi^P \):

\[
(\lambda^P, T^P) = \max_{T, \lambda \in \{0\} \cup [\epsilon, 1]} \mathbb{E}[\Pi(T, P^P(T, \lambda, c_E), \lambda, c_E)]
\]

We define an interim function

\[
\hat{T}^P(\lambda) = \max_T \mathbb{E}[\Pi(T, P^P(T, \lambda, c_E), \lambda, c_E)]
\]

**Lemma 3.5.1** The relaxed problem (3.3) is convex in \( \lambda \) with a discontinuity at \( \lambda = 0 \). There exists a threshold on the offshoring cost, \( \bar{c} \), such that:

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

When ignoring legal constraints, Lemma 3.5.1 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 \( \epsilon \) 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 \( \epsilon \) (see Figure 3.2). Also notice that in the absence of legal constraints, the profit function is convex in \( \lambda \). 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 \( \lambda \), 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 \( \lambda \).

Now, we re-introduce the legal constraints. Since \( P^P(T, \lambda, c_E) \) is increasing in \( c_E \), we replace (3.2) with \( (T, P^P(T, \lambda, c_E)) \in C \). When the transfer price is bounded from above, the company is limited on how much tax advantage it can obtain from offshoring. In Proposition 3.5.1, we characterize the optimal strategy that complies with these legal bounds on the transfer price.

**Proposition 3.5.1**

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 \( \lambda^P \).

In Proposition 3.5.1, the sourcing decision no longer has an all-or-nothing structure. In order to build up intuition for Proposition 3.5.1 we revisit the main result of Lemma 3.5.1. 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 \( \lambda \) 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 the conditions under which the partial solution holds. Instead, we demonstrate its behavior with a numerical example in Figure 3.3. 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
Figure 3.3: Optimal sourcing strategy. Parameters: $\xi = 10$, $b = 1$, $\mu = 1$, $\beta = 1$, $t = 0.35$, and $\alpha = 1$

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.
3.5.2 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:

$$\Pi^S = \max_{P,T} \mathbb{E} \left[ \Pi (T, P, \lambda^S (T, P, c_E), c_E) \right]$$

subject to

$$(T, P) \in C$$

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

Define now

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

**Lemma 3.5.2** The optimal strategy of the local management is as follows:

$$\lambda^S (T, P, c_E) = \lambda^o (T, c_E), \forall (T, P) \in C$$

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 3.5.2

$$\hat{P}^S (T) = \arg \max_P \mathbb{E} \left[ \Pi (T, P, \lambda^o (T, c_E), c_E) \right]$$
Proposition 3.5.2 $T^S = \min \left( \hat{T}^S, c_E \right)$, where $\hat{T}^S$ solves $T = \alpha \hat{P}^S(T)$.

Proposition 3.5.2 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, $c_E$ 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 $c_E$. In our numerical study, the incentive upper bound $c_E$ 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 3.5.3 When $c_E < \hat{T}^S$, there exists a $\hat{\beta}$, such that $\Pi^S$ increases in $\mu$ when $\beta > \hat{\beta}$.

Proposition 3.5.3 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 ($c_E$) 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 $c_E$ (Proposition 3.5.2). When $c_E$ 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

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.

3.5.3 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:

$$\Pi_{PS} = \max_T \mathbb{E}[\Pi(T, P_{PS}(T, c_E), \lambda_{PS}(T, c_E), c_E)] \quad (3.5)$$

s.t. $(T, P_{PS}(T, c_E)) \in \mathcal{C} \forall c_E \in \{c_L, c_E\}$

where $(P_{PS}(T, c_E), \lambda_{PS}(T, c_E)) = \arg \max_{P \geq 0, 0 \leq \lambda \leq 1} \pi_L(T, P, \lambda, c_E) \forall c_E \in \{c_L, c_E\}$

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 3.5.3 provides insight into the solution of (3.5).

Lemma 3.5.3 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,

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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 $[c_L, c_E]$ instead of a two-point distribution.
3.5. Decentralized Models

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

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 ($T^{PS}$) and the other by the sourcing decision of LM ($\bar{c}_E$). 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 3.5.5** When $\bar{c}_E < \min(\hat{T}^{PS}, T^{PS})$, $\Pi^{PS}$ increases in $\mu$ when $\mu < \hat{\mu}$.

This result is similar to Proposition 3.5.3. 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.

### 3.5.4 Summary of Results

In Table 3.1 we summarize the structural results obtained in the previous sections.
3.5. Decentralized Models

In the analytical 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

<table>
<thead>
<tr>
<th></th>
<th>Centralized</th>
<th>Decentralized P</th>
<th>Decentralized S</th>
<th>Decentralized PS</th>
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<tbody>
<tr>
<td>$P$</td>
<td>$P^o(\mu)$</td>
<td>$P^o(\lambda^P(T + (1 - \lambda^P)c_E))$</td>
<td>$P^o(\lambda^S(1 - r) + T^*(r - t))$</td>
<td>$P^o(\min(T, c_E))$</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>$\lambda^C \in {0, 1}$</td>
<td>$\lambda^P \in [0, 1]$</td>
<td>$\lambda^S \in [0, 1]$</td>
<td>$\lambda^{PS} \in {0, 1}$</td>
</tr>
<tr>
<td>$T$</td>
<td>Legal UB</td>
<td>The lowest of:</td>
<td>The lowest of:</td>
<td>The lowest of:</td>
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<tr>
<td></td>
<td></td>
<td>legal UB</td>
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<td>legal UB</td>
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<td></td>
<td></td>
<td>incentive UB for pricing</td>
<td>incentive UB for sourcing</td>
<td>incentive UB for pricing</td>
</tr>
<tr>
<td>$H(\mu)$</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
</tr>
</tbody>
</table>

Table 3.1: Summary of structural results
3.6. Numerical study

In our numerical study summarized below (Table 3.2), 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.

<table>
<thead>
<tr>
<th>Low value</th>
<th>High value</th>
<th>Increment</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>0.2</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.7</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>$c$</td>
<td>$\mu(1 - \beta)$</td>
<td>$\mu(1 + \beta)$</td>
<td>$\frac{2\mu\beta}{3}$</td>
</tr>
</tbody>
</table>

Table 3.2: 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 3.4-3.7), 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 3.4 that focuses on one of the drivers - high cost variability ($\beta = 1$), while the tax differential is set to 0 ($t = \tau$).

When cost is variable, but there is no tax advantage, any decentralized solution, in
3.6. Numerical study

Figure 3.4: 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 ($\tau \in \{0.35\}$).

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 $c = \frac{c}{\mu} = \frac{\mu (1+\beta)}{\mu} = 1 + \beta = 2$ (or to the lowest realization of the external cost $c = \frac{c}{\mu} = \frac{\mu (1-\beta)}{\mu} = 1 - \beta = 0$), 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 3.5, we focus on the second driver: we set tax differential high ($t - \tau \geq 0.15$) and cost variability very low ($\beta = 0.4$).

Now, we can see that when the coefficient of variation is low, the centralized structure
3.6. Numerical study

Figure 3.5: 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 ($\tau \in \{0.15, 0.20\}$).

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 ($c_{\mu} = 0.6$ or $c_{\mu} = 1.4$), 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 3.6, we consider a case when the cost variability is high and the tax differential exists, but it is small ($t - \tau \leq 0.05$).

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 ($c < 0.62$), the centralized structure performs better than
Figure 3.6: 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 ($\tau \in \{0.30, 0.35\}$).

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. $c_\mu = 0.67$), 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 $c_\mu$ is low (e.g. $c_\mu = 0.67$), 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 $c_\mu$ increases and it becomes more
3.6. Numerical study

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 $\frac{c \mu}{\mu}$ reaches its maximum ($\frac{c \mu}{\mu} = 2$ in Figure 3.6), 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 3.7: 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 ($\tau \in \{0.15, 0.20\}$).](image)

Finally, we notice that when the cost variability is high and tax differential is high (Figure 3.7), 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 3.7 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 3.8).

![Figure 3.8: 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 ($\beta = 1$).](image)

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 3.9: 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 3.9). 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
3.7. 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.
Chapter 4

Transfer Pricing and Offshoring in Price-Taking Global Supply Chains Facing Cost and Exchange Rate Uncertainty

4.1. Introduction

Supply chain activities such as procurement decisions and distribution network design were traditionally done independently of the tax planning activities. Recently, however, ample evidence emerged that companies have recognized that significant savings can be achieved if tax considerations are incorporated into supply chain planning decisions (Drucker 2010). A 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 involve tax directors at all (Ernst & Young 2007). Deloitte expounds in its strategic tax vision that, at the beginning of

\footnote{This chapter is joint work with Laurens Debo and Srinagesh Gavirneni.}
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). Therefore, tax-aligned design and management of supply chains is poised to be a new frontier of excellence for global companies.

The importance of tax strategies and their integration into supply chain modeling has also attracted 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.

Ernst & Young study on Global Tax Trends reports that leading practices of multinational companies include “review of the tax effectiveness of every area of a company’s operations potentially affected by a transaction” before planning decisions are made. For example, a tax director of a large steel manufacturer in Pittsburgh says that before a facility location decision is made, the tax department prepares detailed analysis of tax implications of each proposal. Tax implications are impacted by the tax rates in corresponding locations, transfer pricing limitations, proposed business structure, etc. Jackson and Highfield (2010) shows that tax optimization prevails manufacturing location decisions in industries with
automated manufacturing processes that produce items with high profit margins. They use two examples for patent drugs and medical devices and we see a lot of evidence of companies in these industries running their manufacturing plants in low-tax rate countries, such as Ireland, e.g. Forest Laboratories [Drucker] (2010). In our study, we will focus on the effect of taxation on the sourcing location decision.

One of the most popular tools for managing and taking advantage of different tax regimes is transfer pricing. The transfer price is an intrafirm price that is used for transactions between affiliated companies within a multinational enterprise. Transfer pricing can be used 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). Transfer price can also be used to split profits between subdivisions of the global supply chain in order to compute compensation of managers leading these subdivisions. 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 used 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). Global companies incorporated in the U.S. can leverage tax benefits only on the unrepatriated foreign profits. Based on the latest evidence reported in Drucker (2010), as of the end of year 2009, U.S. companies have not repatriated at least $1 trillion in foreign profits. Hence, we assume in our models that the profits realized in foreign location remain at that location for relevant duration.

In addition to tax related challenges, global companies have to deal with issues related
to exchange rate fluctuations and information asymmetry around uncertain procurement cost. Glatzel et al. (2009), Kumar (2007) highlight the prevalence of uncertainty in the current global world and show examples of firms that design their supply chains in a way that allows them to respond to volatility in business conditions. One of the strategies that has been gathering steam in the last few years is onshoring - re-locating production and/or procurement back to the U.S. As stated by Maher and Tita (2010), “The trend, known as onshoring or reshoring, is gaining momentum as a weak U.S. dollar makes it costlier to import products from overseas.” Examples of such strategies include General Electric Co. that announced its plans to move production of water heaters from China to Louisville, KY, in the near future and Caterpillar that plans to move production of heavy equipment to a new plant in the U.S. (Maher and Tita 2010). Another form of flexibility that helps supply chain deal with uncertainty is postponement.

Hewlett Packard’s Design for Supply Chain Program is well known in the operations management community for its successful use of postponement strategies (Feitzinger and Lee 1997). The full Design for Supply Chain Program, however, consist of 6 components, where only one of the components is “Postponement”. The fifth component of the program is “Tax and Duty Reduction”, indicating that Hewlett Packard designs the products and the supporting supply chain infrastructure in a way that increases after-tax and after-duty profitability. They claim that: “For example, the network printing capability of a printer is moved to a removable card built in a low-tax location, saving more than $10 Million” (Jackson and Highfield 2005). Hence, the flexible product structure does not only allow Hewlett Packard to be responsive to uncertainty in demand and cost structure, but also allows to take advantage of a low-tax jurisdiction and increase after-tax profit. We aim to analyze how operational flexibility in our model can be used in a similar dual manner: coping with uncertainty and taking advantage of low tax rates. Cohen and Mallik (1997) identified in the review of global supply chain research that studies should put more emphasis on the risk management aspects of supply chain op-
erations and namely, on the benefits of operational flexibility. Operational flexibility or operational hedging has been used in operations management in many forms to address uncertainty. Kogut and Kulatilaka (1994), Anupindi and Jiang (2008), Tomlin and Wang (2008). For example, ways to cope with uncertainty include investing in an option to change the course of action after realizing the uncertainty or simply postponing the decision making until the uncertainty is resolved (Tomlin and Wang 2008). Kogut and Kulatilaka (1994) analyze a global supply chain with two production facilities in different countries that face exchange rate uncertainty; the supply chain has an option to switch production allocation after realizing uncertainty to mitigate the exchange rate risk. Anupindi and Jiang (2008) study a capacity investment for a supply chain that can postpone production allocation until demand uncertainty is resolved. In our study, the firm sources the final product rather than materials for production; hence, we focus on the sourcing switching option that can be exercised after the uncertainty in cost and exchange rate is realized. Namely, we incorporate supply chain flexibility by allowing for the possibility of changing (at least partially) the sourcing decision once the exchange rate has been revealed. Suppose the firm initially decides to produce abroad; if the exchange rate turns out to be unfavorable, then it can move some of its production back to the local facility. This strategy can be supported either by flexible production networks that allow changing of the supplier at the last moment, or by smart product design that allows for some parts of the product to be independently produced/sourced from different locations.

Finally, we have to address another issue that is relevant both to dealing with uncertainty and setting transfer prices in the supply chain: information asymmetry in decentralized supply chains. Although many studies on transfer pricing in accounting and information economics literature Horst (1972), Hirshleifer (1956) have traditionally focused on the deterministic setting, Ronen and Balachandran (1988) suggested to look at the transfer pricing problem within the agency theory framework claiming that transfer prices have a big role in inducing optimal decisions in decentralized settings. Kaplan and Atkinson (1998) argue that
4.1. Introduction

the main driver for decentralization is information “specialization” that causes asymmetry
and consequently [Goex and Schiller (2006)] state that “one of the fundamental shortcomings
of the standard transfer pricing model is the assumption that the local profit functions are
common knowledge”. Information asymmetry is a common occurrence in supply chains
because some parties have access to more or better information than others. In our model,
local profit function depends on the outsourcing cost that is hard (or very costly) to observe
for the central management of the firm and hence, is privately known to the local division
and therefore, is a source of information asymmetry that affects transfer prices set in the
firm.

In order to combat the information asymmetry problem that arises from cost uncer-
tainty, it is common for firms to delegate the decision making to the party that has better
information and to design a contract that would induce this party to make a decision favor-
able for the firm. Supply chain contracting between manufacturers and retailers has been
studied in the operations management literature [Kim and Netessine (2009), Corbett (2001),
Cachon and Zhang (2006)], however, none of these studies have explicitly considered issues
of international taxation. In our model, the transfer price is a transaction between the
foreign supplier and the local retailer, hence, we use it to design a contract between the two
parties to induce the local manager to make the centrally optimal sourcing decision. The
same transfer price is used for taxation purposes, hence, the unique feature of our model is
that the contract parameter has an additional direct impact on the expected profit of the
firm, which is constrained by legal limitations on transfer prices. Further on, we refer to
the income-shifting role of transfer price that determines taxable profit as the tax role of
transfer prices and to the managerial role that determines incentives for divisional managers
as the incentive role of transfer prices.

To summarize, in order to address the problems highlighted above (business uncertainty
and tax implications), we build a supply chain model in which a) a global firm faces un-
certainty in cost and in exchange rates; b) local manager has perfect information about
the local sourcing cost; c) the firm has an option to operate in different tax regimes; and
d) the firm can invest in flexibility to mitigate the impact of the cost and exchange rate uncertainties. We apply four different accounting and supply chain management tools: 1) transfer pricing, 2) global sourcing strategy, 3) flexibility, and 4) organizational structure to this model and find optimal ways in how these tools can be used jointly to overcome challenges poised by uncertainty and to take advantage of different tax rates across the globe. This model allows us to obtain the optimal sourcing, transfer pricing, and flexibility strategy for global supply chains and lets us address the following research questions:

1. How does the existence of tax differential between global firm divisions affect its sourcing and transfer pricing strategy?

2. What impact does dual role of transfer pricing (tax and incentive role) have on the sourcing and transfer pricing strategies of the tax optimized supply chain?

3. How can a decentralized global firm use supply chain contract based on transfer prices with the local division to achieve optimal sourcing strategy?

4. And finally, what impact does supply chain flexibility have on the transfer prices and sourcing decisions in the decentralized supply chain and what is the optimal flexibility investment?

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. The papers mentioned above only address the tax role of transfer prices, but 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, however, show in section 4.5.1 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. 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-dependent demands with an additive random component. They showed that the benefits of transfer pricing are larger when there is randomness in demand. 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.

Before we present the details of our modeling and analysis, we present a brief summary of our results. We find that the centralized supply chain can achieve high tax benefits by setting the transfer price at the highest legally allowed value, however, the sourcing strategy in this case is hindered because headquarters have limited information about the cost structure. Flexibility in the supply chain that allows to change decisions after realizing uncertainty does not change either the transfer pricing or sourcing strategy but can be profitable for the firm when the tax differential is not too high. Decentralized supply chains, however, are
restricted in setting the transfer price compared to the centralized supply chains because
the transfer price is also used as an incentive mechanism to motivate the local division
to choose the right source. The sourcing decision, however, is based on the realization of
the outsourcing cost. Adding flexibility to such supply chain changes the transfer pricing
strategy and allows the supply chain to set the transfer price higher and hence, increasing
the tax benefit.

The rest of this paper is organized as follows. In section 4.2 we describe the supply chain
model we use and follow that up, in sections 4.3 and 4.4 with analysis of the centralized and
decentralized structures with and without flexibility. We then compare the profit of different
models in section 4.5 using numerical examples and evaluate the benefit of decentralization.
And finally, we close the paper, in section 4.6 with some concluding remarks and ideas for
future research.

4.2. Supply Chain Setup

We consider a global supply chain that consists of three entities, namely (i) the headquarters
(HQ); (ii) a local division that sells a single product in the local market; and (iii) a foreign
subsidiary that can manufacture the product. The product is sold only in the local market
at the retail price of \( p \) per unit in the local currency. We will assume that the demand
for this product is deterministic and, without loss of generality, one unit. Next, we present
our modeling details and assumptions for sourcing, flexibility, transfer pricing, information
asymmetry, tax rates, and organizational structure.

**Sourcing:** The firm can procure the required quantity of the product from two sources,
namely (i) from the foreign subsidiary (offshore) at a cost \( c \); and (ii) from an external third
party supplier (outsource) at a random cost \( \theta \). For analytical tractability, we model \( \theta \) as
a 2-point distribution where \( \theta = \theta \) with probability \( \gamma \) and \( \theta = \theta \) with probability \( 1 - \gamma \)
with \( 0 < \theta < \theta \). In order to understand the impact of volatility on the supply chain’s
4.2. Supply Chain Setup

strategies, we express the lowest and highest realizations of the random variables using the mean \((\mu_\theta)\) and standard deviation \((\sigma_\theta)\) of the random variable: 
\[
\bar{\theta} = \mu_\theta - \sigma_\theta \sqrt{\frac{1+\gamma}{1-\gamma}}, \quad \text{and} \quad \underline{\theta} = \mu_\theta + \sigma_\theta \sqrt{\frac{1-\gamma}{1+\gamma}}.
\]
If the product is imported from the foreign facility, the exchange rate, \(e\), has to be taken into account. Hence, in local currency, the cost is \(ec\). We assume that the average exchange rate \(\mu_e\) is 1, and hence, use \(c\) to denote the expected foreign cost expressed in the local currency. Similarly to \(\theta\), \(e\) is a random variable drawn from a 2-point distribution, where \(e = \underline{e}\) with probability \(\phi\) and \(e = \bar{e}\) with probability \(1 - \phi\). Hence, \(\underline{e} < 1 < \bar{e}\). We also express the lowest and highest realizations of \(e\) as 
\[
\underline{e} = 1 - \sigma_e \sqrt{\frac{1-\phi}{\phi}}, \quad \bar{e} = 1 + \sigma_e \sqrt{\frac{\phi}{1-\phi}},
\]
as functions of its standard deviation \(\sigma_e\).

In order to focus on the cases in which the cost advantage is uncertain, we restrict the parameter space to:
\[
\underline{c}e \leq \theta \leq \bar{c}e \leq \bar{\theta} \tag{4.1}
\]
That is, we consider situations in which the lowest (highest) possible outsourcing cost is no lower than the lowest (highest) possible offshoring cost. If \(\underline{c}e\) were greater than \(\bar{\theta}\) or \(\theta\) were greater than \(\bar{c}e\), then the sourcing decision would be trivial. If \(\underline{c}e \leq \theta \leq \bar{\theta} \leq \bar{c}e\), then the uncertainty in outsourcing cost will not play an important role in the analysis. On the other hand, if \(\underline{\theta} \leq \underline{c}e \leq \bar{c}e \leq \bar{\theta}\), then the exchange rate uncertainty will have a diminished role. In order to capture a rich context for the purposes of analysis, we make the assumption detailed in the inequality of Equation 4.1.

**Flexibility:** HQ can invest in flexibility that allows HQ to change the sourcing decision after the exchange rate and the outsourcing cost are observed and effectively reallocate the flexible portion of production to the other supply source. The degree of flexibility is represented by the decision variable \(x \in [0, 1]\) and comes at a per-unit cost \(K(x) = \frac{kx^2}{2}\). Once \(x\) has been determined, then the company can re-allocate at most a fraction \(x\) after the uncertainty on the exchange rate and outsourcing cost has been resolved.

**Transfer Pricing:** When the HQ offshores, the product is imported to the local country
at a transfer price \((T)\) written in the local currency. One of the most widely used methods for transfer pricing is the market price based strategy (Tang 2002). Under this approach, the transfer price 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 \(\alpha p\), where \(\alpha\) is an exogenous markdown parameter such that \(0 \leq \alpha \leq 1\) and \(p\) is the per-unit retail price. As motivated in the introduction section, we use the same transfer price for managerial and incentive purpose. 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 worst realization of foreign production cost \((c_e)\). Based on the evidence from Eccles and White (1988), there exists a significant number of companies that set the transfer prices at production cost. Notice that this is a conservative modeling approach, since in case of observing \(e\), the firm could lower the transfer price down to \(c_e\). As a result, management is constrained to set the transfer price such that \(c_e \leq T \leq \alpha p\). Another important reference point for setting the transfer price could be outsourcing cost \(\theta\). Federal Income Tax Regulation of the Internal Revenue Code §1.482-1 prescribes transfer pricing rules for the global companies established in the U.S., and states that companies have the freedom to use any one of the rules prescribed or a combination of some of the rules. Hence, we do not impose any additional constraints on the transfer price \(T\) and assume that there exists a rule that can justify the transfer price to be equal to any value in the interval \(c_e \leq T \leq \alpha p\). We impose a restriction \(\bar{\theta} < \alpha p\) to disallow negative profits.

**Information Asymmetry:** Management of the local division has direct contact with the external suppliers and consequently obtains better information about the outsourcing cost earlier than the headquarters. Hence we assume that at the moment of the initial sourcing decision making the headquarters only know the parameters of the distribution of the outsourcing cost, while the local management knows its exact realization, \(\theta\). As time progresses, uncertainty is resolved and the outsourcing cost realization becomes known also
4.2. Supply Chain Setup

to the HQ, which can be used for the re-allocation decision.

**Tax Rates:** Tax rates in the two tax jurisdictions differ and we use $t$ to represent the net portion of profit that remains in the local country after taxes and $\tau$ for the net portion of profit that remains in the foreign country after taxes. That means $1 - t$ and $1 - \tau$ are the local and foreign tax rates respectively and we use this notation for analytical convenience. In order to avoid trivial solutions, we assume that the tax advantage is in the foreign country (i.e. $\tau \geq t$). We will refer to the supply chains that have $\tau > t$ as supply chains *with tax advantage* and to supply chains that have $\tau = t$ as cases *without tax advantage*.

**Organizational Structures:** We assume that the decisions associated with transfer prices, flexibility investment, and reallocation are made by the headquarters. The sourcing decision, however, may be delegated to the local division that has better information about the outsourcing cost. Hence, we examine two different decision-making structures: 1) *centralized* - where all decisions are made by HQ and 2) *decentralized* - in which the local division makes the sourcing decision. Notice that in the centralized structure, transfer price is used purely as a profit-shifting mechanism that can be set at the very end of the decision horizon. In the decentralized structure, however, the transfer price is also used as an incentive mechanism, i.e. the local division makes its sourcing decision based on the transfer price offered, and hence the transfer pricing decision has to be made at the beginning of the horizon. Based on these modeling criteria, we formulate, solve, and analyze the following four models:

1. **Model C.** This model does not incorporate flexibility (in effect, we are assuming $k = +\infty$ or $x = 0$) and the transfer pricing and sourcing decisions are made by the headquarters before the uncertainties are resolved.

2. **Model CF.** In this model, we enhance Model C by allowing the possibility of upfront investment in flexibility and reallocation after the uncertainties have been resolved.

3. **Model D.** This model does not incorporate flexibility and the transfer pricing de-
decisions are made by the headquarters before the uncertainties are resolved while the sourcing decision is made by the local division after the cost uncertainty has been resolved, but before the exchange rate uncertainty resolution.

4. **Model DF.** This is similar to Model D with a flexibility investment and transfer pricing decisions by the HQ, a sourcing decision by the local division, and a reallocation decision made by the HQ after exchange rate resolution.

In the following two sections, we describe detailed mathematical models underlying these four settings, solve them for optimality, and explain the behavior of the optimal solutions.

### 4.3. Centralized Models: CF and C

We first formulate the model in which all decisions are made in the centralized manner by the HQ and there is the possibility of flexibility investment and ex-post reallocation (Model CF). To build intuition we also present a model in which the flexibility option is eliminated, i.e. setting $x = 0$ (Model C). The timeline of the decisions in Model CF is represented in Figure 4.1. The HQ has to (i) make the flexibility investment and transfer pricing decisions and select the sourcing location (Stage 1), (ii) then the uncertainty is resolved, HQ observes both the outsourcing cost and the exchange rate and (iii) re-allocate the flexible portion of the production and set the transfer price (Stage 2).

![Figure 4.1: Timeline of decisions in the centralized model](image)

If the HQ decide to outsource in Stage 1 and not re-allocate the production in Stage 2,
the payoff for the HQ equals:

\[(p - \theta)t - K(x)t; \quad (4.2)\]

if they re-allocate portion \(x\), the payoff would change to:

\[(p - \theta)t - K(x)t + x(\theta - T)t + x(T - ce)\tau. \quad (4.3)\]

Hence, comparing Equation (4.2) with Equation (4.3), HQ would choose to re-allocate when \((\theta - T)t + (T - ce)\tau > 0\). Re-arranging terms allows us to reformulate this condition as \(TB(T) > CB(e, \theta)\) where \(CB(e, \theta) = c\tau e - t\theta\) can be interpreted as the after-tax cost benefit of outsourcing and \(TB(T) = T(\tau - t)\) and can be interpreted as the tax benefit of transfer pricing.

Similarly, if HQ decide to offshore in Stage 1 and not re-allocate the production in Stage 2, the payoff for HQ equals:

\[(p - T)t + (T - ce)\tau - K(x)t, \quad (4.4)\]

if they re-allocate portion \(x\), the payoff would change to:

\[(p - T)t + (T - ce)\tau - K(x)t + x(T - \theta)t - x(T - ce)\tau. \quad (4.5)\]

Hence, comparing Equation (4.4) with Equation (4.5), HQ would choose to re-allocate when \(CB(e, \theta) > TB(T)\).

In addition to making the re-allocation decision, HQ also has to pick the optimal transfer price \((T)\) in Stage 2; hence, we can write the HQ’s payoff after Stage 2 decisions and conditional on the sourcing decision as follows (the subscript \(O\) means that the sourcing decision made in Stage 1 was to Outsource and \(F\) – to offshore):

\[\Pi^C_O(\theta, e, x) = (p - \theta)t + x \max_{e \leq T \leq \alpha_p} [TB(T) - CB(e, \theta)]^+ - K(x)t\]
4.3. Centralized Models: CF and C

\[
\Pi_F^C(\theta, e, x) = \max_{e\leq T \leq \alpha_p} ((p - T)t + (T - ec) \tau + x[TB(T) - CB(e, \theta)] - K(x)t,
\]

where we use \( z^+ \) for \( \max(0, z) \) and \( z^- \) for \( \max(0, -z) \).

Then, the HQ’s optimization model for the centralized supply chain is:

\[
\max_{0 \leq x \leq 1} \max\{E_{e, \theta}[\Pi_O^C(\theta, e, x)], E_{e, \theta}[\Pi_F^C(\theta, e, x)]\}. \tag{4.6}
\]

4.3.1 Analysis of Model C

To build intuition and to understand the impact of flexibility on the optimal sourcing and transfer pricing strategies of the firm, we first analyze the model in which the supply chain has no option to invest in flexibility (that is, we set \( x = 0 \)):

\[
\max\{E_{e, \theta}[\Pi_O^C(\theta, e, 0)], E_{e, \theta}[\Pi_F^C(\theta, e, 0)]\}. \tag{4.7}
\]

Let \( T^C \) denote the optimal transfer price in Model C. In the following Proposition, we find the optimal transfer price (\( T^C \)) and the optimal sourcing strategy for the centralized firm.

**Proposition 4.3.1 (Model C)** When there is no supply chain flexibility (\( x = 0 \)), the optimal strategy of the firm is as follows:

1. Set transfer price at its legal upper bound: \( T^C = \alpha_p \);

2. Offshore when tax benefit exceeds average cost benefit \( (TB(\alpha_p) > CB(1, \mu_\theta)) \) and outsource otherwise.

All proofs are provided in the Appendix. In the centralized organizational structure, transfer price has only one role: shifting income to another jurisdiction; hence, when the tax advantage is in the foreign country, HQ can set the transfer price at the legal upper bound and attain the highest tax benefit as permitted by law (\( TB(\alpha_p) \)). Since HQ has to
make the sourcing decision before the uncertainty on cost and exchange rate is realized and the payoff function is linear in both random variables, this decision is made based on the expected values of corresponding random variables\footnote{This implies that the results of this section are not an artifact of the distributional assumptions on the outsourcing cost $\theta$ and exchange rate $e$; and extend to all distributions with finite mean}. In particular, the sourcing strategy is determined by a threshold on the expected foreign cost that depends on the tax differential and the average outsourcing cost.

![Threshold curve](image.png)

**Figure 4.2**: Threshold curve that determines the sourcing decision of a non-flexible centralized global supply chain. Parameters: $\tau = 0.9$, $\alpha = 0.5$, $p = 2$, and $\mu_\theta = 0.9$.

The threshold 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 4.2, where we plot the threshold on the tax differential ($\tau - t$) on the vertical axis and the expected foreign cost ($c$) on the horizontal axis. In the shaded area the optimal solution is to offshore and in the white area, the optimal solution is to outsource. The area in region Offshoring A is self-explanatory: when there is a cost advantage and a tax advantage in the foreign country the firm offshores. In region Offshoring B, even though
4.3. Centralized Models: CF and C

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.

Next, we present the analysis of the centralized model with flexibility (Model CF).

4.3.2 Analysis of Model CF

In the flexible supply chain, HQ has an option to re-allocate the production once it observes realizations of outsourcing cost and exchange rate in Stage 2. First, we present the optimal re-allocation strategy of the firm for a given initial sourcing decision and flexibility investment, $x$, in Lemma 4.3.1.

**Lemma 4.3.1** The re-allocation strategy of the firm is as follows:

1. If the initial decision was to offshore, the HQ will re-allocate a fraction $x$ only if it observes $(\theta, \tau)$ and $TB(T^{CF}) < CB(\tau, \theta)$.

2. If the initial decision was to outsource, the HQ will re-allocate a fraction $x$ if
   - it observes $(\theta, \epsilon)$, $(\bar{\theta}, \bar{\tau})$, or $(\theta, \bar{\tau})$; or
   - it observes $(\bar{\theta}, \bar{\tau})$ and $TB(T^{CF}) \geq CB(\tau, \theta)$.

Lemma 4.3.1 follows from the legal bounds on the transfer price. Given this optimal re-allocation strategy outlined in Lemma 4.3.1 we find the optimal sourcing and transfer pricing strategy in Proposition 4.3.2.

**Proposition 4.3.2 (Model CF)** When there is an option to invest in supply chain flexibility ($x > 0$), the optimal strategy of the firm is as follows:

1. When $TB(\alpha p) > CB(\tau, \theta)$, $x^{CF} = 0$ and otherwise, $x^{CF} > 0$.

2. Set transfer price at its legal upper bound: $T^{CF} = \alpha p$ for any $x^{CF} \geq 0$;

3. Offshore when tax benefit exceeds average cost benefit ($TB(\alpha p) > CB(1, \mu_\theta)$) and outsource otherwise for any $x^{CF} \geq 0$;
In Proposition 4.3.2, we find that neither the sourcing nor the transfer pricing policy changes with introduction of flexibility. The transfer price can still be set at its highest legal upper limit and the sourcing decision is made based on the average outsourcing cost and exchange rate. Notice that when the tax benefit is substantially high \( TB(\alpha p) > CB(\bar{e}, \theta) \), the firm will always want to offshore (regardless of the exchange rate and outsourcing cost realizations) and hence, flexibility has no value. Next, we discuss the properties of the optimal flexibility investment in Proposition 4.3.3.

**Proposition 4.3.3 (Properties of flexibility)**  
Optimal flexibility investment has the following properties:

1. \( x^{CF} \) increases (decreases) in the expected offshoring cost \( c \) when \( TB(\alpha p) > (\leq)CB(1, \mu_\theta) \);  
2. \( x^{CF} \) increases in outsourcing cost volatility \( \sigma_\theta \);  
3. \( x^{CF} \) increases in exchange rate volatility \( \sigma_e \).

We illustrate the interesting insights from Proposition 4.3.3 using numerical examples in Figures 4.3 and 4.4. On each figure, the solid line represents the optimal flexibility investment in the presence of tax advantage and dashed curve - in the absence of tax advantage. Contrasting these two cases helps us understand the impact of tax differential on the insights we obtain from our model.

First of all, notice the non-monotonicity of the optimal flexibility investment when the expected foreign cost increases. When the expected foreign cost is less than the threshold (indicated by a vertical line and corresponding to the point that makes \( TB(\alpha p) = CB(1, \mu_\theta) \)), the firm offshores and hence if the expected foreign cost increases, the firm is more likely to need to re-allocate sourcing after realizing uncertainty. To the right of the threshold, the firm outsources and hence, as the expected foreign cost increases, the firm is likely to keep the sourcing decision unchanged after realizing uncertainty and hence, the value of flexibility decreases. In the presence of tax advantage, the threshold that determines the sourcing decision is higher. For low expected foreign cost values, cost advantage
4.3. Centralized Models: CF and C

Figure 4.3: Optimal flexibility investment as the expected foreign cost changes. Solid curve - case with tax advantage ($\tau - t = 0.05$), dashed curve - case without tax advantage ($\tau - t = 0$). Parameters: $\tau = 0.9$, $\alpha = 1$, $p = 3$, $\phi = 0.5$, $\gamma = 0.8$, $\mu_{\theta} = 1$, $k = 0.5$, $\sigma_c = 0.4$, and $\sigma_{\theta} = 0.4$

in the foreign country and tax advantage in the foreign country complement each other, i.e. the location is attractive from cost perspective and from tax perspective; hence, it is likely that the HQ will want to offshore in Stage 2 after realizing uncertainty. Complementarity of tax and cost reasons means that tax advantage helps the HQ make the right decision in Stage 1 before realizing uncertainty, therefore, re-allocation will be needed less often and flexibility has less value. Therefore, flexibility investment is higher for the supply chains that do not have a tax differential between the sourcing locations. On the contrary, for the high expected foreign cost values, tax advantage and cost advantage compete with each other, i.e. the foreign location is attractive for tax reasons, but not for cost reasons; hence, the HQ that faces a tax advantage may need to re-allocate its sourcing decision more often than the HQ that does not have a tax advantage. Therefore, for high values of the expected foreign cost, flexibility investment is higher for the supply chains that have a tax advantage in the foreign country. Next, we discuss the sensitivity of the flexibility investment with respect to outsourcing cost volatility.
In Figure 4.4, not surprisingly, both lines increase because flexibility has more value when uncertainty is higher. Based on the parameters in this example, the HQ initially chooses to offshore. At the first glance, it is intuitive to expect that in the presence of tax advantage, the HQ should need less flexibility because tax advantage makes the offshoring option more attractive for the HQ and they will want to reallocate less often than in the case of no tax advantage. However, notice that when the volatility is low, the supply chain that faces a tax advantage needs more flexibility than the supply chain without tax advantage. This behavior can be explained as follows. Given our outsourcing cost distribution, increasing volatility effectively decreases the lowest realization of the outsourcing cost (which is beneficial for the supply chain) and increases the highest realization (which has no impact on the supply chain’s profit in case of offshoring). Hence, we reason only about the low realization of outsourcing cost. When the volatility is low, the low realization of outsourcing cost is high, but for the supply chain with tax advantage, the after-tax outsourcing cost ($\theta t$) is lower than for the supply chain without tax advantage. Hence, such
supply chains will prefer to re-allocate more often than the supply chains that do not have a tax advantage. In the case with higher outsourcing cost volatility, after-tax outsourcing cost for both types of supply chains is low enough to re-allocate and hence, the value of flexibility follows our initial logic and supply chain with tax advantage needs less flexibility.

4.4. Decentralized Models: DF and D

In the decentralized model, the HQ delegates the sourcing decision to the local manager that has private information about the outsourcing cost. The HQ learns about the outsourcing cost realization after the sourcing decision needs to be made. The sequence of decisions in this model is as following (Figure 4.5).

<table>
<thead>
<tr>
<th>STAGE 1</th>
<th>STAGE 2</th>
<th>STAGE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>HQ makes the flexibility investment decision and offers a transfer pricing contract to the local manager.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local manager observes realization of outsourcing cost and makes the sourcing decision.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HQ observes realizations of outsourcing cost and exchange rate.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HQ makes the re-allocation decision.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.5: Timeline of decisions in Model DF.

In Stage 1, the HQ makes the flexibility investment, \( x \), and sets transfer prices \( T_F \) and \( T_O \). Transfer price \( T_F \) is used if the local manager decides to offshore and transfer price \( T_O \) is used if the local manager decides to outsource but the HQ decides to re-allocate to the foreign facility. In Stage 2, the local manager observes the realization of the outsourcing cost \( \theta \) and makes the sourcing decision. Next, outsourcing cost and exchange rate realizations are observed by both parties, and in Stage 3, the HQ has an option to change the sourcing decision made by the local manager for the flexible portion \( x \) of production.

Now, we discuss the payoffs of the HQ and the manager. We start solving the problem backwards with Stage 3. In Stage 3, the payoff of the HQ conditional on the sourcing
4.4. Decentralized Models: DF and D

The decision made by the local manager (subscripts $O$ and $F$) is as following:

$$\Pi^D F (T_O, \theta, e, x) = pt - \theta t + x[TB(T) - CB(e, \theta)]^+ - K(x)t$$

$$\Pi^D F (T_F, \theta, e, x) = pt - ce\tau + T_F(\tau - t) + x[TB(T) - CB(e, \theta)]^- - K(x)t$$

The local manager’s payoff in Stage 2 conditional on the sourcing decision is:

$$\pi^D F (T_O, \theta, e, x) = \begin{cases} (p - (1 - x)\theta - xT_O)t, & \text{if } TB(T_O) \geq CB(e, \theta) \\ (p - \theta)t, & \text{o/w} \end{cases}$$

$$\pi^D F (T_F, \theta, e, x) = \begin{cases} (p - T_F)t, & \text{if } TB(T_F) \geq CB(e, \theta) \\ (p - (1 - x)T_F - x\theta)t, & \text{o/w} \end{cases}$$

For ease of exposition, we introduce function $\Delta(T_O, T_F, x, \theta) = \frac{1}{T}E_e[\pi_O(T_O, \theta, e, x) - \pi_F(T_F, \theta, e, x)]$ that represents the benefit of choosing outsourcing option vs. the offshoring option normalized for local tax for the local manager. If $\Delta(T_O, T_F, x, \theta) > 0$, it is beneficial for the manager to outsource, and if $\Delta(T_O, T_F, x, \theta) < 0$, it is beneficial for the manager to offshore.

In Stage 1, the HQ offers a transfer pricing contract to the local manager that consists of transfer prices $T_O$ and $T_F$. Based on the set of transfer prices $(T_O, T_F)$, $\Delta(T_O, T_F, x, \theta)$ may be positive or negative and consequently the local manager will decide to either outsource or offshore. Hence, the HQ can set the transfer prices to motivate four different types of behaviors of the local manager. We summarize these incentive strategies that can be taken by the HQ and the behaviors that can be motivated by these strategies in Table 4.1. To break the tie, we let the local manager choose offshoring if the expected payoffs are the same (i.e. $\Delta(T_O, T_F, x, \theta) = 0$).

Let $\hat{\Pi}^D_i(T_O, T_F, x)$ indicate the expected HQ profit obtained if HQ sets the contract such as to motivate behavior of Strategy $i$. Based on the selected strategy, the HQ’s profit will be different and the profit functions for different strategies are summarized in Table 4.2.
4.4. Decentralized Models: DF and D

| Strategy # | $\hat{\theta}$ | I $\theta$ | $\overline{TC}_i(x)$ | $\overline{IC}_i(x)$ |
|------------|----------------|---------|-----------------|-----------------
| 1          | offshore       | outsource | $\Delta(T_O, T_F, x, \hat{\theta}) < 0$ | $\Delta(T_O, T_F, x, \hat{\theta}) \geq 0$ |
| 2          | outsource      | offshore  | $\Delta(T_O, T_F, x, \hat{\theta}) \geq 0$ | $\Delta(T_O, T_F, x, \hat{\theta}) < 0$ |
| 3          | offshore       | offshore  | $\Delta(T_O, T_F, x, \hat{\theta}) < 0$ | $\Delta(T_O, T_F, x, \hat{\theta}) < 0$ |
| 4          | outsource      | outsource | $\Delta(T_O, T_F, x, \hat{\theta}) \geq 0$ | $\Delta(T_O, T_F, x, \hat{\theta}) \geq 0$ |

Table 4.1: Incentive strategies of the HQ with corresponding incentive compatibility constraints.

<table>
<thead>
<tr>
<th>Strategy #</th>
<th>$\hat{\Pi}_i^D(T_O, T_F, x)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\gamma E_e[\hat{\Pi}_O^D(T_O, \hat{\theta}, e, x)] + (1 - \gamma)E_e[\hat{\Pi}_F^D(T_F, \hat{\theta}, e, x)] - K(x)t$</td>
</tr>
<tr>
<td>2</td>
<td>$(1 - \gamma)E_e[\hat{\Pi}_O^D(T_O, \hat{\theta}, e, x)] + \gamma E_e[\hat{\Pi}_F^D(T_F, \hat{\theta}, e, x)] - K(x)t$</td>
</tr>
<tr>
<td>3</td>
<td>$E_e[\hat{\Pi}_F^D(T_F, \mu\theta, e, x)] - K(x)t$</td>
</tr>
<tr>
<td>4</td>
<td>$E_e[\hat{\Pi}_O^D(T_O, \mu\theta, e, x)] - K(x)t$</td>
</tr>
</tbody>
</table>

Table 4.2: HQ profit functions.

The HQ optimization problem in Stage 1 is then to motivate the manager to select the best strategy ($i \in \{1, 2, 3, 4\}$) and to select the corresponding investment in flexibility ($x$) and the transfer pricing contract ($T_O, T_F$):

$$\max_{i \in \{1, 2, 3, 4\}} \max_{T_O, T_F, x \in [0, 1]} \hat{\Pi}_i^D(T_O, T_F, x)$$

subject to $\overline{TC}_i(x)$ and $\overline{IC}_i(x)$

Let $T_F^D$ and $(T_F^D, T_O^D)$ denote the optimal transfer prices for Models D and DF respectively, and $i^D$ and $i^{DF}$ denote the optimal strategy. To build intuition, in the next subsection, we present the analysis of the model that does not have a flexibility option.

4.4.1 Analysis of Model D

In the absence of flexibility option (that is, when $x = 0$), the HQ never changes the sourcing decision and hence, $T_O$ does not exist. The contract with the local manager consists of only one transfer price $T_F$. We use $\hat{\Pi}_i^D(T_F) = \hat{\Pi}_i^{DF}(T_F, \cdot, 0)$ for $i \in \{1, 2, 3, 4\}$ to denote the expected profit of the HQ given that the contract motivates the local manager’s behavior.
In Proposition 4.4.1, we find the optimal transfer price ($T^D_F$) and the optimal sourcing strategy for the decentralized firm.

**Proposition 4.4.1 (Model D)** When there is no supply chain flexibility ($x = 0$), the optimal strategy of the firm is as follows:

1. Set transfer price as: $T^D_F = \bar{T}^D_i (T^D_O$ does not exist);

2. The optimal strategy is to motivate the manager to outsource if he observes $\underline{\theta}$ and offshore if he observes $\theta$ ($i^D = 1$).

Recall from Proposition 4.3.1 that in the centralized supply chain transfer price is always set at the legal upper bound because the transfer price has a purely income shifting role. In the decentralized structure, however, the transfer price is used not only as an income shifting mechanism, but also as an incentive mechanism for the local manager. Therefore, the transfer price is restricted by its incentive role by $\bar{\theta}$, which is lower than the legal upper bound ($\alpha p$). Hence, in the decentralized structure, the HQ faces the tradeoff between obtaining a better sourcing decision by delegating it to the better informed party and attaining less tax benefits because of the reduced transfer price. Since, there is no flexibility option, it is optimal to choose Strategy 1, in which the manager that observes $\underline{\theta}$ outsources and the manager that observes $\bar{\theta}$ offshores. This way the HQ benefits from the local manager’s

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3If $\theta$ was a continuous random variable with pdf $f(\theta)$ and cdf $F(\theta)$, $T^D_F$ would be the largest number satisfying the equation: $(\epsilon \mu c - T\tau)f(T) = (t - \tau)(1 - F(T))$; for example, for $\theta \sim U[A, B]$, $T^D_F = \frac{\frac{B(t - \tau) - \epsilon \mu c}{t - 2\tau}}{A}$. which similarly to the result discussed in this Proposition increases in the upper bound of the random variable domain.
information. Notice that the transfer price $T_F^D$ increases as $\theta$ increases, which leads to the observation that global supply chains that have potentially more expensive outsourcing options are better off than the supply chains that have cheaper outsourcing options. High outsourcing cost makes it easier to motivate the local manager to offshore and as a result the supply chain can attain higher tax benefit.

In the next subsection, we present the analysis of the model that has an option to invest in flexibility.

### 4.4.2 Analysis of Model DF

In this model, in addition to setting up the contract that motivates the best Strategy, HQ has to make a flexibility investment in Stage 1. In Stage 3, the HQ will have to make the re-allocation decision, which is identical to the decision in the centralized case and the resulting re-allocation strategy is hence, identical to the strategy presented in Lemma 4.3.1.

For different levels of flexibility investment, different incentive strategies can be optimal. We show in Proposition 4.4.2 that when the marginal cost of flexibility $k$ is high, Strategy 1 is optimal and present the corresponding optimal solution for the contract and for the flexibility investment.

**Proposition 4.4.2 (Model DF with Optimized Flexibility)** There exists a threshold $\hat{k}$ on the marginal cost of flexibility $k$, such that for all $\hat{k} \leq k < \infty$, the optimal strategy of the HQ is as follows:

1. $x^{DF} > 0$;

2. Set transfer prices as: $T_O^{DF} = \alpha p$ and $T_F^{DF} = (1 - x^{DF})\theta + x^{DF}\alpha p$;

3. Motivate the manager that observes $\theta$ to outsource and the manager that observes $\overline{\theta}$ to offshore ($t^{DF} = 1$).

First, we notice that as $\alpha p \geq \overline{\theta}$ the presence of flexibility allows the HQ to increase the transfer price $T_F^{DF}$ above $\overline{\theta}$, hence, supply chain flexibility does not only allow the
firm to respond to cost uncertainty, but also *increases* the tax benefit that the supply chain can achieve. When marginal cost of flexibility is high, flexibility investment will be low; however, optimal $x^{DF}$ is always positive ($\lim_{k \to \infty} x^{DF} = 0$). Recall that in the centralized model, the optimal flexibility investment is equal to zero when tax benefit is high ($TB(\alpha_p) > CB(\tau, \theta)$), see Proposition [1.3.2]. The difference between the centralized and decentralized models can be explained as follows. In the centralized case, flexibility is useful only to combat randomness in the outsourcing cost and exchange rate and if the tax benefit is so high that regardless of the outsourcing cost and exchange rate realization it would be optimal for the HQ to offshore, flexibility has no value. In the decentralized case, on the other hand, benefit of flexibility is two-fold: 1) it allows the supply chain to combat randomness and 2) it allows the supply chain to raise transfer prices and to attain larger tax benefits. Hence, when the potential tax advantage in the foreign country is high, the supply chain needs flexibility to be able to leverage this tax advantage. When flexibility is expensive, it is intuitive to expect that the optimal flexibility investment is low. Hence, the HQ does not have an opportunity to change the local manager’s decision on large quantities. Therefore, it is in the best interest of the HQ to let the local manager use the outsourcing cost information to make the sourcing decision rather than to force the local manager to always offshore or always outsource. For brevity of exposition, from now on we focus on the case where marginal cost of flexibility $k$ is large, which is practically relevant and provides interesting analytical insights. Next, we discuss the properties of the optimal flexibility investment in Proposition [1.4.3].

**Proposition 4.4.3 (Properties of $x^{DF}$)** *Optimal flexibility investment has the following properties:*

1. $x^{DF}$ decreases in the expected foreign cost $c$;
2. $x^{DF}$ decreases in $\sigma_\theta$;
3. $x^{DF}$ increases in $\sigma_e$. 
It is intuitive that the optimal flexibility investment increases as the volatility of the exchange rate goes up (part 3. of Proposition 4.4.3). We illustrate the comparative statics in parts 1. and 2. of Proposition 4.4.3 with numerical examples in Figures 4.6 and 4.7 and contrast them with the results for the centralized model (Figures 4.3 and 4.4).

Figure 4.6: Optimal flexibility investment as the expected foreign cost changes. Solid curve - case with tax advantage ($\tau - t = 0.2$), dashed curve - case without tax advantage ($\tau - t = 0$). Parameters: $\tau = 0.9$, $\alpha = 0.8$, $p = 2$, $\phi = 0.5$, $\gamma = 0.4$, $\mu_\theta = 1$, $\sigma_e = 0.8$, $\sigma_\theta = 0.4$, and $k = 0.5$.

Combining the result of Lemma 4.3.1 with the result of Proposition 4.4.2, we notice that in the decentralized supply chain, the HQ never re-allocates if the local manager chooses offshoring. The HQ will only change the decision from outsourcing to offshoring if the offshoring option is more attractive. As the expected foreign cost ($c$) increases, the offshoring option becomes less attractive, hence, flexibility is not used often and loses value. Consequently, the investment in flexibility always decreases as the expected foreign cost ($c$) increases. Recall that in the centralized case, the HQ can change the sourcing decision in both directions, hence, the value of flexibility can be increasing or decreasing in $c$.

It is intuitive to expect that flexibility should be more beneficial when the volatility increases (which is indeed the case for the centralized supply chain, Proposition 4.3.2).
However, in the decentralized supply chain, the sourcing decision is made by the local manager after realization of uncertainty. The contract ensures that this decision is made in the best interest of the HQ. However, there are two effects that the outsourcing cost volatility has on the flexibility investment. First, increasing the outsourcing cost volatility increases the high realization of outsourcing cost $\theta$. $\theta$ in turn affects the incentive constraint on the transfer price ($IC_1(x) < 0 : TF < TOx + (1-x)\theta$) that does not allow the supply chain to set the transfer price at its legal upper bound. Flexibility, however, loosens this bound (part 2. of Proposition 4.4.2) and therefore, can be used by the firm to attain higher tax benefit. Consequently, when the volatility is low, $\theta$ is low, and the HQ needs flexibility to push the upper bound imposed by the incentive constraint up; when the volatility is high, $\theta$ is high, and the HQ does not need as much flexibility. Second, the increase in outsourcing cost volatility decreases the lowest cost realization, which is beneficial for the HQ and makes the probability of needing to reverse the local manager’s decision lower.

The supply chain with tax advantage sees both effects of the outsourcing cost volatility,
while the supply chain without tax advantage only sees the second effect. Hence, flexibility brings more value for the decentralized supply chains with tax advantage and the flexibility investment is higher for such supply chains.

Next, we present the results of our computational study, which compares Models CF and DF and studies sensitivity of this comparison.

4.5. Computational study

In the computational study, we address the following questions: 1) How do the different structures compare and how is this comparison impacted by the tax advantage and other parameters? and 2) What is the difference between the flexibility strategy for the centralized and decentralized structures and how is this difference impacted by the tax advantage?

4.5.1 Dominance of the decentralized structure

In this subsection, we compare the expected supply chain profit for the decentralized and centralized structures and show when does decentralized structure outperform the centralized using numerical examples in Figure 4.8.

Region C in Figure 4.8 represents the area in which decentralized structure dominates the centralized structure. It is not surprising that decentralization is beneficial when the outsourcing cost volatility is high and the expected foreign cost is high. The outsourcing cost volatility implies that the value of local manager’s private information is high and the high expected foreign cost means that the cost of making a sourcing mistake is high. Recall the tradeoff that the HQ faces in the decentralized setting: local manager makes the sourcing decision based on the private information, but ignores the tax differences. Hence, there exists Region B, in which the decentralized structure becomes unattractive for tax reasons. This region exists only in the presence of tax advantage. In Region A, centralized structure dominates the decentralized structure for cost reasons and exists even in the absence of tax
Figure 4.8: Decentralized organizational structure always dominates the centralized structure in Region C, centralized structure dominates the decentralized structure because of tax benefits in Region B, and centralized structure always dominates in Region A (even in the absence of tax advantage). Effect of the expected foreign cost and outsourcing cost volatility. Parameters: $\alpha = 0.8$, $p = 2$, $\tau = .9$, $t = .7$, $\phi = 0.5$, $\gamma = 0.5$, $k = 0.5$, $\sigma_e = 0.5$, and $\mu_\theta = 1$.

advantage. Next, we would like to fix the tax advantage and look at the comparisons of all four models.

In this example (Figure 4.9), the local supplier is cheaper on average, i.e. the average outsourcing cost is 0.5, while the average foreign cost ranges from 0.7 to 0.9 on the plot. Hence, at high values of the foreign cost, it is unlikely that the foreign source may be attractive and the centralized control outperforms the decentralized control. When the foreign cost is low, however, there is a higher probability that the foreign supply source may be attractive and hence, there is value in delegating the sourcing decision to the local division.
4.5. Computational study

Figure 4.9: Since, on average, the local supplier is cheaper, centralized control outperforms decentralized when the average foreign cost is high. When foreign cost is low, decentralization. Solid lines represent centralized models (C and CF) and dashed lines - decentralized models (D and DF), thick lines indicate presence of flexibility option. Parameters: $\alpha = 1$, $p = 2$, $\tau = 1$, $t = .9$, $\phi = 0.5$, $\gamma = 0.5$, $k = 0.3$, $\sigma_c = 0.1$, $\mu_\theta = 0.5$, and $\sigma_\theta = 0.3$.

4.5.2 Optimal flexibility investment for centralized and decentralized organizational structures

In this subsection, we analyze how the flexibility investment is impacted by the organizational structure, tax advantage, and randomness in the outsourcing cost and the exchange rate using numerical examples in Figures 4.10 and 4.11.

First, we compare the optimal flexibility investment under different organizational structures as the outsourcing cost volatility increases. It is intuitive to assume that the flexibility investment in the centralized supply chain should be greater than the flexibility investment in the decentralized supply chain because in the centralized supply chain, flexibility is used to react to outsourcing cost volatility and exchange rate volatility, while in the decentralized supply chain uncertainty in the outsourcing cost is resolved before the sourcing decision is made, which is indeed the case in the absence of tax advantage (Figure 4.10(b)). However,
4.5. Computational study

Figure 4.10: Optimal flexibility investment for the decentralized and centralized organizational structure with respect to the outsourcing cost volatility. Solid line - Model CF, dashed line - Model DF. Parameters: $c = 0.87$, $\alpha = 0.8$, $p = 2$, $\tau = 0.9$, $\phi = 0.5$, $\gamma = 0.5$, $k = 0.5$, $\sigma_e = 0.5$, and $\mu_\theta = 1$.

Notice that in the case with tax advantage (Figure 4.10(a)), when the outsourcing cost volatility is low, decentralized supply chain invests more in flexibility than the centralized supply chain. This phenomenon can be explained as follows. Outsourcing cost volatility has a direct impact on the worst realization of the outsourcing cost $\theta$. When $\theta$ is low, the HQ has a tight incentive bound on the transfer price, which can be loosened using flexibility. Hence, the HQ invests in flexibility in order to be able to attain tax benefit. The centralized supply chain does not need as much flexibility at low volatility values because the probability of making a wrong sourcing decision based on the average is low. As outsourcing cost volatility increases, the centralized supply chain needs more flexibility because the probability of making the wrong sourcing decision increases (Proposition 4.3.3), while it is optimal for the decentralized supply chain to decrease the flexibility investment because $\bar{\theta}$ increases and the transfer pricing constraints are not as tight (Proposition 4.4.3).

Now, we compare the optimal flexibility investment under different organizational structures as the exchange rate volatility increases. As shown in Propositions 4.3.3 and 4.4.3, flexibility increases in the exchange rate volatility; the question that we want to address here is whether the flexibility investment is higher or lower for the decentralized supply
4.6. Summary of the results

Global supply chains trying to take advantage of tax differentials must do so in the presence of uncertainty in both sourcing costs and exchange rates. We formulate and analyze mathematical models, centralized as well as decentralized, that can be used to determine the optimal sourcing, transfer pricing, and flexibility investment strategies. A sourcing-dependent
contract in transfer prices is used to alleviate the impact of information asymmetry while the flexibility is used to respond to exchange rate uncertainty. Analysis of the centralized model enables us to identify the trade-off between cost advantage and tax advantage. Use of transfer pricing strategies enable us to demonstrate that an expensive foreign source may be attractive, from an after-tax perspective, if the tax rate there is low.

Flexibility plays an important role in improving the performance of both centralized and decentralized supply chains. In the centralized setting, flexibility serves as a managerial tool to respond to the uncertainty in both sourcing costs and exchange rates. In the decentralized setting, flexibility not only allows to respond to uncertainty, but is also useful for loosening the incentive constraints on the transfer price that allows the firm to attain higher tax benefits from offshoring.

Analysis of the decentralized models reveals interesting and potentially useful insights. Flexibility is always useful for the decentralized supply chains. However, since value of flexibility in the decentralized supply chain is driven by the flexibility’s ability to loosen the incentive bound on the transfer price, flexibility investment decreases as the outsourcing cost volatility increases. In addition, we find that the total after-tax profit may increase when the outsourcing cost increases. This is because the more expensive sourcing option facilitates HQ in providing proper incentives to the local manager and as a result, HQ can set larger transfer prices enabling them to move more profit to the lower tax foreign location.

Comparing the performance of the centralized and decentralized models reveals that due to information asymmetry inherent to our system, decentralized settings sometimes have a larger profit than the centralized models. The decentralized organizational structure is preferred when the expected foreign cost is large and the outsourcing cost variability is large: in such cases, the value of cost information that the local division is high and hence, it outweighs the tax advantage that the HQ can benefit from by centralizing the sourcing decision.
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, an endogenous sourcing decision, flexibility, and exchange rate uncertainty.
Chapter 5

Conclusions

This thesis incorporates tax perspectives into global supply chain optimization modeling, which is of high importance for practitioners operating multinational corporations. In each chapter, we address a different supply chain setting and study how tax differentials between the supply chain locations can be used to the advantage of the company using coordinated sourcing and transfer pricing strategies. We utilize the knowledge from supply chain management literature, taxation code, and accounting research to build the models that address these problems and to obtain insights on the solutions to these models.

In the first chapter, we analyze a supply chain that operates in two countries with different tax rates and faces random demand. We set up the problem as a newsvendor model and compare the benefit that the firm can achieve from optimizing transfer pricing for a firm that faces random demand to the benefit of a firm that faces deterministic demand. We show that findings from existing deterministic models analyzed by economists may be extended to obtain important managerial insights. Our major conclusion is that global supply chains facing random demand benefit more from engaging in transfer pricing practices than supply chains facing deterministic demand. Another interesting finding is that the optimal selling price for the stochastic supply chain is lower than the optimal selling price for the corresponding deterministic supply chain. We also found that certain business
characteristics (such as high price elasticity of demand, high cost of underage as compared to cost of overage) of the global supply chains contribute to the magnitude of their profit improvement experienced from transfer pricing strategies.

In the second chapter, we analyze the price-setting supply chain that faces random cost and has an option to offshore production to a low-tax jurisdiction. We derive a tradeoff curve between the cost and tax advantages that drives the global firms’ choice of sourcing strategy. 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 final chapter, we analyze the price-taking supply chain that faces random outsourcing cost and exchange rate, has an option to produce in a low-tax jurisdiction, and also can invest in supply chain flexibility that helps to respond to uncertainty. We analyze two different ways in which supply chains can respond to uncertainty: decentralization, i.e. delegation of certain decisions to the party that has better information, and flexibility, investing in an option to change the sourcing decision after realizing uncertainty. We find that flexibility has a positive impact on the potential tax benefit and hence, not only reduces the negative impact of uncertainty, but also facilitates the decentralization strategy, by lowering the cost of providing incentives. In addition, we find that the total after-tax profit may increase when the outsourcing cost increases. This is because the more expensive sourcing option facilitates HQ in providing proper incentives to the local manager and as a result, HQ can set larger transfer prices enabling them to move more profit to the lower tax foreign location.

This thesis opens a new direction that is of great importance to global supply chain
design literature. There are many possible extensions that can lead to new insights relevant to global supply chains. For example, 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 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, we have considered different sources of uncertainty in different chapters of this thesis. It would be interesting to combine the three sources of uncertainty and see how the results of our analysis and the insights would change for a supply chain that faced random demand, random costs, and random exchange rate.
Appendix A

Transfer Pricing in Global Supply Chains with Random Demands
A.1. Alternative analysis for determining optimal selling price and order quantity

This subsection contains an alternative analysis for determining the optimal selling price and order quantity that jointly maximize the retailer profit. Proceeding with representation 2.3 of the profit function, we observe the following results.

**Proposition A.1.1** The optimal price in the stochastic setting as a function of $z$ can be computed as

$$P_S^*(z) = \frac{4av + 4bTv - (v-z)^2}{8bv}.$$  

**Proof of Proposition A.1.1** First, observe that $\pi_R(z)$ is concave in $P$ for a given $z$:

$$\frac{\partial^2 \pi_R(z)}{\partial P^2} = -2b < 0.$$  

We can solve for optimal $P$ as a function of $z$ by evaluating first order conditions:

$$\frac{\partial \pi_R(z)}{\partial P} = a - \frac{4b(-2P + T)v + (v - z)^2}{4v} = 0,$$

$$P_S^*(z) = \frac{4av + 4bTv - (v-z)^2}{8bv}. \quad (A.1)$$

**Proposition A.1.2** Optimal order quantity in the stochastic setting $Q_s^*$ equals:

$$Q^* = a - bP_s^* + z^*,$$

where $z^*$ is the unique $z$ in the support $[-v,v]$ that satisfies $\frac{\partial \pi_R(z)}{\partial z} = 0$.

**Proof of Proposition A.1.2** First, from the definition of $z$:

$$Q = \mu + z,$$

$$Q^* = a - bP_s^* + z^*. \quad (A.2)$$
Second, observe that $T < P \Rightarrow (T - 2C_u) < P \Rightarrow a - b(T - 2C_u) - v > a - bP - v > 0$. Third, we note that uniform distribution has a nondecreasing hazard rate. Therefore, according to part c of Theorem 1 in Petruzzi and Dada (1999), $z^*$ is the unique $z$ in the support $[-v, v]$ that satisfies the first order condition $\frac{\partial \pi_R(z)}{\partial z} = 0$.

A.2. Proofs

Proof of Proposition 2.3.1. First we maximize the retailer’s profit by taking its first-order derivative and setting it equal to zero (note that since $Q$ is a linear function of $P$, we can solve Problems $Q$ and $P$ simultaneously):

$$\pi_R(P, T) = (a - bP)(P - T)(1 - t_R),$$

$$\frac{\partial \pi_R}{\partial P} = (a + bT - 2bP)(1 - t_R),$$

$$P^* = \frac{a + bT}{2b}.$$  \hspace{1cm} (A.3)

Therefore,

$$Q^* = a - bP^* = \frac{a - bT}{2}. \hspace{1cm} (A.4)$$

Then we find optimal transfer price by maximizing total supply chain profit:

$$\Pi = \left(\frac{a - bT}{2}\right)\left(\frac{a + bT}{2} - T\right)(1 - t_R) + \left(\frac{a - bT}{2}\right)T(1 - t_M),$$

$$\frac{\partial \Pi}{\partial T} = -\frac{bT}{2} - a - 2bTt_M + a - bTt_R,$$

$$T^* = \frac{a(t_M - t_R)}{b(2t_M - t_R - 1)}.$$  \hspace{1cm} (A.5)

Now, we can substitute (A.3), (A.4), and (A.5) into the profit equation (2.1) and get:

$$\Pi^* = \frac{a^2(t_M - 1)^2}{4b(t_R + 1 - 2t_M)}.$$
A.2. Proofs

Proof of Proposition 2.4.1. Taking the derivative of the retailer’s profit with respect to $Q$ results in:

\[
\frac{\partial \pi_{RB}(Q)}{\partial Q} = \frac{(a - bP)(C_o - C_u - P) - (T + Q)(C_o + C_u + P)}{2v} - T.
\]

We set the derivative equal to zero and solve for the optimal $Q$ resulting in:

\[
Q^* = a - bP - v + 2v \frac{(P - T + C_u)}{(P + C_o + C_u)}.
\] \quad (A.6)

Proof of Proposition 2.4.2. The profit formula above results from substituting (A.6) into the profit function (2.5).

Proof of Proposition 2.4.3. We show that, for every $\Delta > 0$, profit at $P_d^* + \Delta$ is less than profit at $P_d^*$.

Retailer’s profit in the stochastic setting at $P_d = \frac{a + bT}{2b}$ is:

\[
\left[ \pi_{RB} | P = \frac{a + bT}{2b} \right] = \frac{(a - bT)^2}{4b} - v(C_o + T) \frac{a + 2C_u b - bT}{a + bT + 2C_o b + 2C_u b}.
\]

Retailer’s profit in the stochastic setting at some larger selling price $P = \frac{a + bT}{2b} + \Delta$ is:

\[
\left[ \pi_{RB} | P = \frac{a + bT}{2b} + \Delta \right] = \frac{(a - bT)^2 - 4b\Delta^2}{4b} - v(C_o + T) \frac{a + 2b\Delta + 2C_u b - bT}{a + 2b\Delta + 2C_u b + 2C_o b + bT}.
\] \quad (A.7)

Calculating \([\pi_{RB} | P = (\frac{a + bT}{2b} + \Delta)] - [\pi_{RB} | P = (\frac{a + bT}{2b})]\) and observing that all terms in the numerator are negative and all terms in the denominator are positive reveals that the difference is negative. Therefore, \([\pi_{RB} | (\frac{a + bT}{2b} + \Delta)] < [\pi_{RB} | (\frac{a + bT}{2b})]\).

Proof of Proposition 2.6.1. From Proposition 2.3.1 we know that deterministic profit with transfer price equals $-\frac{a^2}{4b} \left( \frac{(t_M - 1)^2}{2t_M - t_R - 1} \right)$. We can show that deterministic profit without transfer price equals $\frac{a^2}{4b}(1 - t_R)$ by taking the first derivative of the corresponding profit
equation, obtaining optimal $P^*$ and $Q^*$ and substituting them back into the profit function. Now we can calculate profit ratio:

\[
\text{Profit Ratio} = \frac{-\frac{a^2}{4b} \left( \frac{(t_M-1)^2}{2(t_M-t_R-1)} \right) - \frac{a^2}{4b} (1 - t_R)}{\frac{a^2}{4b} (1 - t_R)} = \frac{(t_R - t_M)^2}{(2t_M - t_R - 1)(t_R - 1)}.
\]
Appendix B

Transfer Pricing and Offshoring in Price-Setting Global Supply Chains Facing Cost Uncertainty
B.1. Table of Notation

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
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<td>$\xi$</td>
<td>Market size</td>
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<tr>
<td>$b$</td>
<td>Price elasticity</td>
</tr>
<tr>
<td>$t$ and $\tau$</td>
<td>Tax rates in the local and foreign countries respectively</td>
</tr>
<tr>
<td>$c$</td>
<td>Offshoring cost</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Markdown on retail price</td>
</tr>
<tr>
<td>$c_E$</td>
<td>Outsourcing cost: $\Pr(c_E = c_E) = \Pr(c_E = \bar{c}_E) = \frac{1}{2}$</td>
</tr>
<tr>
<td>$\mu$ and $\beta$</td>
<td>Mean and coefficient of variation of the outsourcing cost</td>
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<table>
<thead>
<tr>
<th>Decision variables</th>
<th>Description</th>
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<tr>
<td>$P$</td>
<td>Price</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Offshoring proportion</td>
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<tr>
<td>$T$</td>
<td>Transfer price</td>
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<table>
<thead>
<tr>
<th>Superscripts identifying organizational structures</th>
<th>Description</th>
</tr>
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<tr>
<td>$C$</td>
<td>Centralized decision making with information asymmetry</td>
</tr>
<tr>
<td>$P$</td>
<td>Decentralized retail pricing</td>
</tr>
<tr>
<td>$S$</td>
<td>Decentralized sourcing</td>
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<td>$PS$</td>
<td>Decentralized retail pricing and sourcing</td>
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</table>

<table>
<thead>
<tr>
<th>Subscripts</th>
<th>Description</th>
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<tbody>
<tr>
<td>$L$ and $F$</td>
<td>Refer to the Local and Foreign divisions</td>
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<table>
<thead>
<tr>
<th>Functions</th>
<th>Description</th>
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<tbody>
<tr>
<td>$D(P)$</td>
<td>Demand function</td>
</tr>
<tr>
<td>$\pi_L(T,P,\lambda,c_E)$ and $\pi_F(T,P,\lambda,c_E)$</td>
<td>Pre-tax profits of the Local and Foreign divisions</td>
</tr>
<tr>
<td>$\Pi(T,P,\lambda,c_E)$</td>
<td>Consolidated after-tax profit of the firm</td>
</tr>
<tr>
<td>$\Pi^o(T,c_E)$</td>
<td>Is equal to $\Pi(T,P,0,c_E)$ which is independent of $T$</td>
</tr>
<tr>
<td>$\lambda^o(T,c_E)$</td>
<td>Is equal to 1 if $T &lt; c_E$ and 0 if $T &gt; c_E$</td>
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<tr>
<th>Set</th>
<th>Description</th>
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<tr>
<td>$\mathcal{C}$</td>
<td>Legal bounds on the transfer price</td>
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<table>
<thead>
<tr>
<th>Thresholds</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>$\hat{c},\bar{c},\hat{\alpha},\hat{\beta},\mu$</td>
<td>Thresholds on corresponding parameters</td>
</tr>
</tbody>
</table>

Table B.1: Summary of notation

B.2. Summary of parameter restrictions

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

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

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

Positive demand: $\xi > \max(\frac{c}{\alpha},\bar{c}_E)$, which implies $\xi > c_E$, $\xi > c$, and $\xi > \mu$. 
B.3. Proofs

Proof of Lemma 3.4.1. 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 $\lambda^C$ by using the envelope theorem to show that $\Pi^C(T,P,\lambda,\mu|t=\tau)$ increases (decreases) in $\lambda$ 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 $\lambda^C$. By envelope theorem, $\frac{d\hat{\Pi}^C(P,\lambda,\mu)}{d\lambda} = \left. \frac{\partial\hat{\Pi}^C(P,\lambda,\mu)}{\partial\lambda} \right|_{P=\hat{P}^C(\lambda)} = (\xi - b\hat{P}^C(\lambda))(1-t)(\mu - c)$, 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 $\lambda$, 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 $P^C = P^o(c)$. □

Proof of Proposition 3.4.1. In Proposition 3.4.1, 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 $\lambda$ ($\hat{P}^C(\lambda)$) and plug it into the profit function (Step 2). Next, we show that $\Pi(\hat{P}^C(\lambda),\lambda,\mu)$ is convex in $\lambda$ and hence, there are two candidate solutions (Step 3).
Next, derive the threshold on $c$ that determines which candidate solution for $\lambda$ 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 $\lambda$; 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 $\lambda$.** 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 $\lambda$. 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

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

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

Therefore, $\mu A + B > \mu$. □

**Proof of Lemma 3.4.2.** We find comparative statics (CS) of the threshold $\hat{c}$ by taking partial derivatives with respect to relevant parameters $\alpha$, $\xi$, and $b$ and evaluating their signs:

**Step 1:** CS with respect to $\alpha$.

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

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 $\alpha$ by showing that $\frac{\partial^2 \hat{c}}{\partial \alpha^2}$ is positive $\forall \alpha \in [0, 1]$:

$$
\frac{\partial \hat{c}}{\partial \alpha}\bigg|_{\alpha=0} = \frac{(b\mu + \xi)(t - \tau)}{2b(1 - \tau)} > 0 \quad \text{and} \quad \frac{\partial^2 \hat{c}}{\partial \alpha^2} = \frac{\sqrt{1 - t}(\xi - b\mu)(t - \tau)^2}{4b(1 - \tau)(1 - t + \alpha(t - \tau))^{3/2}} > 0 \Rightarrow \frac{\partial \hat{c}}{\partial \alpha} > 0
$$
Step 2: CS with respect to $\xi$.

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

Step 3: CS with respect to $b$.

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

Proof of Lemma 3.5.1. In Lemma 3.5.1 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 $\lambda$ ($\hat{P}^P(\lambda)$) (Step 2), and then, show that HQ’s profit is convex in $\lambda$, is discontinuous at $\lambda = 0$, $\lim_{\lambda \to 0} E[\Pi(\hat{P}^P(\lambda), P^P(\hat{P}^P(\lambda), \lambda, c_E), \lambda)] > E[\Pi^P(\lambda = 0, P^o(c_E))]$, and hence, there are two candidate sourcing solutions: full offshoring and $\epsilon$-offshoring, where $\epsilon$ represents a smallest unit that the company can offshore (Step 3). Finally, we derive the threshold that determines whether the full or $\epsilon$-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:

\[
\Pi(T, P^P(T, \lambda, c_E), \lambda, c_E) = \frac{(\xi - b c_E (1 - \lambda) - b T \lambda)((1 - t)(\xi - b c_E (1 - \lambda)) + b T \lambda (t + 2\tau + 1) - 2b\lambda (1 - \tau)c)}{4b}
\]

**Step 2: Find \( \hat{T}^P(\lambda) \).** Since \( \mathbb{E}[\Pi(T, P^P(T, \lambda, c_E), \lambda)] \) is concave in \( T \) for all \( \lambda \neq 0 \)

\[
(\frac{\partial^2 \mathbb{E}[\Pi(T, P^P(T, \lambda, c_E), \lambda, c_E)]}{\partial T^2}) = -\frac{1}{2}b\lambda^2 (1 + t - 2\tau) < 0,
\]

we will first optimize over \( T \) using the first order condition:

\[
\frac{\partial \mathbb{E}[\Pi(T, P^P(T, \lambda, c_E), \lambda, c_E)]}{\partial T} = \frac{1}{2} \lambda ((t - \tau)(\xi - b\mu (1 - \lambda)) - T b\lambda (t - 2\tau + 1) + b\lambda c (1 - \tau))
\]

\[
\hat{T}^P(\lambda) = \frac{b\lambda (\tau - 1)c + (\xi + b(\lambda - 1)\mu)(\tau - t)}{b\lambda (2\tau - t - 1)} = \frac{c(1 - \tau)}{1 - 2\tau + t} + \frac{(\xi - b(1 - \lambda)\mu)(t - \tau)}{b\lambda (1 - 2\tau + t)}
\]

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

\[
\mathbb{E}[\Pi(\hat{T}^P(\lambda), P^P(\hat{T}^P(\lambda), \lambda, c_E), \lambda)] =
\]

\[
\frac{1}{4b} \frac{(1 - \tau)^2 (\mu - c)^2}{t - 2\tau + 1} + \frac{\sigma^2}{2}\frac{(1 - t)\lambda ((\tau - 1)^2 (\xi - b\mu) + \mu - c}{t - 2\tau + 1} + \frac{b\sigma^2}{t - 2\tau + 1} + \frac{(\xi - b\mu)^2}{t - 2\tau + 1} - \frac{1}{4}b\sigma^2 (t - 1)
\]

\[
\mathbb{E}[\Pi(\hat{T}^P(\lambda), P^P(\hat{T}^P(\lambda), \lambda, c_E), \lambda)] \text{ is quadratic in } \lambda \text{ and the quadratic coefficient is positive, therefore the function is convex in } \lambda \text{ and the optimum is at an extreme point.}
\]

\[
\lim_{\lambda \to 0} \mathbb{E}[\Pi(\hat{T}^P(\lambda), P^P(\hat{T}^P(\lambda), \lambda, c_E), \lambda)] = \frac{(\xi - b\mu)^2}{4b} \frac{(1 - \tau)^2}{t - 2\tau + 1} + \frac{1}{4}b\sigma^2 (1 - t) \text{ and } \mathbb{E}[\Pi(P = 0, P^o(c_E))] = \frac{(\xi - b\mu)^2}{4b} (1 - t), \text{ the function is discontinuous at } \lambda = 0 \text{ and since } \frac{(1 - \tau)^2}{t - 2\tau + 1} > (1 - t), \lim_{\lambda \to 0} \mathbb{E}[\Pi(\hat{T}^P(\lambda), P^P(\hat{T}^P(\lambda), \lambda, c_E), \lambda)] > \mathbb{E}[\Pi(P = 0, P^o(c_E))] \text{ and } \lambda = 0 \text{ is not a candidate solution.}
\]

When \( \lambda = 1 \), optimal profit is \( \mathbb{E}[\Pi(\hat{T}^P(1), P^o(\hat{T}^P(1)), 1)] = \)
Step 4: Find threshold on $c$ that determines between full offshoring or $\epsilon$-offshoring.

We compare $\lim_{\lambda \to 0} \mathbb{E}[\Pi(\hat{T}P(\lambda), \hat{T}P(\lambda, \alpha, \mu, \epsilon))]$ with $\mathbb{E}[\Pi(\hat{T}P(1), P^\alpha(\hat{T}P(1)), 1)]$ to find threshold $\tilde{c}$:

$$
\frac{(\xi - b\mu)^2}{4b} \left( \frac{1 - \tau}{t - 2\tau + 1} \right) + \frac{1}{4} \frac{b\sigma^2}{4b} \left( \frac{1 - \tau}{t - 2\tau + 1} \right) = 0
$$

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

Since $c \leq \frac{\xi}{b}$ by assumption, only one solution is feasible:

$$
\tilde{c} = \frac{\xi}{b} - \frac{1}{b(1 - \tau)} \sqrt{(\tau - 1)^2 (\xi - b\mu)^2 - b^2\sigma^2 (t - 1) (t - 2\tau + 1)}. \quad \Box
$$

**Proof of Proposition 3.5.1.** In Proposition 3.5.1 we add the legal constraint to the result from Lemma 3.5.1 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 3.5.1 may not be feasible as it has to satisfy the legal constraint $B(\lambda)$: $\hat{T}P(\lambda) - \alpha P^\alpha(\hat{T}P(\lambda), \lambda, \epsilon) \leq 0$. In the proof we first demonstrate using a numerical example that there may exist an interior solution for $\lambda$ 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 $B(\lambda)$ is violated only for $\lambda < \hat{\lambda}$ (Step 2).

**Step 1: Existence of an interior solution.** We use $T^\star(\lambda)$ to denote the solution to $T = \alpha P^\lambda(T, \lambda, \epsilon) \Rightarrow T^\star(\lambda) = \frac{\alpha(\xi + b\mu(1 - \lambda))}{b(2 - \alpha\lambda)}$. For all $\lambda$, such that $B(\lambda) > 0$, optimal profit as a function of $\lambda$ is $\mathbb{E}[\Pi(T^\star(\lambda), P^\lambda(T^\star(\lambda), \lambda, \epsilon), \lambda)]$. Notice that $\mathbb{E}[\Pi(T, P, \lambda, \mu)]$ is a function of $P \times T \times \lambda$. Hence, given the form of $T^\star(\lambda)$, $\mathbb{E}[\Pi(T^\star(\lambda), P^\lambda(T^\star(\lambda), \lambda, \epsilon), \lambda)]$ 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 B.1(a)).

![Interior solution, c = 0.4.](image)

![Boundary solution, c = 0.55.](image)

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

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

$$B(\lambda) = \frac{2bc\lambda(\tau - 1) + (2b(\lambda - 1)\mu + 2\xi)(\tau - t)}{2b\lambda(-t + 2\tau - 1)} + \frac{\xi + b(1 - \lambda)\xi_E}{b(\lambda - 2)} \leq 0$$

We show that there exists a unique $\hat{\lambda}$, such that $\forall \lambda < \hat{\lambda}, B$ does not hold. $\lim_{\lambda \to 0} B(\lambda) = \infty, B(1) = -\frac{(\xi - b\mu)(1 - \tau)}{b(t - 2\tau + 1)} \leq 0$.

$\frac{dB(\lambda)}{d\lambda} = \frac{b\mu(t - \tau)(\lambda - 2)^2 - \xi(3\tau \lambda^2 + \lambda^2 + 4\tau \lambda + 2(\lambda^2 - 2\lambda + 2 - 4\tau) + b\lambda^2(t - 2\tau + 1)\xi_E)}{b(\lambda - 2)^2 \lambda^2 (t - 2\tau + 1)}$, the numerator of $\frac{d B(\lambda)}{d\lambda}$ is quadratic in $\lambda$, and the discriminant is less than zero $(-16(\xi - b\mu)(t - 2\tau + 1)(t - \tau)(\xi - b\xi_E) < 0)$, thus, $\frac{dB(\lambda)}{d\lambda} = 0$ does not have real roots, the derivative does not change its sign, and the function is always decreasing. Therefore, $B(\lambda) = 0$ has a unique root $\hat{\lambda}$.

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

\[ \Box \]

**Proof of Lemma 3.5.2.**

Local management finds optimal \( \lambda \) 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 \( T < c_E \).

\[ \Box \]

**Proof of Proposition 3.5.2.**

In Proposition 3.5.2, we derive optimal transfer pricing policy for a firm that decentralizes sourcing decisions. Given the optimal sourcing reaction from Lemma 3.5.2, we optimize total profit over \( T \) and \( P \). If \( T \) is above \( \bar{c}_E \), local division will never offshore, thus, the expected total profit is independent of \( T \). First, we break the analysis into two cases \( (T > \bar{c}_E \text{ and } c < T < \bar{c}_E) \) 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: \( T > \bar{c}_E \).**

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

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: \( c < T < \bar{c}_E \).** Since \( \bar{c}_E < c \), \( c < T \) implies \( \bar{c}_E < T \). Hence the cost advantage is always random. Expected profit in this case is:

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

$$
\frac{\partial \mathbb{E}[\Pi(T,P,\lambda^o|c < T < \tau_E)]}{\partial P} = (\xi - 2Pb)(1 - t) + \frac{1}{2}b(c_E(1 - t) + c(1 - \tau) + T(\tau - t))
$$

The optimal price is: $\hat{P}^S(T) = \frac{(2\xi + bc)(1 - t)}{16b(1 - t)}$. Define $\hat{T}^S$ as the solution to $T = \alpha \hat{P}^S(T)$ ($\hat{T}^S = \frac{a(b(1 - \tau) + (1 - t)(2\xi + bc_E))}{b(\alpha - 4 - \alpha \tau + 4)}$).

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

**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 $\text{Min}[\bar{c}_E, \hat{T}^S]$. Given the form of the solution for transfer price, we perform the following analysis also by separating the problem into two settings ($\bar{c}_E < \hat{T}^S$ and $\bar{c}_E > \hat{T}^S$):

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

\[
\mathbb{E}[\Pi(T, \hat{P}^S(T), \lambda^o|c < T < \bar{c}_E \text{ and } \bar{c}_E < \hat{T}^S)] = \frac{(2\xi - b\bar{c}_E)(1 - t) - bc(1 - \tau) + bT(\tau - t))^2}{16b(1 - t)}
\]

\[
= \frac{(2\xi - b\bar{c}_E)(1 - t) - bc(1 - \tau) - b\bar{c}_E(1 - t) + b\bar{c}_E(1 - \tau))^2}{16b(1 - t)}
\]

\[
= \frac{(2\xi - b\bar{c}_E - b\bar{c}_E)(1 - t) + (b\bar{c}_E - bc(1 - \tau))^2}{16b(1 - t)}
\]

\[
= \frac{(2\xi - b(\bar{c}_E + \bar{c}_E))(1 - t) + (b\bar{c}_E - bc)(1 - \tau))^2}{16b(1 - t)}
\]

\[
= \frac{(2\xi - b\mu)(1 - t) + (b\bar{c}_E - bc)(1 - \tau))^2}{16b(1 - t)}
\]

\[
= \frac{(\xi - b\mu)^2(1 - t)}{4b} + (\bar{c}_E - c)(1 - \tau) \left( \frac{4(\xi - b\mu)}{16} + \frac{b(\tau_E - c)(1 - \tau)}{16(1 - t)} \right)
\]
We compare expected profit from Case 2 with the profit from Case 1. Thus, we need to sign: \( \text{diff}_1 = 4(\xi - b\mu)(1-t) + b(\tau_E - c)(1-\tau); \) since \( c < \tau_E \) and \( \xi - b\mu > 0 \) by assumption \( \Rightarrow E[\Pi(T, \hat{P}(T), \lambda^0|c < T < \tau_E \text{ and } \tau_E < \hat{T}^S)] > \Pi^0(P, \lambda). \)

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

\[
E[\Pi(\hat{T}^S, \hat{P}(\hat{T}^S), \lambda^0|c < T < \tau_E \text{ and } \tau_E > \hat{T}^S)] - \Pi^0(P, \lambda^0) = (1-t) \left( \frac{\alpha(\xi)}{4b} \left[ \frac{2(\xi + b\varepsilon_E)}{b(4-a)} \right] \right)
\]

Thus, we need to sign \( \text{diff}_2 = \left( \frac{\alpha(\xi)}{4b} \left[ \frac{2(\xi + b\varepsilon_E)}{b(4-a)} \right] \right). \)

We first calculate the value of \( \text{diff}_2 \) when \( \tau = t: \frac{1}{4b}(\tau_E - c)(4\xi - bc - b\tau_E - 2b\varepsilon_E) \) and observe that it is always positive. Next, we evaluate

\[
\frac{d\text{diff}_2}{dt} = \frac{8(1-\tau)(b\xi(\tau-1) + \xi(\tau(a-2)-a\tau+2))}{(t(a-4)-a\tau+4)^2}
\]

and observe that it is positive when \( c < \frac{\alpha(2\xi + b\varepsilon_E)}{b(4-a)}, \) which is a necessary restriction for ensuring that \( C \) is nonempty. Therefore \( \text{diff}_2 > 0, E[\Pi(\hat{T}^S, \hat{P}(\hat{T}^S), \lambda^0|c < T < \tau_E \text{ and } \tau_E > \hat{T}^S)] > \Pi^0(P, \lambda^0) \) and \( \hat{T}^S = \min[\tau_E, \hat{T}^S]. \)

**Proof of Proposition 3.5.3.** In Proposition 3.5.3 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 \( E[\Pi(T, \hat{P}(T), \lambda^0|c < T < \tau_E \text{ and } \tau_E < \hat{T}^S)] \) with respect to \( \mu \) and show when it is positive.

\[
\frac{\partial E[\Pi(T, \hat{P}(T), \lambda^0|c < T < \tau_E \text{ and } \tau_E < \hat{T}^S)]}{\partial \mu} = \frac{(-2t - \beta + (\beta + 1)\tau + 1)((1-t)(b\mu - 2\xi) + bc(1-\tau) + b\mu(-t - \beta + (\beta + 1)\tau))}{8(1-t)}
\]
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 $\beta > \hat{\beta} = \frac{-2t + r + 1}{1 - \tau}$. Thus, the function is increasing in $\mu$ when $\beta > \hat{\beta}$.

**Proof of Lemma 3.5.3** 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 $\lambda$ by applying envelope theorem:

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

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, $P^{PS}(T, c_E) = \frac{bc_E + \xi}{2b} = P^o(\text{min}(T, c_E))$;
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, $P^{PS}(T, c_E) = \frac{bT + \xi}{2b} = P^o(\text{min}(T, c_E))$. □

**Proof of Proposition 3.5.4** In Proposition 3.5.4 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 3.5.2: $T > \tau_E$ and $c < T < \tau_E$. 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 3.5.2. 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 \(E[\Pi(T, P^{PS}(T, c_E), \lambda^o|c < T < \bar{c}_E)]\) is concave in \(T\), we find unconstrained optimal transfer price \(T^{PS}\) using first order condition:

\[
\frac{d}{dT}E[\Pi(T, P^{PS}(T, c_E), \lambda^o|c < T < \bar{c}_E)] = \frac{d}{dT}(T(t-2(\tau-1)+2(\tau-1))b^2+T(t-2(\tau-1))b^2-2\xi(t-\tau)b) = 0.
\]

Hence, \(T^{PS} = \xi(t-\tau)-b(\tau-1)c\).

**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 \(\hat{T}^{PS} = \frac{\alpha(bE_\xi+E_\xi)}{2b}\) 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 \(T\): \(\hat{T}^{PS}, T^{PS}, \bar{c}_E\), we need to look at 3 sub-cases where either of the bounds may be minimum.

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

\[
E[\Pi(T, P, \lambda^o|c < T < \bar{c}_E)] - \Pi^o(P, \lambda^o) = \\
\frac{1}{2} \Pi(P^o(\bar{c}_E), \lambda^o) + \frac{1}{2} \Pi(T, P^o(T), \lambda^o) - \frac{1}{2} \Pi^o(P^o(\bar{c}_E), \lambda^o) - \frac{1}{2} \Pi^o(P^o(\bar{c}_E), \lambda^o) = \\
\frac{1}{2} (\Pi(\min(\hat{T}^{PS}, \bar{c}_E), P^o(\min(\hat{T}^{PS}, \bar{c}_E)), \lambda^o) - \Pi^o(P^o(\bar{c}_E), \lambda^o)) = \\
\frac{1}{2} (D(P^o(\bar{c}_E))(P^o(\bar{c}_E) - \bar{c}_E)(1-t) + D(P^o(\bar{c}_E))(\bar{c}_E - c)(1-\tau) - \\
D(P^o(\bar{c}_E))(P^o(\bar{c}_E) - \bar{c}_E)(1-t)) = \\
\frac{1}{2} D(P^o(\bar{c}_E))(\bar{c}_E - c)(1-\tau) \geq 0
\]

\(E[\Pi(T, P, \lambda^o|c < T < \bar{c}_E)] > \Pi^o(P, \lambda^o) \Rightarrow \text{offer } T^{PS} = \bar{c}_E\)
2. \( \min(\hat{T}^{PS}, T^{PS}, \bar{c}_E) = T^{PS} \)

\[
\mathbb{E}[\Pi(T, P, \lambda^0|c < T < \bar{c}_E)] - \mathbb{E}[\Pi(T, P, \lambda^0|T > \bar{c}_E)] = D(P^o(T^{PS}))(P^o(T^{PS}) - T^{PS})(1 - t) + D(P^o(T^{PS}))(T^{PS} - c)(1 - \tau)
\]

\[
D(P^o(\bar{c}_E))(P^o(\bar{c}_E) - \bar{c}_E)(1 - t) =
\]

\[
D(P^o(T^{PS}))(P^o(T^{PS}) - T^{PS})(1 - t) + D(P^o(T^{PS}))(T^{PS} - c)(1 - \tau)
\]

\[
D(P^o(\bar{c}_E))(P^o(\bar{c}_E) - \bar{c}_E)(1 - t) =
\]

\[
(\xi - bc)^2(\tau - 1)^2 + (t - 1)(t - 2\tau + 1)(\xi - b\bar{c}_E)^2
\]

\[
8b(t - 2\tau + 1)
\]

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

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

\[
\mathbb{E}[\Pi(T, P, \lambda^0|c < T < \bar{c}_E)] - \mathbb{E}[\Pi(T, P, \lambda^0|T > \bar{c}_E)] =
\]

\[
= D(P^o(\hat{T}^{PS}))(P^o(\hat{T}^{PS}) - \hat{T}^{PS})(1 - t) + D(P^o(\hat{T}^{PS}))(\hat{T}^{PS} - c)(1 - \tau)
\]

\[
- D(P^o(\bar{c}_E))(P^o(\bar{c}_E) - \bar{c}_E)(1 - t)
\]

\[
= (4(t - 1)^2 \bar{c}_E - \alpha \xi E (4c(\tau - 1) + \alpha(t - 2\tau + 1)\xi E)) b^2 -
\]

\[
- 2\xi (2c(\alpha - 2)(\tau - 1) + 4(t - 1)\bar{c}_E + \alpha(t(\alpha - 2) + \alpha - 2\alpha\tau + 2\tau)\xi E)^2 b
\]

\[
- \alpha \xi^2 (t(\alpha - 4) + \alpha - 2\alpha\tau + 4\tau)
\]

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:

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

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

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

**Proof of Proposition 3.5.5.** In Proposition 3.5.5, 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 $\mu$ is positive, and in Step 2, we show that profit increases in $\mu$ by showing that the first derivative is positive when $\mu < \hat{\mu}$ and derive $\hat{\mu}$.

**Step 1: Show concavity.**

$$E[\Pi(\bar{c}_E, P^o(\min(c_E, \bar{c}_E)), \lambda^o)] =$$

$$\frac{2\xi( - t\xi + \xi + bc(\tau - 1)) - b(b(t - 2\tau + 1)\bar{c}_E + 2(bc(\tau - 1) - \xi(t - \tau))\bar{c}_E - (1 - t)\xi_E (b\xi_E - 2\xi))}{8b}$$

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

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

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

**Step 2: Show that profit increases in $\mu$.**

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

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

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

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

Transfer Pricing and Offshoring in Price-Taking Global Supply Chains Facing Cost and Exchange Rate Uncertainty
# C.1. Table of Notation

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<td>$T_O$</td>
<td>Transfer price in the decentralized case if the local division outsources and HQ re-allocates</td>
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<td>$T_F$</td>
<td>Transfer price in the decentralized case if the local division offshores</td>
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<tr>
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<td>Optimal $T$ in model $CF$</td>
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<td>$T^{DF}_O$, $T^{DF}_F$</td>
<td>Optimal $T_O$, $T_F$ in model $DF$</td>
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<td>$T^D_O$, $T^D_F$</td>
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</tr>
<tr>
<td>$x^{CF}$, $x^{DF}$</td>
<td>Optimal flexibility proportion $x$ in models $CF$ and $DF$</td>
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<td>$i^D$, $i^{DF}$</td>
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<td>Markdown parameter</td>
</tr>
<tr>
<td>$c$</td>
<td>Offshoring cost</td>
</tr>
<tr>
<td>$\tau$</td>
<td>Net profit rate in the foreign country</td>
</tr>
<tr>
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<td>$k$</td>
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<thead>
<tr>
<th>Random variables and associated parameters</th>
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</tr>
</thead>
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<td>$\theta$</td>
<td>Outsourcing cost</td>
</tr>
<tr>
<td>$\theta_l, \theta_h$</td>
<td>Low and high realizations of the outsourcing cost</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Probability of observing $\theta$</td>
</tr>
<tr>
<td>$\mu_\theta$</td>
<td>Average outsourcing cost</td>
</tr>
<tr>
<td>$e$</td>
<td>Exchange rate</td>
</tr>
<tr>
<td>$e_{\min}, e_{\max}$</td>
<td>Lowest and highest realizations of the exchange rate</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Probability of observing $e$</td>
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<thead>
<tr>
<th>Profit functions</th>
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<td>$\Pi^C_O(\theta, e, x)$</td>
<td>HQ profit optimized over $T_O$ given outsourcing procurement option</td>
</tr>
<tr>
<td>$\Pi^C_F(\theta, e, x)$</td>
<td>HQ profit optimized over $T_F$ given outsourcing procurement option</td>
</tr>
<tr>
<td>$\Pi^{DF}_O(T_O, \theta, e, x)$</td>
<td>HQ profit in model $DF$ given outsourcing procurement option</td>
</tr>
<tr>
<td>$\Pi^{DF}_F(T_F, \theta, e, x)$</td>
<td>HQ profit in model $DF$ given offshoring procurement option</td>
</tr>
<tr>
<td>$\pi^{DF}_O(T_O, \theta, e, x)$</td>
<td>Local division’s profit in model $DF$ given outsourcing procurement option</td>
</tr>
<tr>
<td>$\pi^{DF}_F(T_F, \theta, e, x)$</td>
<td>Local division’s profit in model $DF$ given offshoring procurement option</td>
</tr>
<tr>
<td>$\Pi^{DF}_i(T_O, T_F, x)$</td>
<td>Expected HQ profit in model $DF$ following incentive Strategy $i$</td>
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<td>$\Pi^{D}_i(T)$</td>
<td>Expected HQ profit in model $D$ following incentive Strategy $i$</td>
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<table>
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<tr>
<th>Other functions</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>$K(x)$</td>
<td>Per unit cost of flexibility</td>
</tr>
<tr>
<td>$TB(T)$</td>
<td>Tax benefit</td>
</tr>
<tr>
<td>$CB(e, \theta)$</td>
<td>Cost benefit from the sourcing decision</td>
</tr>
</tbody>
</table>
C.2. Summary of parameter restrictions

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

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

Cost and exchange rate parameters: $c_\ell < \bar{\theta} < c\bar{\rho} < \bar{\theta}$ and $\ell < 1 < \bar{\ell}$.

C.3. Proofs of Lemmas and Propositions

Proof of Proposition 4.3.1. In this Proposition, we derive the optimal transfer pricing and sourcing strategy for the centralized supply chain that has no flexibility option (Model C). In Model C, HQ selects the transfer price after realizations of uncertainty and selects the sourcing strategy before observing realizations of the outsourcing cost and the exchange rate. Solving the model backwards, we first find $T^C$ which maximizes $\Pi_F^{C}(\theta, e, 0) = pt - ct + (\tau - t)T$ and then choose the best sourcing option by comparing equations C.1 and C.2:

$$\mathbb{E}_{e,\theta}[\Pi_F^{C}(\theta, e, 0)] = pt - \mu_\theta t$$  \hspace{1cm} (C.1)

with

$$\mathbb{E}_{e,\theta}[\Pi_F^{C}(\theta, e, 0)] = pt - ct + (\tau - t)T^C$$  \hspace{1cm} (C.2)

Since $\tau > t$, $\Pi_F^{C}(\theta, e, 0)$ increases in $T$; hence, $T$ is set at its legal upper bound: $T^C = \alpha p$.

Based on the comparison of C.1 and C.2, the HQ chooses offshoring when $(\tau - t)\alpha_p < ct - \mu_\theta t$.  \Box

Proof of Lemma 4.3.1. In this Lemma, we derive the optimal re-allocation strategy of the HQ after realization of uncertainty. The HQ’s payoff after uncertainty realizations can be characterized as follows:

$$\Pi_O^{C}(\theta, e, x) = (p - \theta)t + \max_{\bar{c} \leq T \leq \alpha p} \ x[TB(T) - CB(e, \theta)]^+ - K(x)t$$  \hspace{1cm} (C.3)

$$\Pi_F^{C}(\theta, e, x) = \max_{\bar{c} \leq T \leq \alpha p} \ ((p - T)t + (T - ec)\tau + x[TB(T) - CB(e, \theta)]^- - K(x)t$$  \hspace{1cm} (C.4)
Combining the legal constraint \( T \geq c \bar{e} \) with our parameter restrictions \( c \epsilon < \bar{\theta} < c \epsilon < \bar{\theta} \) that ensure uncertainty in cost advantage, we derive the following properties of \( T \):

\[
T \geq c \bar{e} \\
T(\tau - t) \geq c \bar{e}(\tau - t) \\
T(\tau - t) \geq c \bar{e} \tau - c \bar{e} t \\
T(\tau - t) \geq c \bar{e} \tau - c \theta t \\
T \geq \frac{c \bar{e} \tau - c \theta t}{(\tau - t)} > \frac{c \epsilon \tau - \theta t}{(\tau - t)} \quad (C.5)
\]

\[
T \geq \bar{\theta} \\
T(\tau - t) \geq \bar{\theta}(\tau - t) \\
T(\tau - t) \geq \bar{\theta} \tau - \bar{\theta} t \\
T(\tau - t) \geq c \bar{e} \tau - \bar{\theta} t \\
T \geq \frac{c \epsilon \tau - \bar{\theta} t}{(\tau - t)} \quad (C.6)
\]

From now on, we will refer to equations \([C.5] \) and \([C.6] \) as legal properties of transfer price.

According to the legal properties of \( T \), the outcome of the conditional functions \([TB(T) - CB(e, \theta)]^+ \) and \([TB(T) - CB(e, \theta)]^- \) is predetermined for the following pairs of observations: \((\bar{\theta}, \bar{e})\), \((\bar{\theta}, \bar{e})\), and \((\epsilon, \epsilon)\):

<table>
<thead>
<tr>
<th></th>
<th>([TB(T) - CB(e, \theta)]^+)</th>
<th>([TB(T) - CB(e, \theta)]^-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>((\bar{\theta}, \bar{e}))</td>
<td>(TB(T) - CB(\bar{e}, \bar{\theta}))</td>
<td>0</td>
</tr>
<tr>
<td>((\bar{\theta}, \bar{e}))</td>
<td>(TB(T) - CB(\bar{e}, \bar{\theta}))</td>
<td>0</td>
</tr>
<tr>
<td>((\epsilon, \epsilon))</td>
<td>(TB(T) - CB(\epsilon, \theta))</td>
<td>0</td>
</tr>
</tbody>
</table>

Hence, the HQ will change the sourcing decision according to the following scheme:
1. If the initial decision was to offshore, the HQ will re-allocate only if it observes \((\theta, \bar{e})\) and \(TB(T_{CF}) < CB(\bar{e}, \theta)\).

2. If the initial decision was to outsource, the HQ will re-allocate if
   - it observes \((\bar{\theta}, e), (\bar{\theta}, \bar{e})\), or \((\theta, \bar{e})\); or
   - it observes \((\theta, \bar{e})\) and \(TB(T_{CF}) \geq CB(\bar{e}, \theta)\).

**Proof of Proposition 4.3.2**

In this Proposition, we derive the optimal transfer pricing, sourcing, and flexibility strategy for the centralized supply chain that has a flexibility option (Model CF). In Model CF, the sequence of decisions is similar to Model C, but HQ also has a flexibility investment to make along with the sourcing decision and a re-allocation option to exercise after realizations of uncertainty.

First, we observe that \(\Pi^C_O(\theta, e, x)\) and \(\Pi^C_F(\theta, e, x)\) increase in \(T \forall e, \theta\). Hence, \(T_{CF} = \alpha p\).

Next, we use the result of Lemma 4.3.1 to write the expected HQ profit as following:

\[
E_{e, \theta}[\Pi^C_O(\theta, e, x)] = pt - K(x)t - \mu_g t + (1 - \gamma)x[TB(T) - CB(1, \bar{\theta})] + \gamma \phi x[TB(\alpha p) - CB(\bar{e}, \bar{\theta})] + \gamma (1 - \phi)x[TB(\alpha p) - CB(\bar{e}, \bar{\theta})] + (C.7)
\]

\[
E_{e, \theta}[\Pi^C_F(\theta, e, x)] = pt - K(x)t - ct + \alpha p(\tau - t) + \gamma (1 - \phi)x[TB(\alpha p) - CB(\bar{e}, \bar{\theta})] + (C.8)
\]

Next, to find the optimal \(x\) and sourcing strategy, we break the analysis into two cases:

<table>
<thead>
<tr>
<th>Case #</th>
<th>Conditions:</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>(CB(e, \theta) &lt; TB(\alpha p) \leq CB(\bar{e}, \bar{\theta}))</td>
</tr>
<tr>
<td>2</td>
<td>(TB(\alpha p) &gt; CB(\bar{e}, \bar{\theta}))</td>
</tr>
</tbody>
</table>

Now, we focus on each case individually.

1. Case 1. Expected profit of the HQ given the case condition and substituting the
C.3. Proofs of Lemmas and Propositions

convex flexibility cost function \( \frac{kx^2}{2} \) for \( K(x) \):

\[
E_{e, \theta}[\Pi^C_O(\theta, e, x)] = pt + \alpha px(\tau - t) - \frac{kx^2}{2} t - cx\tau - t(1 - x)\mu_\theta + x\gamma (ct - cr_\varepsilon - (1 - \phi) (\alpha p(\tau - t) + t\theta))
\]

\[
E_{e, \theta}[\Pi^C_F(\theta, e, x)] = pt + \alpha p(\tau - t) - \frac{kx^2}{2} t - cr - x\gamma (1 - \phi) (\alpha p(\tau - t) - cr_\varepsilon + t\theta)
\]

To find the optimal sourcing strategy, we subtract \( E_{e, \theta}[\Pi^C_F(\theta, e, x)] \) from \( E_{e, \theta}[\Pi^C_O(\theta, e, x)] \) and find that the HQ prefers outsourcing when \((T(t - \tau) + c(t - t\mu_\theta) < 0 \) and vice versa. This threshold is independent of \( x \), hence, we solve for \( x \) separately.

\[
\frac{\partial^2 E_{e, \theta}[\Pi^C_i(\theta, e, x)]}{\partial x^2} = -k < 0 \quad \forall \quad i \in \{O, F\}, \text{ therefore we use the first order conditions to find candidate solutions for optimal } x \text{ and compare it with the boundary conditions } (x \in \{0, 1\})
\]

\[
\frac{\partial E_{e, \theta}[\Pi^C_O(\theta, e, x)]}{\partial x} = \alpha p(\tau - t) - kxt - c\tau + t\mu_\theta + \gamma (ct - cr_\varepsilon - (1 - \phi) (\alpha p(\tau - t) + t\theta)) = 0
\]

\[
\frac{\partial E_{e, \theta}[\Pi^C_F(\theta, e, x)]}{\partial x} = -kxt - \gamma (1 - \phi) (\alpha p(\tau - t) - cr_\varepsilon + t\theta) = 0
\]

Both solutions are greater than zero, but can go above 1, hence, we write the Case 1 solution as following:

\[
x^{CF} = \begin{cases} \min(1, \frac{\alpha p(\tau - t)(1 - \gamma + \phi) - \gamma (1 - \gamma) t + t\mu_\theta - c\gamma r_\varepsilon - t\gamma (1 - \phi)\theta}{kt}) & \text{if } TB(\alpha p) < CB(1, \mu_\theta); \\ \min(1, \frac{\gamma (1 - \phi)(c\gamma r_\varepsilon - t\theta - \alpha p(\tau - t))}{kt}) & \text{if } TB(\alpha p) \geq CB(1, \mu_\theta); \end{cases}
\]

2. Case 2:

\[
E_{e, \theta}[\Pi^C_O(\theta, e, x)] = pt + \alpha px(\tau - t) - \frac{kx^2}{2} t - cx\tau - t(1 - x)\mu_\theta
\]

\[
E_{e, \theta}[\Pi^C_F(\theta, e, x)] = pt + \alpha p(\tau - t) - \frac{kx^2}{2} t - c\tau
\]

Case 2 condition \( TB(\alpha p) > CB(\tau, \theta) \) implies \( TB(\alpha p) > CB(1, \mu_\theta) \), therefore, HQ will always offshore. Hence, we only look at \( E_{e, \theta}[\Pi^C_F(\theta, e, x)] \) to find optimal \( x \): \( \frac{\partial E_{e, \theta}[\Pi^C_F(\theta, e, x)]}{\partial x} = -kxt < 0 \). Therefore, \( x^{CF} = 0 \).
Proof of Proposition 4.3.3. In this Proposition, we find properties of the optimal flexibility investment by looking at comparative statics of $x^{CF}$ with respect to the expected foreign cost $c$, outsourcing cost volatility $\sigma_\theta$, and exchange rate volatility $\sigma_e$ when $CB(e, \theta) < TB(\alpha_p) \leq CB(\bar{e}, \bar{\theta})$.

1. $TB(\alpha_p) \leq CB(1, \mu_\theta)$;

\[
\frac{dx^{CF}}{d\sigma_\theta} = \frac{\sqrt{1-\gamma} \gamma (1 - \phi)}{k} > 0 \\
\frac{dx^{CF}}{d\sigma_e} = \frac{c \gamma \tau \sqrt{1-\phi}}{kt} > 0 \\
\frac{dx^{CF}}{dc} = \frac{-(1 - \gamma) \tau - \gamma \phi (1 - \sqrt{1-\phi} \sigma_e)}{kt} < 0
\]

2. $TB(\alpha_p) \geq CB(1, \mu_\theta)$;

\[
\frac{dx^{CF}}{d\sigma_\theta} = \frac{\sqrt{1-\gamma} \gamma (1 - \phi)}{k} > 0 \\
\frac{dx^{CF}}{d\sigma_e} = \frac{c \gamma \tau (1 - \phi) \sqrt{\phi}}{kt} > 0 \\
\frac{dx^{CF}}{dc} = \frac{\gamma \tau (1 - \phi) \left( 1 + \sqrt{\frac{\phi}{1-\phi} \sigma_e} \right)}{kt} > 0
\]

Proof of Proposition 4.4.1. In this Proposition, we derive the optimal transfer pricing and sourcing strategy for the decentralized supply chain that has no flexibility option. When $x = 0$, $T_O$ does not exist, local manager’s payoff is independent of $e$ and reduces to $(p - T_F)t$ in the offshoring case and $(p - \theta)t$ in the outsourcing case. Hence, the local manager chooses to offshore when $T_F \leq \theta$ and vice versa. To break ties, we assume that when payoffs from two sourcing options are equal, the local manager will choose to offshore.

As described in Section 4.4, the HQ sets its contract terms with the local manager by optimizing over the transfer price and choosing the best of the following strategies:
C.3. Proofs of Lemmas and Propositions

Since $\underline{\theta} < \bar{\theta}$, strategy 2 is not feasible, and since $T_F \geq \bar{c} \geq \underline{\theta}$, Strategy 3 is not feasible. Next, we find the optimal $T_F$ in Strategies 1 and 4 and compare the resulting solutions to choose the best Strategy.

Strategy 1. Provide incentives so that the manager that observes $\bar{\theta}$ - offshores, and $\underline{\theta}$ - outsources:

$$\max_{\bar{c} \leq T_F \leq \alpha p} pt + T_F(1 - \gamma)(\tau - t) - c (1 - \gamma)\tau - t\gamma\underline{\theta}$$

subject to $c\bar{c} \leq T_F \leq \bar{\theta}$

The objective function increases in $T_F$ and since $\bar{\theta} \leq \alpha p$, $T_F^e = \bar{\theta}$.

Strategy 4. Provide incentives so that the manager always outsources:

$$\max_{\bar{c} \leq T_F \leq \alpha p} pt - \mu \underline{\theta}t$$

subject to $T_F > \underline{\theta}$

Any $T_F$ in the interval $(\bar{\theta}, \alpha p]$ satisfies the constraints.

Hence, there are two candidate solutions:

Strategy 1, that provides HQ with $pt + \bar{\theta}(1 - \gamma)(\tau - t) - c (1 - \gamma)\tau - t\gamma\bar{\theta} = pt - \mu \underline{\theta}t + (1 - \gamma)\tau(\bar{\theta} - c)$

and Strategy 4, which provides $pt - \mu \underline{\theta}t$ in profit. It is easy to see that with our parameter restrictions: $\bar{\theta} > \bar{c}$, hence Strategy 1 is always better than Strategy 4. Hence, the optimal HQ strategy is to set $T_F^e = \bar{\theta}$ that will make LM offshore if he observes $\bar{\theta}$ and
outsource if he observes $\theta$. □

**Proof of Proposition 4.4.2.** In this Proposition, we find threshold on the marginal cost of flexibility $k$, above which it is optimal for the HQ to choose Strategy 1, and derive the optimal transfer pricing and flexibility strategy for the decentralized supply chain that has a flexibility option. We perform the proof in 4 steps. First, we break the problem into 4 cases that determine the outcome of the conditional function $\Delta(T_O, T_F, x, \theta)$. Second, we find the optimal solution to Case 1a. Third, we find the optimal solution to Case 2b. And fourth, we show that the solution to Case 2b is always better for the HQ than the solution to Cases 1a, 1b, and 2b.

As introduced in section 4.4, the HQ’s problem is:

$$\max_{T_O, T_F, x \in [0,1], i \in \{1,2,3,4\}} \hat{\Pi}^F_i(T_O, T_F, x)$$

$$\text{s.t. } IC_i(x) \text{ and } IC_i(x)$$

$$c \leq T_O, T_F \leq \alpha p$$

where constraints depend on Strategy $i$ as follows:

<table>
<thead>
<tr>
<th>Strategy #</th>
<th>$\theta$</th>
<th>$\hat{\theta}$</th>
<th>$IC_i(x)$</th>
<th>$TC_i(x)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>offshore</td>
<td>outsource</td>
<td>$\Delta(T_O, T_F, x, \theta) &lt; 0$</td>
<td>$\Delta(T_O, T_F, x, \theta) \geq 0$</td>
</tr>
<tr>
<td>2</td>
<td>outsource</td>
<td>offshore</td>
<td>$\Delta(T_O, T_F, x, \theta) \geq 0$</td>
<td>$\Delta(T_O, T_F, x, \theta) &lt; 0$</td>
</tr>
<tr>
<td>3</td>
<td>offshore</td>
<td>offshore</td>
<td>$\Delta(T_O, T_F, x, \theta) &lt; 0$</td>
<td>$\Delta(T_O, T_F, x, \theta) &lt; 0$</td>
</tr>
<tr>
<td>4</td>
<td>outsource</td>
<td>outsource</td>
<td>$\Delta(T_O, T_F, x, \theta) \geq 0$</td>
<td>$\Delta(T_O, T_F, x, \theta) \geq 0$</td>
</tr>
</tbody>
</table>

1. Break the problem into 4 cases that determine the outcome of the $\Delta(T_O, T_F, x, \theta)$ function. As introduced in section 4.4, $\Delta(T_O, T_F, x, \theta) = \frac{1}{t}E_e[\pi_O(T_O, \theta, e, x) - \pi_F(T_F, \theta, e, x)]$.

Recall from Section 4.4 that:

$$\pi_O(T_O, \theta, e, x) = pt - \theta t + x(\theta - T_O)1_{\{T_O(\tau-t)>(c\epsilon-\theta t)\}}$$

$$\pi_F(T_F, \theta, e, x) = pt - T_F t + x(T_F - \theta)1_{\{T_F(\tau-t)<(c\epsilon-\theta t)\}}$$

$\Delta(T_O, T_F, x, \theta) = T_F - \theta + xE_e[(\theta - T_O)1_{\{T_O(\tau-t)>(c\epsilon-\theta t)\}} - (T_F - \theta)1_{\{T_F(\tau-t)<(c\epsilon-\theta t)\}}]$. 


Given the property $T_F > \frac{c \tau - \bar{m}}{\tau - t}$ derived above (refer to the proof of Lemma 4.3.1),
we can simplify $\Delta(T_O, T_F, x, \theta)$ as:

$$\Delta(T_O, T_F, x, \theta) = T_F - \bar{\theta} + x E_e[(\theta - T_O) 1_{\{T_O(\tau-t)>(c \tau - \bar{m})\}}]$$
and:

$$\Delta(T_O, T_F, x, \theta) = T_F - \bar{\theta} + x (\bar{\theta} - T_O) = T_F - T_O x - (1 - x) \bar{\theta}.$$ 

Since $\Delta(T_O, T_F, x, \theta)$ includes two conditional functions, we break the further analysis
into 4 cases that determine the outcome of the conditions as summarized in Table ??:

Notice that when $\alpha p < c \bar{\tau} - \theta t$, only Case 1a is feasible; and when $\alpha p \geq c \bar{\tau} - \theta t$, all
4 cases are feasible. We first solve Cases 1a and 2b and then argue about how Cases
1b and 2a are dominated by Case 2b.

2. Analyze Case 1a.

We analyze the problem in Case 1a in the following steps. First, we write down the IC
constraints (inequalities 4.9 in Section 4.4) for this Case and find an upper bound on
$x (\hat{x})$ that makes Strategies 2 and 3 infeasible. Second, we find optimal transfer prices
for Strategies 1 and 4 as a function of $x$. Third, we show that Strategy 1 outperforms
Strategy 4 for all $x$. Fourth, we plug $T_O^*(x)$ and $T_F^*(x)$ into the objective function
(equation 4.8 in Section 4.4) and solve for the optimal $x$. And finally, we use the
solution for $x$ to convert $\hat{x}$ into a threshold on the marginal cost of flexibility $k$.

In this case, $\Delta(T_O, T_F, x, \theta) = T_F - \bar{\theta} + x \phi (\theta - T_O) - x (1 - \phi) (T_F - \theta)$ and $\Delta(T_O, T_F, x, \theta) = T_F - T_O x - (1 - x) \bar{\theta}$. Consider different incentive strategies and corresponding IC con-
straints:

Legal bounds: $\bar{\tau} c \leq T_i \leq \alpha p \forall i \in \{O, F\}$.

When $\frac{\theta (1 - x) + x \phi \alpha p}{1 - x + x \phi} < \bar{\tau} c$, there is no transfer price within legal limits ($\bar{\tau} c \leq T_i \leq \alpha p$)
that would make Strategies 2 or 3 feasible. We express this bound as a threshold on
$x$: $\hat{x} = \frac{\tau - \theta}{c (1 - \phi) \bar{e} + \phi \alpha p - \theta} \geq 0.$
The HQ’s optimization problem assuming Strategy 1 is:

\[
\hat{\Pi}_{DF}^1(T_O, T_F, x) = \max_{T_F, T_O, x} pt + (1 - \gamma) (T_F (\tau - t) - cr) + \gamma (T_O x (\tau - t) - cxr) - t (1 - x) \theta \\
\frac{\theta (1 - x) + x \phi T_O}{1 - x + x \phi} \leq T_F \leq T_O x + (1 - x) \bar{\theta} \\
\bar{c} \leq T_i \leq \alpha p \forall i \in \{O, F\}
\]

The profit increases in both \(T_F\) and \(T_O\). The solution is then \(T_O^*(x) = \alpha p\) and \(T_F^*(x) = \alpha px + (1 - x) \bar{\theta}\).

The HQ’s optimization problem assuming Strategy 4 is:

\[
\hat{\Pi}_{DF}^4(T_O, T_F, x) = \max_{T_F, T_O, x} pt - \mu t + (1 - \gamma + \gamma \phi) x T_O (\tau - t) - (1 - \gamma) x (c r - \bar{\theta} t) - \gamma \phi x (c r - \bar{\theta} t) \\
\max(T_O x + (1 - x) \bar{\theta}, \frac{\theta (1 - x) + x \phi T_O}{1 - x + x \phi}) \leq T_F \\
\bar{c} \leq T_i \leq \alpha p \forall i \in \{O, F\}
\]

Since \(T_O\) has an upper bound \(T_O \leq \alpha p\), \(\hat{\Pi}_{DF}^4(T_O, T_F, x) \leq \hat{\Pi}_{DF}^4(\alpha p, T_F, x)\).

\[
\hat{\Pi}_{DF}^1(T_O^*(x), T_F^*(x), x) - \hat{\Pi}_{DF}^4(\alpha p, T_F, x) = (1 - x)(1 - \gamma) (\bar{\theta} - c) > 0
\]

Therefore, Strategy 1 always dominates Strategy 4 for all \(x \leq \hat{x}\) and the optimal contract is \(T_O^*(x) = \alpha p\) and \(T_F^*(x) = \alpha px + (1 - x) \bar{\theta}\).

Now, we find \(x\) by solving the FOC: \(\frac{d\hat{\Pi}_{DF}^1(T_O(x), T_F(x), x)}{dx} = 0\) \(\frac{d^2\hat{\Pi}_{DF}^1(T_O(x), T_F(x), x)}{dx^2} = -kt < 0\).

\[
x_{DF}^* = \frac{\alpha \tau (1 + \gamma (-1 + \phi)) - (1 - \gamma) (\tau - t) \bar{\theta} - c \gamma r \phi + t \gamma \phi \theta}{kt}
\]

This solution will be optimal when \(x_{DF}^* < \hat{x}\), which is equivalent to the following
threshold on $k$:

$$
\hat{k}_1 = \frac{(p\alpha + c(1 - \phi)(1 + \gamma(-1 + \phi)) + (1 - \gamma)(t - \tau)\bar{\theta} - c\gamma \tau \phi \bar{e} + t\gamma \phi \bar{\theta})}{t(\bar{c} - \bar{\theta})}
$$

When $\alpha p < \frac{c\tau - \theta}{t - \tau}$, Case 1a is the only feasible case. Hence, the solution to this case is the optimal solution for all $\alpha p$ satisfying this restriction.

3. **Analyze Case 2b.** Analogously to Case 1a, we analyze the problem in Case 2b in the following steps. First, we write down the IC constraints for this Case and find an upper bound on $x$ ($\hat{x}$) that makes Strategy 3 infeasible (it is easy to see that Strategy 2 is never feasible in this case). Second, we find optimal transfer prices for Strategies 1 and 4 as a function of $x$. Third, we show that Strategy 1 dominates Strategy 4 for all $x$. Fourth, we plug $T_O(x)$ and $T_F(x)$ into the objective function and solve for the optimal $x$. And finally, we use the solution for $x$ to convert $\hat{x}$ into a threshold on the marginal cost of flexibility $k$.

**Case 2b condition:** $\alpha p > \frac{c\tau - \theta}{t - \tau}$. In this case, $\Delta(T_O, T_F, x, \bar{\theta}) = T_F - \bar{\theta}(1 - x) - xT_O$ and $\Delta(T_O, T_F, x, \bar{\theta}) = T_F - T_O x - (1 - x)\bar{\theta}$. Consider different incentive strategies and corresponding IC constraints:

<table>
<thead>
<tr>
<th>Strategy #</th>
<th>$\Delta(T_O, T_F, x, \bar{\theta})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\bar{\theta}(1 - x) + xT_O \leq T_F \leq T_O x + (1 - x)\bar{\theta}$</td>
</tr>
<tr>
<td>2</td>
<td>$T_O x + (1 - x)\bar{\theta} \leq T_F \leq \bar{\theta}(1 - x) + xT_O$</td>
</tr>
<tr>
<td>3</td>
<td>$T_F \leq \bar{\theta}(1 - x) + xT_O$</td>
</tr>
<tr>
<td>4</td>
<td>$T_O x + (1 - x)\bar{\theta} \leq T_F$</td>
</tr>
</tbody>
</table>

Legal bounds: $\bar{c}c \leq T_i \leq \alpha p \quad \forall i \in \{O, F\}$.

Strategy 2 is never feasible because $\bar{\theta} > \bar{\theta}$.

Strategy 3 is infeasible when $\bar{\theta}(1 - x) + x\alpha p < \bar{c}c$ or expressed as a threshold on $x$,
when  \( x \leq \frac{\bar{c} - \theta}{\alpha p - \theta} > 0 \).

The HQ’s optimization problem assuming Strategy 1 is:

\[
\hat{\Pi}_1^{DF}(T_O, T_F, x) = \max_{T_F, T_O, x} pt + (1 - \gamma) (T_F(\tau - t) - ct) + \gamma(-\theta t + x(T_O(\tau - t) - ct + t\theta)) \\
\theta(1 - x) + xT_O \leq T_F \leq T_Ox + (1 - x)\bar{\theta} \\
\bar{c} \leq T_i \leq \alpha p \ \forall i \in \{O, F\}
\]

The profit increases in both  \( T_F \) and  \( T_O \). The solution is then  \( T_O^*(x) = \alpha p \) and  \( T_F^*(x) = \alpha px + (1 - x)\bar{\theta} \).

The HQ’s optimization problem assuming Strategy 4 is:

\[
\hat{\Pi}_4^{DF}(T_O, T_F, x) = \max_{T_F, T_O, x} pt - \mu \theta t + x(T_O(\tau - t) - ct + \mu \theta t) \\
T_Ox + (1 - x)\bar{\theta} \leq T_F \\
\bar{c} \leq T_i \leq \alpha p \ \forall i \in \{O, F\}
\]

To compare strategies 1 and 4, we look at the difference between the optimized profit for Strategy 1 and the largest value of profit for Strategy 4:

\[
\hat{\Pi}_1^{DF}(T_O^*(x), T_F^*(x), x) - \hat{\Pi}_4(\alpha p, T_F, x) = (1 - \gamma)\tau (\bar{\theta} - c) > 0
\]

Therefore, Strategy 1 always dominates Strategy 4 for all  \( x \leq \hat{x} \) and the optimal contract is  \( T_O^* = \alpha p \) and  \( T_F^* = \alpha px + (1 - x)\bar{\theta} \).

Now, we find  \( x \) by solving the FOC:  \( \frac{d\hat{\Pi}_1^{DF}(T_O^*(x), T_F^*(x), x)}{dx} = 0 \)  \( \left( \frac{d^2\hat{\Pi}_1^{DF}(T_O^*(x), T_F^*(x), x)}{dx^2} = -kt < 0 \right) \).

\[
x^{DF} = \frac{(\tau - t)(p\alpha - \mu \theta) + \gamma \tau (\bar{\theta} - c)}{kt}
\]
Show that $x^{DF} > 0$: $p\alpha(\tau - t) - (1 - \gamma)(\tau - t)t - c\gamma\tau + t\gamma\theta > p\alpha(\tau - t) - (1 - \gamma)(\tau - t)p\alpha - c\gamma\tau + t\gamma\theta = p\alpha(\tau - t)\gamma - c\gamma\tau + t\gamma\theta > 0$.

This solution will be optimal when $x^{DF} < \hat{x}$, which is equivalent to the following threshold on $k$:

$$
\hat{k}_2 = \frac{(p\alpha - \theta)(pt\alpha - pao\tau + c\gamma\tau + (1 - \gamma)(t - \tau)t - t\gamma\theta)}{t(c\gamma - \theta)}
$$

4. Show that Case 2b dominates all other cases. When $\alpha p > \frac{c\gamma - \theta t}{\tau - t}$, all cases are feasible; next, we show that the profit obtained using the solution to Case 2b dominates Cases 1a, 1b, and 2a. We report the comparison for Strategy 1, similar arguments are used to compare all other strategies. Notice that the IC constraint for Strategy 1 provides the same upper bound on $T_F$ in all cases. Below, we compare the objective functions for all cases in Strategy 1:

<table>
<thead>
<tr>
<th>Case</th>
<th>$\hat{\Pi}(T_O, T_F, x)_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>$pt + (1 - \gamma)(T_F(\tau - t) - c\tau) - \gamma\theta t + \gamma x\phi T_O(\tau - t) + \gamma(-cxt\phi e + t\tau\theta)$</td>
</tr>
<tr>
<td>1b</td>
<td>$pt + (1 - \gamma)(T_F(\tau - t) - c\tau) - \gamma\theta t + \gamma x\phi T_O(\tau - t) + \gamma(-c\gamma + \theta t)$</td>
</tr>
<tr>
<td>2a</td>
<td>$pt + (1 - \gamma)(T_F(\tau - t) - c\tau) - \gamma\theta t + \gamma xT_O(\tau - t) + \gamma(-c\tau + t\theta) - \gamma x\phi(T_F(\tau - t) - c\tau) - x(1 - \gamma)\phi T_O$</td>
</tr>
<tr>
<td>2b</td>
<td>$pt + (1 - \gamma)(T_F(\tau - t) - c\tau) - \gamma\theta t + \gamma xT_O(\tau - t) + \gamma(-c\tau + t\theta)$</td>
</tr>
</tbody>
</table>

Clearly, the objective function in Case 2b gives the highest value for the expected HQ profit $\forall x$ and for the identical values for $T_O$ and $T_F$. Since Cases 1a, 1b, and 2a have additional upper bounds on $T_O$ and/or $T_F$, Case 2b also has the largest values for $T_O$ and $T_F$. Hence, Case 2b dominates other cases. \(\square\)

**Proof of Proposition 4.4.3.** In this Proposition, we find properties of the optimal flexibility investment by looking at comparative statics on $x^{DF}$ with respect to the foreign
C.3. Proofs of Lemmas and Propositions

Cost $c$, outsourcing cost volatility $\sigma_\theta$, and $\sigma_e$ when $CB(\epsilon, \theta) < TB(\alpha p) \leq CB(\bar{\epsilon}, \bar{\theta})$. For clarity of exposition, denote $\sqrt{\frac{1-\gamma}{\tau}}$ with $A$.

1. $\alpha p \geq \frac{c \tau - \theta t}{\tau - t}$:

$$\frac{dx^{DF}}{d\sigma_\theta} = -A t \gamma - \frac{(1-\gamma)(\tau-t)}{A} \frac{k t}{A} < 0$$

$$\frac{dx^{DF}}{d\sigma_e} = 0$$

$$\frac{dx^{DF}}{dc} = -\frac{\gamma \tau}{k t} < 0$$

2. $\alpha p < \frac{c \tau - \theta t}{\tau - t}$:

$$\frac{dx^{DF}}{d\sigma_\theta} = -\frac{(1-\gamma)(\tau-t)}{A} + At \gamma \phi \frac{k t}{A} < 0$$

$$\frac{dx^{DF}}{d\sigma_e} = c \gamma \tau \sqrt{\frac{1-\phi}{\phi}} \frac{\phi}{k t} > 0$$

$$\frac{dx^{DF}}{dc} = -\frac{\gamma \tau \phi \left(1 - \frac{1-\phi}{\phi} \sigma_e\right)}{k t} < 0 \quad \Box$$
Bibliography


