IMPACT OF TARIFF REGULATIONS ON GLOBAL SOURCING STRATEGIES

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Impact of Tariff Regulations on Global Sourcing Strategies

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CERTIFICATE OF ORIGINALITY

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Abstract

The past decades have witnessed significant shifts in the global trade landscape, with evolving tariff regulations reshaping the structure of global supply chains. In particular, growing concerns over carbon emissions have led to the implementation or proposal of regulatory frameworks such as the European Union's Carbon Border Adjustment Mechanism (CBAM) and the United States' Clean Competition Act (CCA). These initiatives aim to mitigate carbon leakage and encourage greener production practices. Meanwhile, different types of trade contracts specified by International Commercial Terms (Incoterms), such as EXW (Ex Works), DAP (Delivered at Place), and DDP (Delivered Duty Paid), play a crucial role in determining the responsibility allocation for tariffs and freight charges between buyers and suppliers, thereby influencing firms' global sourcing strategies. In this thesis, we investigate how different carbon border tax regulations and trade contracts impact global procurement decisions.

In the first topic, we consider the challenge faced by policymakers and global supply chains arising from disparate carbon pricing standards across countries. Specifically, many countries, such as China, Canada, and the European Union, have adopted carbon pricing measures to encourage high-carbon companies to reduce carbon emissions. However, the disparity in carbon pricing standards across countries has led to the frequently observed issue of "carbon leakage," whereby emissions are transferred from regions with high carbon prices to those with lower or no carbon pricing. To address this issue, there are two proposed carbon border tax regulations: (1) CBAM, introduced by the European Union, which imposes carbon tariffs on imported goods equal to the difference in carbon prices between the two countries; and (2) CCA, proposed by the United States Senate, which imposes a carbon tax

on imported products with emission intensity exceeding a pre-specified benchmark. Motivated by the intrinsic difference between these two regulations, we examine the impact of such carbon border tax regulations on the buyer's sourcing strategies and the suppliers' carbon emissions. We find that CCA is more effective than CBAM in encouraging the buyer to source from the domestic supplier, generating more domestic employment opportunities. We also show that when the domestic supplier's production cost is low, CCA generates a win-win situation (i.e., higher expected profit and higher social welfare) as compared to CBAM. By contrast, when the domestic supplier's production cost is moderate and its investment cost coefficient is high, both the government and the buyer are indifferent between CBAM and CCA. Furthermore, CCA always performs better than CBAM in incentivizing emission abatement investment, but this may result in higher total carbon emissions.

In the second topic, we investigate a decentralized global supply chain composed of a domestic buyer, two types of overseas suppliers, and a logistics service provider (LSP). One supplier offers high reliability but faces a substantial tariff, as is typical for suppliers located outside free trade areas. The other supplier is less reliable but enjoys a lower tariff rate, for instance, one based within a free trade area. Based on who shall bear the freight charge and import tariff, the buyer and the supplier can undertake one of the following three trade contracts specified by Incoterms: EXW, DAP, or DDP. Interestingly, we find that as the tariff rate increases, the buyer becomes more willing to assume responsibility for both freight and tariff costs, which contradicts common intuition. Moreover, across all three trade contracts, a higher supplier unreliability weakens the competition between suppliers. By contrast, a higher tariff rate can intensify supplier competition, particularly under DAP. Our findings suggest that both buyers and reliable suppliers outside free trade areas could tailor-make their trade contract decisions based on the prevailing tariff environment to safeguard profitability, while unreliable suppliers within free trade areas need to take into account both reliability and cost to stay competitive. Furthermore, our results highlight the role of tariff adjustments as an effective short-term mechanism to maintain sourcing within free trade areas.

Publications Arising from the Thesis

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Chapter 1

Introduction

Amid rising geopolitical tensions, escalating trade disputes, and a push for economic resilience, the global trade landscape is undergoing rapid transformation. Tariff policies, in particular, have become a key lever through which governments influence supply chain configurations and global sourcing strategies. Policies such as the European Union's Carbon Border Adjustment Mechanism (CBAM) and the proposed U.S. Clean Competition Act (CCA) exemplify efforts by policymakers to mitigate carbon leakage, ensure fair competition for domestic industries, and promote low-carbon manufacturing across borders. At the same time, free trade agreements (FTAs) and tariff barriers play a crucial role in shaping global procurement decisions. In practice, the allocation of tariff and freight responsibilities between buyers and suppliers is governed by trade contracts specified by International Commercial Terms (Incoterms). Among these, EXW (Ex Works), DAP (Delivered at Place), and DDP (Delivered Duty Paid) are particularly influential in shaping firms' sourcing strategies and logistics coordination. However, there is little research investigating how these regulatory mechanisms and trade contracts influence firms' sourcing strategies and the resulting supply chain performance.

In Chapter 2, we study the impact of carbon border tax regulations on global sourcing and carbon emissions. We note that in recent years, countries such as China, Canada, and members of the European Union have implemented carbon pricing measures to curb emissions. However, the inconsistency in carbon pricing standards across regions has led to carbon leakage, where companies shift emissionsintensive activities to countries with lower or no carbon prices. To address this issue, two carbon border tax mechanisms have been proposed: (1) CBAM, introduced by the European Union, which levies carbon tariffs on imports to reflect the gap in carbon pricing; and (2) CCA, proposed in the United States Senate, which imposes a tax on imports that exceed a benchmark level of emission intensity. We examine the fundamental differences between these two approaches and analyze their impact on buyers' sourcing strategies and suppliers' carbon emissions. We investigate two research questions: (1) How do different carbon border tax policies influence supply chain decisions and environmental outcomes? (2) Which carbon border tax regulation (CBAM or CCA) is more effective in reducing total emissions and improving social welfare? We can derive the following main insights. Compared to CBAM, CCA is more effective in encouraging buyers to source from domestic suppliers, thereby supporting domestic job creation and enhancing economic outcomes. Furthermore, CCA can generate a win-win outcome—enhancing both buyer profits and social welfare—particularly when domestic production costs are low. However, when production costs are moderate and investment costs are high, the choice between CCA and CBAM has little impact on outcomes, as adjustments in carbon pricing offset the effects of regulation. Additionally, while CCA consistently encourages more investment in emission abatement than CBAM, it does not always lead to lower total emissions, as these depend on both technological improvements and shifts in market demand. These results highlight the importance of aligning regulatory design with supplier cost structures to optimize both economic and environmental outcomes.

In Chapter 3, we consider a diversified sourcing setting where a buyer sources from two potential suppliers, one more reliable and another tariff-exempt, through a logistic service provider (LSP). We consider three trade contracts specified by Incoterms: (1) EXW, in which the buyer bears both the tariff and freight charge, (2) DAP, in which the buyer bears the tariff while the supplier bears the freight charge, and (3) DDP, in which the supplier bears both the tariff and freight charge. We aim to investigate how these trade contracts specified by Incoterms affect supply chain performance, how supply chain parties' preferences vary under different conditions, and how tariff rates, disruption risks, and LSP market competition influence global sourcing strategies. We obtain two key insights. First, one may intuit that a firm is less willing to undertake the tariff when its rate becomes higher. Interestingly, our result shows that a buyer might benefit from bearing both tariffs and freight charges when the tariff rate is high. Second, the tariff rate and disruption risk have distinct effects on supply chain profits. Specifically, under EXW, as the tariff rate increases, the profit of the reliable supplier outside free trade areas decreases, while the profits of other supply chain parties remain unchanged. By contrast, under DAP and DDP, a higher tariff rate reduces profits for the reliable supplier outside free trade areas and the LSP, but benefits the unreliable supplier within free trade areas. Notably, the buyer's profit exhibits a unimodal relationship with respect to the tariff rate, peaking at an intermediate level. A higher disruption risk, on the other hand, lowers the profits of both the buyer and the LSP, but can favor the unreliable supplier within free trade areas due to weakened competition. Building on these findings, we suggest that both buyers and reliable suppliers outside free trade areas may adapt their trade contract choices in response to current tariff conditions to safeguard their profits. Additionally, our analysis highlights the importance of tariff adjustments as an effective short-term tool for maintaining sourcing activities within free trade areas.

Chapter 2

Impact of Carbon Border Tax Regulations on Global Sourcing and Carbon Emission

2.1 Introduction

Rising greenhouse gas (GHG) emissions have significantly accelerated the pace of climate change, leading to a range of adverse consequences. These include increasing global average temperatures, more frequent and severe extreme weather events such as hurricanes, droughts, and floods, as well as widespread environmental degradation affecting ecosystems and biodiversity. Despite growing awareness of these risks, global carbon dioxide (CO_2) emissions have continued to rise at a concerning rate. According to the International Energy Agency, CO_2 emissions increased by 1.5% from 2021 to 2022, underscoring the persistent challenge of curbing emissions in the face of economic and population growth (IEA 2022). In light of these trends, it is more important than ever to implement effective strategies and policies aimed at reducing GHG emissions. International initiatives such as the Paris Agreement and the United Nations Climate Action framework exemplify the global commitment to addressing climate change and highlight the urgent need for coordinated action across nations.

An increasing number of countries, including China, Canada, and most European nations, are now adopting carbon pricing measures (New York Times 2019). Carbon pricing requires carbon-emitting companies to bear the costs associated with GHG emissions, thereby incentivizing them to invest in renewable energy, new technologies, and the development of low-carbon products. However, carbon pricing inevitably increases procurement costs when a company sources from carbon-intensive suppliers, encouraging them to shift production to countries with lower carbon prices or no carbon pricing schemes. Countries such as India and Russia have not yet introduced carbon pricing (Carbon Credit 2024). Although China has established a carbon emissions trading market, the carbon price is expected to be only €25 per metric ton by 2030 (Clearblue Market 2025), much lower than the €150 per metric ton in the EU emissions trading system (ETS) during the same period (BloombergNEF 2025). Differences in carbon pricing may cause a notable "carbon leakage" problem, where emissions decline in countries with strict carbon pricing but rise in those with little or no pricing, resulting in no overall decrease in global emissions.

To tackle the issue of carbon leakage, the European Parliament and the Council of the European Union have recently formalized an agreement on the implementation of the Carbon Border Adjustment Mechanism (CBAM). Effective from October 2023, CBAM requires importers to pay a carbon tariff equivalent to the carbon price established by the EU ETS on imported goods such as aluminum, fertilizer, and steel products (European Commission 2023). Importers are allowed to offset the carbon price previously paid in the country of origin. Essentially, CBAM imposes taxes on products imported from countries with lower carbon prices than the EU ETS, charging carbon taxes based on the price difference, regardless of the product's carbon emissions. Meanwhile, the U.S. Senate introduced the Clean Competition Act (CCA), a carbon border tax regulation that has passed its second reading in 2023, with the third reading scheduled for September 2024 (Congress.Gov 2024). The CCA will impose a carbon tax on imported products with emission intensities that exceed a pre-specified benchmark. Under this regulation, importers pay carbon taxes only on the portion of carbon emissions that exceed the benchmark.

In summary, CBAM focuses on the carbon price disparity between EU products and imports, while the CCA focuses on the emissions of imported products. Although both CBAM and CCA aim to reduce carbon emissions by encouraging buyers to source from suppliers with lower emissions, their effectiveness remains unclear. Additionally, due to their inherently different focuses, comparing their relative effectiveness is of interest. These observations motivate us to conduct a thorough analysis to gain a deeper understanding regarding the impact of these regulations, particularly on buyers' sourcing strategies, suppliers' carbon emission reductions, and overall supply chain performance. Specifically, we intend to investigate the following research questions that have not yet been adequately explored in the literature: What are the equilibrium wholesale price, suppliers' carbon emission intensity, and carbon price under each regulation? How do buyers' sourcing strategies differ under CBAM and CCA? Which carbon border tax regulation (CBAM or CCA) is more effective in reducing total emissions and improving social welfare?

To address these questions, we develop a parsimonious game-theoretic model of a supply chain in which a buyer, located in a country with carbon regulations, faces two sourcing options: purchasing products from a domestic supplier subject to these regulations, or sourcing from a foreign supplier based in a country without such regulatory constraints. Both suppliers invest in new technologies to reduce carbon emissions. We examine the aforementioned two carbon border tax regulations: (1) CBAM requires the buyer to pay a carbon tax on imported products, which is calculated based on the carbon price difference between the importer's country and the foreign production country; and (2) CCA requires the buyer to pay a carbon tax on imported products for the carbon emissions that are produced beyond a baseline level for that product. For each regulation, we analytically derive the equilibrium outcomes, including the equilibrium carbon price, carbon emission intensity, wholesale price, retail price, and the buyer's optimal sourcing strategy. We also investigate how variations in the buyer's purchasing costs influence its equilibrium sourcing decisions. Furthermore, by comparing the profits of supply chain participants, the total emissions generated, consumer surplus, and overall social welfare under both CBAM and CCA regulations, we assess the preferences of supply chain parties for each regulatory approach. This allows us to determine which regulation is more effective in incentivizing suppliers to adopt carbon reduction measures and in enhancing social welfare. Below, we highlight our main findings.

First, CCA is more effective than CBAM in encouraging the buyer to source from the domestic supplier, thereby supporting the creation of more domestic jobs. This advantage stems from the implementation of a specified emissions baseline under CCA, which provides targeted incentives for domestic suppliers—particularly those with lower production costs and more favorable investment coefficients—to invest in emission abatement technologies. As these suppliers increase their investments in reducing emissions, they are able to lower their wholesale prices, making their products more attractive to the buyer. This dynamic not only stimulates greater consumer demand but also enhances the profitability of the buyer, creating a positive feedback loop that benefits the domestic economy.

Second, CCA has the potential to create a win-win outcome—yielding both higher expected profits for the buyer and greater social welfare—compared to CBAM, particularly when the domestic supplier's production costs are low. This finding suggests that, although CCA is still under consideration as a policy proposal, it may offer significant strategic advantages over CBAM in certain contexts. Interestingly, our analysis also reveals that when the domestic supplier's production costs are moderate and its investment cost coefficient is high, both the government and the buyer are largely indifferent between CBAM and CCA. In this scenario, the introduction of a specified emission baseline under CCA does not materially impact either party, as endogenous adjustments in the carbon price effectively neutralize its influence. This highlights the importance of considering supplier cost structures and investment capabilities when evaluating the relative effectiveness of different carbon regulation policies.

Third, we examine the effectiveness of different regulatory regimes in promoting emission abatement by domestic suppliers. Our analysis indicates CCA always offers stronger incentives for emission abatement investment than CBAM. However, the total carbon emissions under CCA are not necessarily lower than those under CBAM, as overall emissions depend on both technology investment and market demand, with the latter decreasing as production costs rise. These findings underscore the nuanced relationship between regulatory design, supplier cost structures, and environmental outcomes.

The structure of the remainder of this paper is as follows. We first review the relevant literature in Section 2.2 and then elaborate on our modeling framework in Section 2.3. In Section 2.4, we present our equilibrium outcomes and analysis related to CBAM and CCA. Section 2.5 compares the performances of these two carbon border tax regulations. In Section 2.6, we explore two extensions that examine the impact of environmental concerns from governmental and consumer perspectives, respectively. Finally, we conclude the research in Section 2.7.

2.2 Literature Review

Our paper contributes to the stream of research on sustainable operations management. In particular, it is related to those studies that investigate the effects of carbon emission regulations, such as those examining the emission trading system (Fan et al. 2023, Smale et al. 2006), emission allocation rules (Bushnell and Chen 2012, Demailly and Quirion 2006, Sunar and Plambeck 2016), and the uncertainty of the emission regulation (Fan et al. 2010, Heutel 2011).

In terms of carbon border tax regulation, Sunar and Plambeck (2016) examine the impact of an import carbon tax on supply chain performance and total carbon emissions under different emission allocation rules for co-products. They show that under the value-based allocation, imposing a carbon tax can raise emissions. Drake (2018) examines a set of domestic and foreign firms that determine both their production quantities and the clean technologies to adopt in a market subject to stringent emission regulations. The author shows that an import carbon tax does not necessarily eliminate carbon leakage, but it reduces emissions when carbon leakage occurs. Huang et al. (2021) compare two anti-leakage policies, Border Tax (BT) and Output-Based Allocation, and show that BT is more effective in reducing carbon leakage, especially when carbon leakage risk is high. Unlike Drake (2018) and Huang et al. (2021), where the carbon price is treated as either exogenous or a random variable, we endogenize the carbon price by analyzing the government's pricing decisions. In addition to considering CBAM similar to that in the aforementioned studies, we also examine another type of carbon border tax regulation, namely, CCA. While CBAM addresses the carbon price disparity between domestic products and imports, CCA specifically penalizes emission-intensive products. Our findings indicate that CCA performs better than CBAM in encouraging domestic sourcing, thereby more effectively mitigating carbon leakage.

Moreover, our work is also closely related to the stream of research examining sourcing strategies, especially those driven by cost advantage; see, for example, Dada et al. (2007), Federgruen and Yang (2009), Feng and Lu (2012), Wu and Zhang (2014) and Shan et al. (2022). Whereas these works focus on production cost, we will incorporate suppliers' carbon reduction costs, which can also affect equilibrium pricing and sourcing decisions. Recently, there has been growing research on how trade policy affects firms' sourcing strategies. Wang et al. (2011) study the impact of non-tariff barriers on the performance of three procurement strategies: direct procurement, split procurement, and outward processing arrangements. Cui and Lu (2019) characterize original equipment manufacturers' optimal sourcing decisions when they face both product-level and component-level local content requirements. Lai et al. (2021) study how international taxation affects multinational firms' production outsourcing strategies and demonstrate that tax disparity can lead a multinational firm to prefer sourcing materials from overseas subsidiaries and subsequently resell them to contract manufacturers. Our paper enriches this stream of literature by investigating the impact of two carbon border tax regulations on firms' sourcing strategies. In addition, we incorporate both governmental and consumer environmental concerns, enabling us to examine how the buyer's sourcing decisions and overall environmental performance are influenced by government pricing policies and consumer characteristics.

Given its subject matter, this paper also belongs to the stream of research on the impact of taxation on firms' operations, particularly the effects of tariffs (Chen and Hu 2017, Dong and Kouvelis 2020). Chen et al. (2022a) investigate the sourcing decisions of a global manufacturer with operations in both domestic and foreign markets, and reveal a nonmonotonic relationship between tariff levels and the choice between domestic and global sourcing. Wu et al. (2024) examine how multinational firms strategically decide whether to develop new contract manufacturers under tariff uncertainty. More recently, by considering the imposition of tariffs at both raw material and finished goods levels, Kouvelis et al. (2025) investigate a reshoring problem under domestic market competition and tariff uncertainty. Compared with the above-mentioned literature focusing on the impact of imposing tariffs on sourcing strategies, we further examine how tariffs influence environmental performance in terms of carbon emissions. Moreover, we compare different types of carbon border tax regulations and demonstrate that the effectiveness of these regulations in reducing emissions depends on the characteristics of the domestic supplier. In addition to the aforementioned studies, several papers have examined the effects of other taxes, such as corporate taxes and value-added taxes, on firms' operational decisions (Hsu and Zhu 2011, Lai et al. 2021, Xu et al. 2018).

2.3 Model Setup

Consider that a buyer (labeled B) located in a country (e.g., the United States and Germany) that imposes a carbon regulation can choose to buy products from a domestic supplier (labeled D) subject to the regulation or a foreign supplier (labeled F) located in a non-carbon regulated country (e.g., India). We examine two carbon border tax regulations: (1) CBAM (labeled $\mathcal{M}$), which imposes a carbon tax on imported products based on the carbon price differential between the domestic and foreign countries; and (2) CCA (labeled $\mathcal{A}$), which levies a carbon tax on imported products for emissions exceeding a baseline level for that product. The following sections provide a detailed explanation of each key modeling element.

Supplier's emission investment coefficient β_i and emission intensity e_i. To isolate the impact of carbon regulation, we assume that both suppliers (D or F) incur the same carbon emission intensity, denoted by $\bar{e}$ (that we let $\bar{e} = 1$), before the imposition of the carbon regulation. After the imposition of the carbon regulation, each supplier $i \in \{D, F\}$, invests in new technologies to reduce its emission intensity from 1 to e_i by incurring an investment cost $I_i = \beta_i(1 - e_i)^2$, where $e_i \in (0, 1)$ and

$\beta_i > 0$ represents supplier i's investment cost coefficient. Without loss of generality, we assume that $\beta_F = 1$ and let $\beta_D = \beta$ (> 0). The above investment cost function has been widely adopted in the related literature (Anand and Giraud-Carrier 2020, Fan et al. 2023, Krishnan and Zhu 2006, Subramanian et al. 2007), which indicates that reducing carbon emissions becomes increasingly expensive.

Domestic supplier's production cost c. In terms of the supplier's production cost, we normalize the unit production cost of the foreign supplier to zero and let that of the domestic supplier be c (> 0). This is aligned with business reality, as suppliers based in domestic countries and regions such as the United States and Germany typically have a higher unit production cost than those based in foreign countries such as China and India (Wu and Zhang 2014). Thus, the magnitude of c represents the cost disparity between the foreign and domestic suppliers.

Product demand q_i and retail price p_i. Consumers differ in their valuation v of the buyer's product, where v is uniformly distributed over $[0, 1]$. Specifically, the consumer's utility from consuming the product sourced from supplier i can be written as

$$u = v - p_i, \ \ i = \{D, F\}, \tag{2.1}$$

where p_i is the retail price. It follows from (2.1) that a consumer with valuation v will purchase when $v > p_i$ and the fact that $v \sim U[0, 1]$. The demand of the product sourced from supplier i at p_i is given by

$$q_i = 1 - p_i, \ \ i = \{D, F\}. \tag{2.2}$$

In our base model, we focus on the case where consumers have no environmental concerns and further conduct a model extension in Section 2.6.2 to check the impact of such concerns on our main results.

Buyer's and supplier's profit functions under CBAM (regime $\mathcal{M}$). First, consider the case when buyer B sources from a foreign supplier F under regime $\mathcal{M}$.[1] The buyer is required to pay the carbon border tax to the domestic government,

[1] Note that dual sourcing does not occur in this context, as there is no uncertainty associated with either the foreign or domestic supplier. As a result, the buyer will consistently choose the supplier offering the lower procurement cost.

where this tax depends on both the price difference between the domestic carbon price and that of the foreign country and the product's emission intensity. Let κ denote the domestic carbon price, and we normalize the carbon price of the foreign country where the supplier is located to zero for simplicity. This way, κe_F is the carbon border tax to be paid by the buyer under regime $\mathcal{M}$. Consequently, by letting w_F be the wholesale price charged by the supplier F, the profits of buyer B and supplier F under regime $\mathcal{M}$ are:

$$\Pi_B^{\mathcal{M}} = (p_F - w_F - \kappa e_F)q_F, \text{ and } \pi_F^{\mathcal{M}} = w_F q_F - (1 - e_F)^2, \tag{2.3}$$

where q_F is given in (2.2) and $(1 - e_F)^2$ is the investment cost borne by supplier F.

Second, we consider the case when buyer B sources from a domestic supplier D under regime $\mathcal{M}$. Because supplier D has already paid the carbon tax κe_D to the domestic government, no additional carbon tax will be incurred by buyer B. Hence, the profits of buyer B and supplier D under regime $\mathcal{M}$ are:

$$\Pi_B^{\mathcal{M}} = (p_D - w_D)q_D, \text{and } \pi_D^{\mathcal{M}} = (w_D - c - \kappa e_D)q_D - \beta(1 - e_D)^2, \tag{2.4}$$

where q_D is given in (2.2) and $\beta(1 - e_D)^2$ is the investment cost borne by supplier D.

Buyer's and supplier's profit functions under CCA (regime $\mathcal{A}$). First, suppose buyer B sources from supplier F under regime $\mathcal{A}$. Then buyer B pays the carbon tax to the local government based on the "excessive emissions above" the pre-specified threshold τ, as specified by CCA according to the average carbon footprint for each product category (Congress.Gov 2024). Hence, the profits of buyer and foreign supplier F under regime $\mathcal{A}$ are:

$$\Pi_B^{\mathcal{A}} = (p_F - w_F - \kappa(e_F - \tau)^+)q_F, \text{ and } \pi_F^{\mathcal{A}} = w_F q_F - (1 - e_F)^2, \tag{2.5}$$

where the term $(e_F - \tau)^+$ represents the excessive emissions committed by supplier F.

Second, suppose buyer B sources from a domestic supplier D, the buyer incurs no carbon tax because this tax $\kappa(e_D - \tau)^+$ has been paid by supplier D and the profits are:

$$\Pi_B^{\mathcal{A}} = (p_D - w_D)q_D, \text{ and } \pi_D^{\mathcal{A}} = (w_D - c - \kappa(e_D - \tau)^+)q_D - \beta(1 - e_D)^2. \quad (2.6)$$

Government's problem. Next, under each regime ($\mathcal{M}$ or $\mathcal{A}$), the government chooses the optimal carbon price κ by maximizing its social welfare. Social welfare captures five components that the local government cares about: the domestic buyer's profit (Π_B), the domestic supplier's profit (π_D), the consumer surplus (U), the carbon tax (T), and the domestic supplier's total carbon emissions (C_D). Specifically, the consumer surplus is given by $U = \int_{p_i}^{1}(v - p_i)dv = \frac{q_i^2}{2}$, the carbon tax is denoted as $T^{\mathcal{M}} = \kappa e_B q_B$ under regime $\mathcal{M}$ and $T^{\mathcal{A}} = \kappa(e_B - \tau)q_B$ under regime $\mathcal{A}$, and the domestic supplier's total carbon emission is expressed as $C_D = e_D q_D$, where $i \in \{F, D\}$.[2] By combining these components, we can define social welfare S under each regime as

$$S^j = \Pi_B^j + \pi_D^j + U_i^j + T_i^j - \lambda C_D^j, \; i = \{D, F\}, \; j = \{\mathcal{M}, \mathcal{A}\}, \quad (2.7)$$

where the parameter $\lambda > 0$ reflects the government's level of concern about carbon emission.

Sequence of events. Under either regime ($\mathcal{M}$ or $\mathcal{A}$), a buyer and a foreign or domestic supplier engage in a sequential game as follows. First, the domestic government decides the carbon price κ for the domestic supplier D. Second, the buyer chooses to source from the supplier D or F. Third, the selected supplier $i \in \{D, F\}$ determines its emission intensity e_i by engaging in technology investment. Next, the selected supplier i determines its wholesale price w_i. Then, the buyer decides the retail price p_i and the purchase from supplier i. Finally, the related costs and revenues are realized. Figure 2.1 depicts the sequence of events. Table 2.1 summarizes the key notations used in the paper for ease of reference.

Analysis roadmap: In our baseline model, to isolate the impact of carbon

[2]The local government focuses solely on profit and carbon emissions within its own market, with both the carbon tax and carbon border tax serving as sources of income.

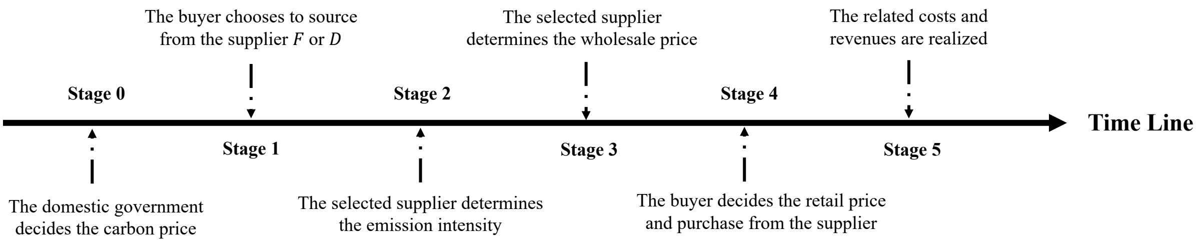


Figure 2.1: Sequence of Events

Table 2.1: List of Notations

Category	Parameter	Description
Parameters	c	Unit production cost of supplier D
	β	Investment cost coefficient of supplier D
	τ	Stipulated baseline emission intensity under regime $\mathcal{A}$
	λ	Government's level of concern about carbon emission
Decision Variables	κ_i^j	Carbon price for supplier i under regime j, $i = \{D, F\}$, $j = \{\mathcal{M}, \mathcal{A}\}$
	e_i^j	Supplier i's emission intensity after the imposition of regime j
	p_i^j	Supplier i's retail price under regime j
	q_i^j	Supplier i's demand under regime j
Objective Functions	Π_B^j	Buyer's profit under regime j
	π_i^j	Supplier i's profit under regime j
	S^j	Government's social welfare under regime j
	U_i^j	Consumer surplus from supplier i under regime j
	T_i^j	Carbon tax from supplier i under regime j
	C_D^j	Total carbon emission from supplier D under regime j

regulations on the buyer's sourcing strategy, we first consider a scenario in which the government is environmentally unconcerned, i.e., $\lambda = 0$. Under each regime, we start by deriving the equilibrium emission intensities and wholesale pricing decisions of the suppliers, the buyer's sourcing strategies, and the government's optimal carbon pricing decisions. Then, we compare the buyer's sourcing decisions, supply chain members' profits, and the carbon emission performance across these two regimes. In the extension, we first examine the limiting cases where $\lambda \to 0$ and $\lambda \to \infty$, and then employ numerical analysis to investigate the effects of intermediate values of λ. We also investigate how consumers' environmental concern affects the supply chain performance under regime $\mathcal{M}$.

2.4 Equilibrium Analysis

In this section, we investigate the sequential game as described in Section 2.3 and obtain the equilibrium outcomes under regime $\mathcal{M}$ and $\mathcal{A}$ using backward induction.

2.4.1 Analysis of CBAM

Under regime $\mathcal{M}$, the unit carbon border tax equals the carbon price disparity between the foreign and domestic countries. We first derive the equilibrium outcomes for a given carbon price κ in Lemma 2.1 and Proposition 2.1, and then obtain the government's optimal carbon price decision $\kappa^{\mathcal{M}*}$ that maximizes the social welfare S defined in (2.7) in Proposition 2.2.

Given the carbon price κ, we can obtain the equilibrium outcomes under CBAM, which are summarized in Table 2.2. Here, to avoid the trivial case where the firm is willing to invest in completely eliminating carbon emissions, we assume that $\kappa < \beta < 1$ and $c < 1 - \kappa$. These conditions ensure a nonnegative interior solution for the emission intensity $e_i^{\mathcal{M}}$, where $i \in \{F, D\}$.

Table 2.2: Equilibrium Outcomes Under CBAM for a Given Carbon Price κ

Supplier F	$e_F^{\mathcal{M}} = \frac{8-\kappa}{8-\kappa^2}$	$w_F^{\mathcal{M}} = \frac{4(1-\kappa)}{8-\kappa^2}$	$q_F^{\mathcal{M}} = \frac{2(1-\kappa)}{8-\kappa^2}$
	$p_F^{\mathcal{M}} = 1 - \frac{2(1-\kappa)}{8-\kappa^2}$	$\pi_F^{\mathcal{M}} = \frac{(1-\kappa)^2}{8-\kappa^2}$	$\Pi_B^{\mathcal{M}} = \frac{4(1-\kappa)^2}{(8-\kappa^2)^2}$
	$U_F^{\mathcal{M}} = \frac{2(1-\kappa)^2}{(8-\kappa^2)^2}$	$C_F^{\mathcal{M}} = \frac{2(8-\kappa)(1-\kappa)}{(8-\kappa^2)^2}$	$T_F^{\mathcal{M}} = \frac{2\kappa(8-\kappa)(1-\kappa)}{(8-\kappa^2)^2}$
Supplier D	$e_D^{\mathcal{M}} = \frac{8\beta-(1-c)\kappa}{8\beta-\kappa^2}$	$w_D^{\mathcal{M}} = \frac{4\beta(1+c+\kappa)-\kappa^2}{8\beta-\kappa^2}$	$q_D^{\mathcal{M}} = \frac{2\beta(1-c-\kappa)}{8\beta-\kappa^2}$
	$p_D^{\mathcal{M}} = 1 - \frac{2\beta(1-c-\kappa)}{8\beta-\kappa^2}$	$\pi_D^{\mathcal{M}} = \frac{\beta(1-c-\kappa)^2}{8\beta-\kappa^2}$	$\Pi_B^{\mathcal{M}} = \frac{4\beta^2(1-c-\kappa)^2}{(8\beta-\kappa^2)^2}$
	$U_D^{\mathcal{M}} = \frac{2\beta^2(1-c-\kappa)^2}{(8\beta-\kappa^2)^2}$	$C_D^{\mathcal{M}} = \frac{2\beta(1-c-\kappa)(8\beta-(1-c)\kappa)}{(8\beta-\kappa^2)^2}$	$T_D^{\mathcal{M}} = \frac{2\beta\kappa(1-c-\kappa)(8\beta-(1-c)\kappa)}{(8\beta-\kappa^2)^2}$

In the subsequent lemma, we analyze the comparative statics of the equilibrium outcomes presented in Table 2.2 with respect to the given carbon price κ.

Lemma 2.1 *Under CBAM, given the carbon price κ, the following statements hold:*

(i) *The investment level $1 - e_i^{\mathcal{M}}$ and carbon tax $T_i^{\mathcal{M}}$ of both suppliers are unimodal in κ. The total carbon emission $C_i^{\mathcal{M}}$, however, is decreasing in κ, regardless of the supplier source.*

(ii) Supplier F's wholesale price $w_F^{\mathcal{M}}$ is decreasing in κ, while supplier D's wholesale price $w_D^{\mathcal{M}}$ is increasing in κ.

(iii) The buyer's retail price $p_i^{\mathcal{M}}$ is increasing in κ, while the demand $q_i^{\mathcal{M}}$, the buyer's profit $\Pi_B^{\mathcal{M}}$, and the consumer surplus $U_i^{\mathcal{M}}$ are decreasing in κ, regardless of the supplier source.

Lemma 2.1 yields several noteworthy results. First, either supplier's investment (i.e., $1 - e_i^{\mathcal{M}}$) exhibits a unimodal relationship with the carbon price κ. Second, supplier F's wholesale price decreases with the carbon price κ, whereas supplier D's wholesale price increases with the carbon price κ. The underlying reasons are as follows: When the buyer sources from supplier F, an increase in the carbon price κ raises the buyer's unit carbon tax. This additional cost is passed on to consumers through a higher retail price, which, in turn, reduces consumer purchase willingness and leads to a decline in demand. Anticipating this behavior and the fact that the carbon price κ is low, supplier F invests more in emission abatement to boost demand. However, as κ continues to rise, the buyer's unit carbon tax (i.e., $\kappa e_i^{\mathcal{M}}$) still increases, and the reduction in emission intensity alone becomes insufficient to offset the buyer's higher marginal cost. This compels supplier F to further lower its wholesale price. Nevertheless, once the expenditure on emission reduction surpasses a specific threshold, additional investment results in a substantial rise in supplier F's investment costs, due to the quadratic form of its investment cost function. This inhibits supplier F from further reducing emission intensity as the carbon price continues to increase. By contrast, if the buyer selects supplier D, an increase in the carbon price κ directly raises the unit carbon tax burden borne by supplier D. To mitigate these higher costs, supplier D increases its investment in emission abatement. However, since the unit carbon tax (i.e., $\kappa e_i^{\mathcal{M}}$) continues to rise with increasing κ, supplier D is compelled to raise the wholesale price to cover these additional costs. Similar to supplier F, when the carbon price κ is high, the excessive investment costs also deter the supplier D from further reducing emission intensity.

In addition, an increase in the unit carbon tax (i.e., $\kappa e_i^{\mathcal{M}}$), irrespective of the entity responsible for its payment, is transferred to the consumers. This leads to diminished demand and, consequently, a reduction in the buyer's profit and total carbon emissions, as shown in Lemma 2.1(i) and 2.1(iii). However, when κ is either very low or high, the former results in a low $\kappa e_i^{\mathcal{M}}$, while the latter leads to a low $q_i^{\mathcal{M}}$. Therefore, the overall carbon tax is high only when κ is at an intermediate level, as shown in Lemma 2.1(i). Next, we present the proposition that characterizes the buyer's equilibrium sourcing strategies.

Proposition 2.1 *Under CBAM, let $c_1^{\mathcal{M}}(\beta, \kappa)$ be a threshold defined in Table A.1. Given the carbon price κ, it is optimal for the buyer to source from a domestic supplier if and only if $c \leq c_1^{\mathcal{M}}(\beta, \kappa)$.*

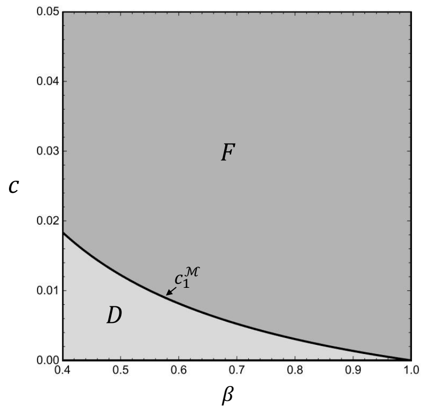


Figure 2.2: Equilibrium Sourcing Strategy Under CBAM for a Given Carbon Price ($\kappa = 0.4$)

Proposition 2.1 shows that the buyer sources from supplier D when its production cost is low. Figure 2.2 further demonstrates that the cost threshold $c_1^{\mathcal{M}}(\beta, \kappa)$ decreases in β. That is, if the investment cost coefficient β is sufficiently low, supplier D can afford to invest in emission abatement, which reduces the buyer's carbon tax, making domestic sourcing appealing. Therefore, if the local government wants to attract more domestic sourcing, initiatives such as investing in renewable energy infrastructure can help suppliers to reduce β, creating more domestic sourcing and jobs.

It is noteworthy that the sourcing condition $c \leq c_1^{\mathcal{M}}(\beta, \kappa)$ can also be written through the lens of the carbon price κ, requiring κ to be either (1) no less than a threshold $\kappa_1^{\mathcal{M}}$ (i.e., $\kappa \geq \kappa_1^{\mathcal{M}}(\beta, c)$) when c is small (i.e., $c \leq c_2^{\mathcal{M}}(\beta)$), or (2) at a moderate level (i.e., $\kappa_1^{\mathcal{M}}(\beta, c) \leq \kappa < \kappa_2^{\mathcal{M}}(\beta, c)$) when c is moderate (i.e., $c_2^{\mathcal{M}}(\beta) < c \leq c_3^{\mathcal{M}}(\beta)$) and β is high (i.e., $\beta > \beta_1^{\mathcal{M}}$). Two observations are helpful in interpreting this result. First, the marginal procurement cost for a buyer sourcing from supplier F is $w_F^{\mathcal{M}} + \kappa e_F^{\mathcal{M}}$, whereas for a buyer sourcing from supplier D, it is $w_D^{\mathcal{M}}$. Second, supplier D, who bears the production cost and carbon taxes, charges a higher wholesale price than supplier F (i.e., $w_D^{\mathcal{M}} > w_F^{\mathcal{M}}$) due to the double marginalization effect. Combining these two observations, along with the fact that a high κ increases the buyer's marginal carbon tax cost (i.e., $\kappa e_F^{\mathcal{M}}$) from supplier F and a low c results in a lower $w_D^{\mathcal{M}}$, we conclude that the buyer is more likely to select supplier D when c is small and κ is high.

By contrast, when c is moderate and β is high, the buyer chooses supplier D only when κ is moderate. This occurs because, when κ is relatively small, the unit carbon tax associated with sourcing from supplier F is negligible (i.e., $\kappa e_F^{\mathcal{M}}$ is small) and the the marginal procurement from supplier D remains high (i.e., $w_D^{\mathcal{M}} > w_F^{\mathcal{M}}$), leading the buyer to prefer supplier F. However, when κ becomes large, although a higher carbon price increases the unit carbon tax imposed on the buyer sourcing from supplier F, it also expands the wholesale price differential between supplier D and F (i.e., $w_D^{\mathcal{M}} - w_F^{\mathcal{M}}$), as established in Lemma 2.1(ii). Moreover, this widening gap can be further amplified by a high β and c, making supplier D less attractive to the buyer when κ is relatively high. As such, the careful determination of an optimal carbon price $\kappa^{\mathcal{M}*}$ becomes essential.

Anticipating the decisions of the supplier and the buyer as outlined in Table 2.2, the government chooses $\kappa^{\mathcal{M}*}$, which maximizes its social welfare S as defined in (2.7). The resulting equilibrium outcomes are shown in Table A.2.

Proposition 2.2 *Under CBAM, there exists a threshold $\bar{c}^{\mathcal{M}}(\beta)$ defined in Table A.1 such that, in equilibrium, the optimal carbon price $\kappa^{\mathcal{M}*}$ set by the government is characterized as follows:*

1. *If $c \leq \bar{c}^{\mathcal{M}}(\beta)$, the optimal carbon price is $\kappa^{\mathcal{M}*} = \kappa_1^{\mathcal{M}}$, and the buyer sources from supplier D.*

2. If $c > \bar{c}^{\mathcal{M}}(\beta)$, the optimal carbon price is

$$\kappa^{\mathcal{M}*} = \begin{cases} 5-\sqrt{23}, & \text{if } \beta > 5-\sqrt{23} \text{ and } \bar{c}^{\mathcal{M}}(\beta) < c \leq \sqrt{23}-4, \\ \beta, & \text{if } \beta \leq 5-\sqrt{23} \text{ and } \bar{c}^{\mathcal{M}}(\beta) < c \leq 1-\beta, \\ 1-c, & \text{otherwise}, \end{cases} \tag{2.8}$$

and the buyer sources from the supplier F.

Proposition 2.2 indicates that when supplier D has a low production cost c, the domestic government is likely to set an intermediate-high carbon price (i.e., $\kappa^{\mathcal{M}*} = \kappa_1^{\mathcal{M}}$) to incentivize the buyer to purchase from supplier D. By contrast, when both c and β for supplier D are high, the domestic government tends to charge an intermediate-low carbon price (i.e., $\kappa^{\mathcal{M}*} = 5-\sqrt{23}$) to encourage the buyer to select supplier F. To better explain this result, we first elaborate on the underlying mechanisms. Recall that the increased carbon tax cost resulting from a higher κ is ultimately transferred to consumers, reducing their willingness to purchase and thereby hurting all supply chain players, including the buyer and suppliers. However, from the government's perspective, an increase in κ leads to higher carbon tax revenues. When the buyer sources from supplier D, the government's social welfare incorporates the profits of the entire supply chain, making the impact of imposing carbon taxes relatively small. As a result, the government prefers a lower carbon price κ, which benefits the buyer, suppliers, and consumers. Conversely, when the buyer sources from supplier F, the government's social welfare does not account for supplier F's profits, making the impact of the carbon tax more pronounced. Consequently, the government tends to choose an intermediate value of κ. This is because carbon tax revenues are low when κ is either small or large—the former due to the low carbon price and the latter due to reduced demand, both of which significantly lower total carbon tax revenue.

Obviously, a relatively low c makes the buyer source from supplier D more preferable for the government because supplier D's profit contributes to the government's social welfare. This prompts the government to impose the carbon price at a high level (i.e., $\kappa^{\mathcal{M}*} \geq \kappa_1^{\mathcal{M}}$) so that the buyer would purchase from supplier D, as stated in

Proposition 2.1. However, given the negligible impact of carbon tax revenue in this region, a higher carbon price harms the buyer, supplier D, and consumers, thereby reducing overall government welfare. Consequently, an intermediate-high carbon price (i.e., $\kappa^{\mathcal{M}*} = \kappa_1^{\mathcal{M}}$) is more advantageous for the government. By contrast, a moderate c and a high β make sourcing from supplier D less preferable for the government. Recall from Proposition 2.1 that under this situation, either a low or an extremely high carbon price (i.e., $\kappa^{\mathcal{M}*} < \kappa_1^{\mathcal{M}}$ or $\kappa^{\mathcal{M}*} > \kappa_2^{\mathcal{M}}$) would lead the buyer to select supplier F. Nevertheless, the domestic government opts for an intermediate-low carbon price (i.e., $\kappa^{\mathcal{M}*} = 5 - \sqrt{23}$) to incentivize the buyer to source from supplier F. This is because, in this case, carbon tax revenue has a higher impact on the government's social welfare. Nonetheless, setting a carbon price that is either excessively high or low undermines carbon tax revenue—the former by suppressing demand, and the latter by lowering the carbon tax rate. Thus, an intermediate-low carbon price is more beneficial for the government. In other cases, due to a small β or a large c, the government is unable to set the optimal carbon price of $5 - \sqrt{23}$ to incentivize the buyer to source from supplier F. Consequently, the carbon price is set at its upper bound, either β or $1 - c$.

2.4.2 Analysis of CCA

Under regime $\mathcal{A}$, the carbon border tax is levied on emissions above a stipulated baseline emission intensity. We examine CCA by adopting an agenda similar to that used to study CBAM. Initially, we derive the equilibrium outcomes for a given carbon price κ in Lemma 2.2 and Proposition 2.3, followed by determining the government's optimal carbon price decision $\kappa^{\mathcal{A}*}$ that maximizes the social welfare S as presented in (2.7) in Proposition 2.4.

Given the carbon price κ, we can obtain the equilibrium outcomes under CCA, which are summarized in Table 2.3. Next, we will examine the impact of the specified baseline τ on the equilibrium outcomes presented in Table 2.3 in the following lemma.[3]

[3]Obviously, when τ is extremely high (i.e., $\tau > \frac{8-\kappa}{8}$ for supplier F and $\tau > \frac{8\beta-(1-c)\kappa}{8\beta}$ for supplier D), both suppliers will invest in emission abatement to the baseline level τ since the

Table 2.3: Equilibrium Outcomes Under CCA for a Given Carbon Price κ

Supplier F $\tau > \frac{8-\kappa}{8}$	$e_F^{\mathcal{A}} = \tau$ $p_F^{\mathcal{A}} = \frac{3}{4}$ $U_F^{\mathcal{A}} = \frac{1}{32}$	$w_F^{\mathcal{A}} = \frac{1}{2}$ $\pi_F^{\mathcal{A}} = (2-\tau)\tau - \frac{7}{8}$ $C_D^{\mathcal{A}} = \frac{\tau}{4}$	$q_F^{\mathcal{A}} = \frac{1}{4}$ $\Pi_B^{\mathcal{A}} = \frac{1}{16}$ $T_F^{\mathcal{A}} = 0$
$\tau \le \frac{8-\kappa}{8}$	$e_F^{\mathcal{A}} = \frac{8-\kappa(1+\kappa\tau)}{8-\kappa^2}$ $p_F^{\mathcal{A}} = \frac{6-\kappa(\kappa-2(1-\tau))}{8-\kappa^2}$ $U_F^{\mathcal{A}} = \frac{2(1-\kappa(1-\tau))^2}{(8-\kappa^2)^2}$	$w_F^{\mathcal{A}} = \frac{4(1-\kappa(1-\tau))}{8-\kappa^2}$ $\pi_F^{\mathcal{A}} = \frac{(1-\kappa(1-\tau))^2}{8-\kappa^2}$ $C_D^{\mathcal{A}} = \frac{(8-\kappa(1+\kappa\tau))(2(1-\kappa(1-\tau)))}{(8-\kappa^2)^2}$	$q_F^{\mathcal{A}} = \frac{2(1-\kappa(1-\tau))}{8-\kappa^2}$ $\Pi_B^{\mathcal{A}} = \frac{4(1-\kappa(1-\tau))^2}{(8-\kappa^2)^2}$ $T_F^{\mathcal{A}} = \frac{2\kappa(1-\kappa(1-\tau))(8(1-\tau)-\kappa)}{\left(8-\kappa^2\right)^2}$
Supplier D $\tau > \frac{8\beta-(1-c)\kappa}{8\beta}$	$e_D^{\mathcal{A}} = \tau$ $p_D^{\mathcal{A}} = \frac{3+c}{4}$ $U_D^{\mathcal{A}} = \frac{1}{32}(1-c)^2$	$w^{\mathcal{A}} = \frac{1+c}{2}$ $\pi_D^{\mathcal{A}} = \frac{1}{8}((1-c)^2 - 8\beta(1-\tau)^2)$ $C_D^{\mathcal{A}} = \frac{1}{4}(1-c)\tau$	$q_D^{\mathcal{A}} = \frac{1-c}{4}$ $\Pi_B^{\mathcal{A}} = \frac{1}{16}(1-c)^2$ $T_D^{\mathcal{A}} = 0$
$\tau \le \frac{8\beta-(1-c)\kappa}{8\beta}$	$e_D^{\mathcal{A}} = \frac{8\beta-\kappa(1-c)-\kappa^2\tau}{8\beta-\kappa^2}$ $p_D^{\mathcal{A}} = \frac{2\beta(3+\kappa+c-\kappa\tau)-\kappa^2}{8\beta-\kappa^2}$ $U_D^{\mathcal{A}} = \frac{2\beta^2(1-c-\kappa(1-\tau))^2}{(8\beta-\kappa^2)^2}$	$w_D^{\mathcal{A}} = \frac{4\beta(1+\kappa(1-\tau)+c)-\kappa^2}{8\beta-\kappa^2}$ $\pi_D^{\mathcal{A}} = \frac{\beta(1-c-\kappa(1-\tau))^2}{8\beta-\kappa^2}$ $C_D^{\mathcal{A}} = \frac{(8\beta-\kappa(1-c)-\kappa^2\tau)(2\beta(1-c-\kappa(1-\tau)))}{(8\beta-\kappa^2)^2}$	$q_D^{\mathcal{A}} = \frac{2\beta(1-c-\kappa(1-\tau))}{8\beta-\kappa^2}$ $\Pi_B^{\mathcal{A}} = \frac{4\beta^2(1-c-\kappa(1-\tau))^2}{(8\beta-\kappa^2)^2}$ $T_D^{\mathcal{A}} = \frac{2\beta\kappa(1-c-\kappa(1-\tau))(8\beta(1-\tau)-(1-c)\kappa)}{\left(8\beta-\kappa^2\right)^2}$

Lemma 2.2 *Under CCA, given the carbon price κ, the following statements hold:*

(i) The investment level $1 - e_i^{\mathcal{A}}$ and total carbon emissions of both suppliers are increasing in τ. The carbon tax $T_i^{\mathcal{A}}$, however, is unimodal in τ, regardless of the supplier source.

(ii) Supplier F's wholesale price $w_F^{\mathcal{A}}$ is increasing in τ, while supplier D's wholesale price $w_D^{\mathcal{A}}$ is decreasing in τ.

(iii) The buyer's retail price $p_i^{\mathcal{A}}$ is decreasing in τ, while the demand $q_i^{\mathcal{A}}$, the buyer's profit $\Pi_B^{\mathcal{A}}$, and the consumer surplus $U_i^{\mathcal{A}}$ are increasing in τ, regardless of the supplier source.

One may intuit that raising the emission intensity baseline τ could lead the supplier to invest less in emission abatement, as a higher standard allows for greater emission intensity without incurring additional carbon taxes. However, Lemma 2.2(i) shows that the supplier's investment in emission abatement increases in τ. Moreover, Lemma 2.2(ii) indicates that supplier F's wholesale price increases with the baseline τ, whereas supplier D's wholesale price decreases with the baseline τ. The intuition behind this is that both suppliers can achieve higher profits by simultaneously adjusting their emission intensity and wholesale price. Specifically, when the buyer sources from supplier F, an increase in τ reduces the buyer's marginal

investment cost is relatively low. In this case, apart from unit emission intensity, total emissions and the supplier's profit, all other equilibrium outcomes are unaffected by τ. Meanwhile, all the equilibrium outcomes are independent of κ, given that the unit carbon tax is zero. So, we focus on the more nontrivial case where the supplier does not reduce emission intensity to the baseline τ.

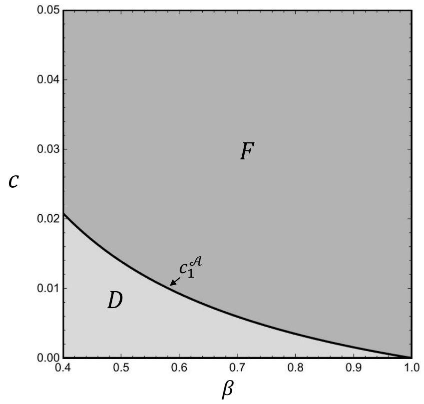
purchasing cost, prompting the buyer to lower the retail price and thereby expanding demand for supplier F. Anticipating this, supplier F is incentivized to raise its wholesale price, as consumers become more willing to purchase. However, a higher wholesale price also increases the buyer's marginal procurement cost, which may inhibit demand expansion. This compels supplier F to also reduce its emission intensity to alleviate the buyer's marginal cost burden. It is worth noting that a higher τ indicates that suppliers can attain carbon tax exemption without reducing their emission intensity to an extremely low level, thereby keeping the marginal increase in technology investment costs relatively moderate. Consequently, when confronted with a higher τ, supplier F can enhance the wholesale price and emission abatement efforts to attain satisfactory profitability.

By contrast, supplier D directly bears the carbon tax. An increase in τ reduces supplier D's marginal emission cost, enabling it to accept a lower wholesale price to stimulate consumer purchases. However, this also diminishes supplier D's marginal profitability, incentivizing it to further invest in emission abatement to sustain overall profit levels. Thus, supplier D strategically employs both a lower wholesale price and reduced emission intensity to maximize its profitability. Overall, as τ increases, both suppliers are able to adjust their wholesale prices and investments in emission abatement flexibly, allowing them to better manage emission costs and enhance sales profitability.

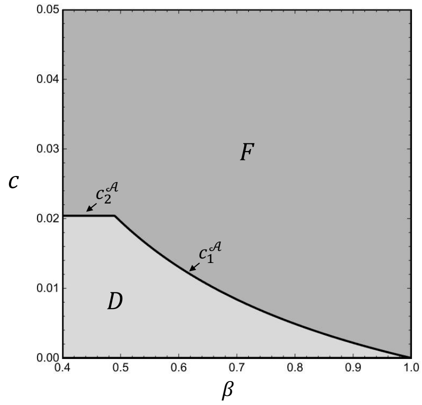
It is worth noting that the specified emission intensity baseline τ exerts an opposite influence on the unit carbon tax (i.e., $\kappa^{\mathcal{A}}(e^{\mathcal{A}}-\tau)$) under CCA compared to the impact of carbon price κ under CBAM. Specifically, while a higher carbon price κ raises the unit carbon tax, a larger specified baseline τ counteracts this effect by partially offsetting the impact of κ. Consequently, the reduction in carbon tax costs associated with a higher τ is passed on to consumers, enhancing their willingness to purchase. This effect is further illustrated in Lemma 2.2(iii), where incorporating the baseline τ stimulates demand and benefits the buyer and consumers. This stands in direct contrast to the effect of raising the carbon price κ, as described in Lemma 2.1(iii). Moreover, Lemma 2.2(i) reveals that the total carbon tax exhibits a non-monotonic relationship with the baseline τ, analogous to the pattern observed with κ in Lemma

2.1(i). This behavior emerges because extreme values of τ create opposing effects: When τ is relatively low, the demand reduction is the dominant factor, while when τ is relatively high, the unit carbon tax becomes negligible. Consequently, the total carbon tax reaches its peak only at an intermediate τ. Next, the buyer's equilibrium sourcing strategies are established in the following proposition.

Proposition 2.3 *Under CCA, there exist thresholds $c_1^{\mathcal{A}}(\beta,\kappa,\tau)$ and $c_2^{\mathcal{A}}(\beta,\kappa,\tau)$ defined in Table A.1 such that it is optimal for the buyer to source from a domestic supplier if and only if $c \le min\{c_1^{\mathcal{A}}(\beta,\kappa,\tau), c_2^{\mathcal{A}}(\beta,\kappa,\tau)\}$.*



(a) $\tau \le \frac{8\beta+(1-\beta)\kappa^2-\kappa}{(1-\beta)\kappa^2+8\beta}$



(b) $\tau > \frac{8\beta+(1-\beta)\kappa^2-\kappa}{(1-\beta)\kappa^2+8\beta}$

Figure 2.3: Equilibrium Sourcing Strategy ($\kappa = 0.4$)

Similar to the case under CBAM, Proposition 2.3 demonstrates that under CCA, the buyer prefers supplier F when its production cost c is low (see Figure 2.3). The difference is that when τ is small, its introduction under CCA enlarges the region in which the buyer prefers supplier D, i.e., $c_1^{\mathcal{A}} > c_1^{\mathcal{M}}$. If we write this sourcing condition in terms of the carbon price κ, it implies that for a lower κ, the buyer is more likely to select supplier D.

Recall that the introduction of τ reduces the unit carbon tax associated with purchasing from either supplier F or D, thereby benefiting all members of the supply chain. Consider a special case first where there is no difference in characteristics between suppliers F and D (i.e., $c = 0$ and $\beta = 1$). The only distinction is that the buyer bears the carbon tax when purchasing from supplier F, whereas the carbon tax is borne by supplier D when the buyer sources from it. In this case, the buyer's profit is identical regardless of the supplier selected. Therefore, the buyer's preference between suppliers primarily arises from the characteristics of supplier D. Specifically, compared with supplier F, the introduction of τ, together with a smaller investment cost coefficient β, incentivizes supplier D to invest more in emission abatement (i.e., $\frac{\partial(1-e_D^{\mathcal{A}})}{\partial\tau} > \frac{\partial(1-e_F^{\mathcal{A}})}{\partial\tau}$), thereby enabling it to reduce the wholesale price. This, in turn, stimulates consumer purchases and enhances the buyer's profit. Hence, the likelihood that the buyer sources from supplier D increases.

However, as τ becomes large, supplier D reduces its emission intensity to τ earlier than supplier F and then ceases further investment in emission abatement, since its profits are no longer affected by additional investment. In contrast, the buyer's profit from purchasing from supplier F continues to increase with τ. Consequently, the region in which the buyer prefers supplier D shrinks.

Following the analytical approach established for CBAM, we examine the optimal carbon price $\kappa^{\mathcal{A}*}$ under CCA, with the complete set of equilibrium outcomes presented in Table A.3. The following proposition presents the government's optimal carbon pricing strategy under CCA.

Proposition 2.4 *Under CCA, there exist thresholds $\bar{c}^{\mathcal{A}}(\beta,\tau)$, $c_5^{\mathcal{A}}(\tau)$, $c_6^{\mathcal{A}}(\tau)$, and $\bar{\beta}^{\mathcal{A}}(\tau)$ defined in Table A.1 such that, in equilibrium, the optimal carbon price $\kappa^{\mathcal{A}*}$ set by the government is characterized as follows:*

1. *If $c \leq \bar{c}^{\mathcal{A}}(\beta,\tau)$, the optimal carbon price is $\kappa^{\mathcal{A}*} = \kappa_1^{\mathcal{A}}$, and the buyer sources from supplier D.*

2. *If $c > \bar{c}^{\mathcal{A}}(\beta,\tau)$, the optimal carbon price is*

$$\kappa^{\mathcal{A}*} = \begin{cases} \kappa_2^{\mathcal{A}}, & \text{if } \tau \leq \frac{7}{10}, \beta > \bar{\beta}^{\mathcal{A}}(\tau) \text{ and } \bar{c}^{\mathcal{A}}(\beta,\tau) < c \leq c_5^{\mathcal{A}}(\tau), \\ \kappa_3^{\mathcal{A}}, & \text{if } \tau > \frac{7}{9}, \beta > \bar{\beta}^{\mathcal{A}}(\tau) \text{ and } \bar{c}^{\mathcal{A}}(\beta,\tau) < c \leq c_6^{\mathcal{A}}(\tau), \\ \beta, & \text{if } \beta \leq \bar{\beta}^{\mathcal{A}}(\tau) \text{ and } \bar{c}^{\mathcal{A}}(\beta,\tau) < c \leq 1-\beta \\ 1-c, & \text{Otherwise.} \end{cases} \tag{2.9}$$

and the buyer sources from the supplier F.

When supplier D has a relatively low cost c, Proposition 2.4 states that under CCA, analogous to the case under CBAM, the local government is inclined to impose an intermediate-high carbon price (i.e., $\kappa^{\mathcal{A}*} = \kappa_1^{\mathcal{A}}$) to encourage the buyer to choose supplier D. This is because the buyer would select supplier D only when the carbon price is set at a high level (i.e., $\kappa > \kappa_1^{\mathcal{A}}$). However, the carbon tax contributes little to the government's social welfare when the buyer selects supplier D; therefore, adopting an intermediate-high carbon price that is beneficial for both the buyer and consumers is more desirable from the government's perspective under CCA.

By contrast, when c is high, Proposition 2.4 further indicates that the carbon price set to induce the buyer to source from supplier F is influenced by the magnitude of τ. Specifically, first, when τ is small (i.e., $\tau \leq \frac{7}{10}$), and both c and β are high, the government sets an intermediate-low carbon price (i.e., $\kappa^{\mathcal{A}*} = \kappa_2^{\mathcal{A}}$) under CCA to incentivize the buyer to source from supplier F. The intuition behind this result is similar to that under CBAM, as an intermediate-low carbon price is more effective for generating carbon tax revenue, which plays a more critical role in maximizing the government's social welfare when the buyer is incentivized to select supplier F. It is worth noting that there exists a one-to-one mapping between the carbon price κ and intensity baseline τ, defined by the equation $\kappa^{\mathcal{A}*} = \kappa_2^{\mathcal{A}}$ (i.e., $\kappa = 5(1-\tau) - \sqrt{25(1-\tau)^2 - 2}$. We can show that under such a mapping relationship, the introduction of τ does not alter the unit carbon tax, which remains the same as in the case where $\tau = 0$. This mapping highlights a substitution effect: an increase in τ requires a proportional increase in κ to maintain equilibrium. In other words, τ acts as a subsidy that diminishes the unit carbon tax, but this reduction is counterbalanced by an increase in κ, which partially offsets the government's loss in tax revenue. However, the substitution effect between τ and κ becomes less efficient at higher levels; that is, maintaining the carbon tax requires an ever-larger increment in κ to offset a marginal increase in τ. This phenomenon is rooted in the mathematical structure of the unit carbon tax, i.e., $\kappa(e - \tau)$. Note that beyond τ and κ, the unit carbon tax is also influenced by the emission intensity e. A higher τ leads to a lower emission intensity, amplifying its subsidy effect. Consequently, the government must substantially increase κ to sustain a constant unit carbon tax.

Therefore, as τ increases (i.e., $\frac{7}{10} < \tau \leq \frac{7}{9}$), the required adjustment in κ to maintain a constant tax level becomes larger. Unfortunately, under CCA, even raising κ to its upper bound (i.e., $\kappa^{\mathcal{A}*} = \beta$ or $1 - c$) fails to fully counteract the decline in the unit carbon tax resulting from a moderate τ. When τ becomes sufficiently large (i.e., $\tau > \frac{7}{9}$), its greater effect leads to a significant reduction in the unit carbon tax. Consequently, the government is unable to offset this decline by adjusting κ. Furthermore, a high τ also implies that the supplier can meet the emission baseline with minimal abatement effort, resulting in zero tax revenue for the government. To combat this, rather than setting a higher κ, the government optimally chooses an intermediate-low carbon price (i.e., $\kappa^{\mathcal{A}*} = \kappa_3^{\mathcal{A}}$) to discourage excessive emission abatement and preserve a certain level of tax revenue.

2.5 Comparative Analysis: CBAM vs. CCA

In this section, we compare the equilibrium outcomes under CBAM and CCA to reveal the impact of implementing the specified baseline τ on the system performance. First, we analyze its impact on the equilibrium sourcing strategy. Next, we examine how it affects the preferences of supply chain participants regarding CBAM and CCA, and evaluate whether implementing the specified baseline τ can yield a win-win outcome for both the buyer and the government. Last, we examine the impact of the specified baseline τ on the environment by comparing the technology investment level and the total carbon emissions under CBAM and CCA.

2.5.1 Equilibrium Sourcing Strategy

In this subsection, we compare the buyer's equilibrium sourcing strategy under regime $\mathcal{M}$ and regime $\mathcal{A}$. Recall from Proposition 2.3 that when κ is exogenously given, the buyer's likelihood of sourcing from supplier D increases only when τ is relatively small. Conversely, when the carbon price κ is optimally determined by the government, we can obtain the following:

Corollary 2.1 *Under optimal carbon price, $\bar{c}^{\mathcal{A}}(\beta, \tau) > \bar{c}^{\mathcal{M}}(\beta)$ holds, indicating that sourcing from supplier D is more possible under CCA.*

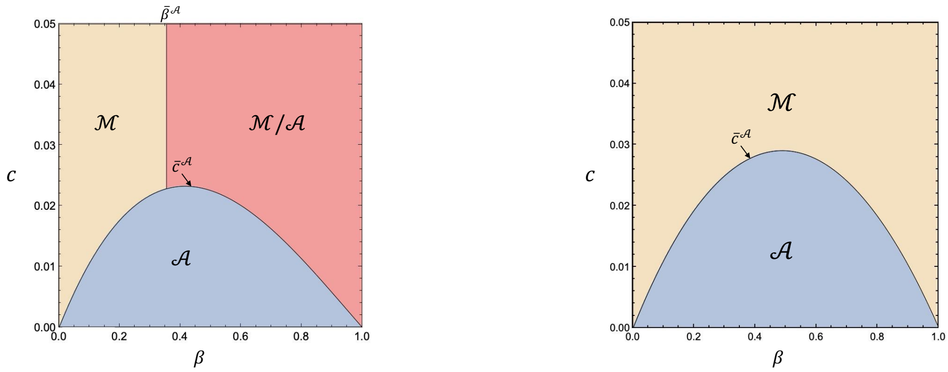
Corollary 2.1 shows that, regardless of the value of τ, the region in which the buyer sources from supplier D expands under CCA compared to that under CBAM. This implies that, when the government can endogenously determine the carbon price κ, the buyer is more likely to source from supplier D under CCA. This stands in contrast to Proposition 2.3, which shows that when κ is exogenously given, only a small τ increases the buyer's likelihood of sourcing from supplier D under CCA relative to CBAM. The underlying intuition is that when τ is large, the government under CCA mitigates the risk of zero tax revenue by lowering the carbon price, thereby discouraging suppliers from reducing their emission intensity to τ. This helps avoid the situation described in Proposition 2.3, where a high τ leads supplier D to reduce its emission intensity to τ before supplier F, making the buyer's profit of sourcing from supplier D independent of τ, while the profit from supplier F continues to increase with it. By discouraging such investment in emission abatement, the government sustains a higher likelihood that the buyer will source from supplier D under CCA than CBAM.

2.5.2 Preference of Supply Chain Stakeholders

By comparing the social welfare of the government and the profit of the buyer and suppliers under regime $\mathcal{M}$ with those under regime $\mathcal{A}$, we can examine how the incorporation of τ influences the supply chain stakeholders' preferences between CBAM and CCA. Our direct comparative analysis of social welfare under the two regimes yields the following corollary.

Corollary 2.2 *There exists thresholds $\bar{\beta}^{\mathcal{A}}(\tau)$, $\bar{c}^{\mathcal{A}}(\beta, \tau)$ and $c_5^{\mathcal{A}}(\tau)$ defined in Table A.1 such that the government prefers CCA if and only if $c \leq \bar{c}^{\mathcal{A}}(\beta, \tau)$, and is indifferent between CCA and CBAM if and only if $\tau \leq \frac{7}{10}$, $\beta > \bar{\beta}^{\mathcal{A}}(\tau)$ and $\bar{c}^{\mathcal{A}}(\beta, \tau) < c \leq c_5^{\mathcal{A}}(\tau)$; otherwise, it prefers CBAM.*

Corollary 2.2 shows that when supplier D's production cost is low (i.e., $c < \bar{c}^{\mathcal{A}}$), implementing a carbon tariff on emissions exceeding τ is advantageous for the government. Two cases underlie this result. First, when the buyer purchases from supplier D under both CBAM and CCA (i.e., $c < \bar{c}^{\mathcal{M}}$), the carbon price imposed



(a) $\tau = 0.4$ (b) $\tau = 0.8$

Figure 2.4: Comparison of Government's Social Welfare Between CBAM and CCA

by the government under CCA is lower than that under CBAM (i.e., $\kappa_1^{\mathcal{A}} < \kappa_1^{\mathcal{M}}$). This occurs because the introduction of τ increases the likelihood that the buyer will choose supplier D, thereby enabling the government to incentivize this choice with a lower carbon price. Consequently, the government is better off under CCA, as the lower carbon price under CCA benefits the buyer, suppliers, and consumers. Second, in the region where the buyer chooses supplier F under CBAM but switches to supplier D under CCA (i.e., $\bar{c}^{\mathcal{M}} < c \leq \bar{c}^{\mathcal{A}}$), the government gains more from CCA. This is because supplier D's low production cost allows it to earn a better profit, which contributes additional revenue to social welfare and further justifies the government's preference for CCA.

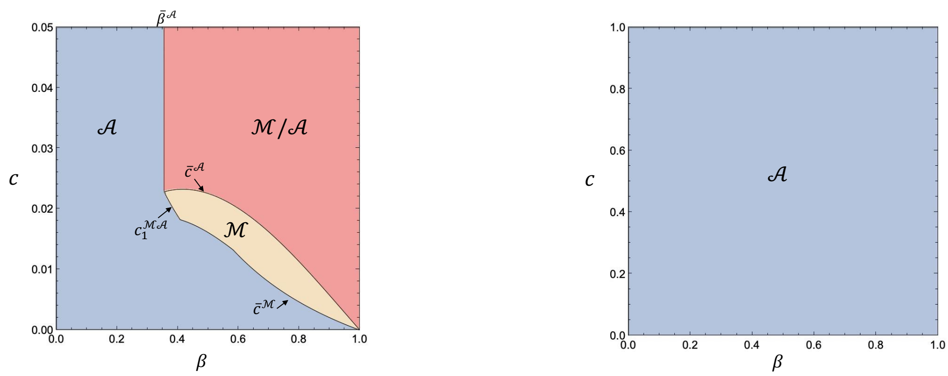
However, as illustrated in Figure 2.4, when τ is small, β is high, and c is moderate, the government finds both CCA and CBAM equally preferable. Note that under this situation, the buyer sources from supplier F under both regimes. Recall from Proposition 2.4 that when τ is small, the government can raise the carbon price under CCA to effectively offset the impact of τ, resulting in the same unit carbon tax as in the case where the specified emission baseline is set to be zero. It is worth pointing out that when $\tau = 0$, the carbon price and emission intensity under CCA are equal to those under CBAM, indicating that CBAM is a special case of CCA with $\tau = 0$. Alternatively, under such a mapping relationship between κ and τ, the unit carbon taxes under CCA and CBAM are equivalent (i.e., $\kappa^{\mathcal{M}*}e^{\mathcal{M}*} = \kappa^{\mathcal{A}*}(\tau)(e^{\mathcal{A}*}(\tau) - \tau)$). Consequently, compared to CBAM, the government sets a higher carbon price under

CCA (i.e., $\kappa_2^{\mathcal{A}} > \kappa_2^{\mathcal{M}}$) to keep the unit carbon tax constant. This enables supplier F to maintain the same wholesale price across the two regimes, leading to identical marginal procurement costs for the buyer. As such, when τ is low, and both β and c are high, the inclusion of τ does not affect the government's social welfare, provided the buyer selects supplier F under both regimes. This indifference implies that CCA and CBAM remain equally viable options for the government.

Finally, the government benefits more from CBAM when its ability to adjust the carbon price under CCA to match the carbon tax level of CBAM is limited. This situation arises when the carbon price is capped under CCA, or when the impact of incorporating τ is significant (i.e., τ is high). Under these situations, the government cannot effectively leverage κ to offset the impact of τ on the unit carbon tax, making CBAM the more favorable option.

Next, we discuss the preferences of the buyer and suppliers by comparing their equilibrium profits under each regime in Corollary 2.3 and 2.4, respectively.

Corollary 2.3 *There exist thresholds $c_1^{\mathcal{MA}}(\beta,\tau)$, $\bar{c}^{\mathcal{M}}(\beta)$, $\bar{c}^{\mathcal{A}}(\beta,\tau)$, $c_5^{\mathcal{A}}(\tau)$, and $\bar{\beta}^{\mathcal{A}}(\tau)$ defined in Table A.1 such that the buyer prefers CBAM if and only if $\tau \leq \frac{7}{10}$, $\beta > \bar{\beta}^{\mathcal{A}}(\tau)$ and $max\{\bar{c}^{\mathcal{M}}(\beta), c_1^{\mathcal{MA}}(\beta,\tau)\} < c \leq \bar{c}^{\mathcal{A}}(\beta,\tau)$, and is indifferent between CBAM and CCA if and only if $\tau \leq \frac{7}{10}$, $\beta > \bar{\beta}^{\mathcal{A}}(\tau)$ and $\bar{c}^{\mathcal{A}}(\beta,\tau) < c \leq c_5^{\mathcal{A}}(\tau)$; otherwise, it prefers CCA.*



(a) $\tau = 0.4$ (b) $\tau = 0.8$

Figure 2.5: Comparison of Buyer's Profits Between CBAM and CCA

Corollary 2.3 shows that incorporating τ in CCA tends to benefit the buyer in most scenarios; see Figure 2.5. This is intuitive because the introduction of τ allows the buyer to benefit from a lower unit carbon tax cost, regardless of the supplier source. Corollary 2.3 also indicates that CCA could be detrimental to the buyer when τ is low, β is high, and c is moderate. This is because when c is moderate (i.e., $\bar{c}^{\mathcal{M}} < c \leq \bar{c}^{\mathcal{A}}$), the buyer's preference shifts from supplier F under CBAM to supplier D under CCA. Consequently, if supplier D has high values of c and β (i.e., $c > c_1^{\mathcal{MA}}$ and $\beta > \beta_2^{\mathcal{A}}$), it adversely affects the buyer under CCA by increasing the marginal procurement cost.

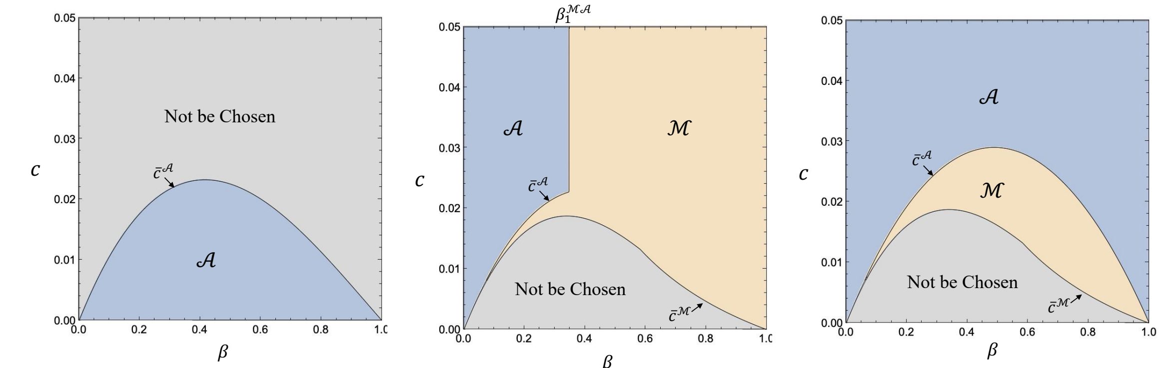
More interestingly, when τ is small, and both β and c are high, the buyer's profits are identical under both CBAM and CCA. Again, in this region, the buyer sources from supplier F under both regimes. To cover the marginal profit loss resulting from the introduction of τ, the government raises the carbon price under CCA relative to CBAM, thereby equalizing the unit carbon tax across regimes. This allows supplier F to maintain the same wholesale price under CBAM and CCA, leaving the buyer's profit unaffected by τ. Thus, the government's adjustment of $\kappa^{\mathcal{A}*}$ under CCA effectively neutralizes any advantages the buyer might have gained from introducing τ.

Corollary 2.4 *Comparing the profit of the foreign supplier and the domestic supplier between CBAM and CCA, there exist thresholds* $\bar{c}^{\mathcal{M}}(\beta)$, $\bar{c}^{\mathcal{A}}(\beta, \tau)$, $\beta_1^{\mathcal{MA}}(\tau)$, *and* $c_2^{\mathcal{MA}}(\tau)$ *defined in Table A.1 such that*

(i) The domestic supplier's profit (=0) under CBAM is equivalent to that under CCA if $c > \bar{c}^{\mathcal{A}}(\beta, \tau)$*; and the domestic supplier is better off under CCA otherwise.*

(ii) The foreign supplier is better off under CBAM if $\bar{c}^{\mathcal{M}}(\beta) < c \leq \bar{c}^{\mathcal{A}}(\beta, \tau)$*, or* $\tau \leq \sqrt{\frac{7}{10}\left(\sqrt{23} - 4\right)}$*,* $\beta > \beta_1^{\mathcal{MA}}(\tau)$*, and* $\bar{c}^{\mathcal{A}}(\beta, \tau) < c \leq c_2^{\mathcal{MA}}(\tau)$*; the foreign supplier's profit (=0) under CBAM is equivalent to that under CCA if* $c \leq \bar{c}^{\mathcal{M}}(\beta)$*; and the foreign supplier is better off under CCA otherwise.*

When considering suppliers F and D, it is intuitive that if a supplier is not chosen under either regime, its profit becomes zero. This is demonstrated in Corollary 2.4(i) for supplier D when c is high (i.e., $c > \bar{c}^{\mathcal{A}}$), and in Corollary 2.4(ii) for supplier F



(a) Domestic Supplier ($\tau = 0.8$) (b) Foreign Supplier ($\tau = 0.4$) (c) Foreign Supplier ($\tau = 0.8$)

Figure 2.6: Comparison of Supplier's Profits Between CBAM and CCA

when c is low (i.e., $c \leq \bar{c}^{\mathcal{M}}$). Corollary 2.4(i) and Figure 2.6(a) also indicate that when c is low (i.e., $c \leq \bar{c}^{\mathcal{A}}$), CCA is more beneficial for supplier D compared to CBAM. This is because imposing a carbon tariff only on the portion of emission intensity exceeding the threshold τ induces the government to lower the carbon price when the buyer selects supplier D, which directly benefits supplier D by decreasing its unit carbon tax.

Unlike supplier D, Corollary 2.4(ii) shows that supplier F may suffer from the introduction of the baseline under CCA, depending on the magnitude of τ as well as the characteristics of supplier D in terms of the investment coefficient β and the production cost c. Specifically, when c is moderate (i.e., $\bar{c}^{\mathcal{M}} < c \leq \bar{c}^{\mathcal{A}}$), the buyer's preference switches from supplier F under CBAM to supplier D under CCA, as illustrated in Figure 2.6(b)(c). Consequently, supplier F suffers from a loss of profit under CCA due to not being chosen by the buyer. When τ is low, and both β and c are high (i.e., $\tau \leq \sqrt{\frac{7}{10}\left(\sqrt{23}-4\right)}$, $\beta > \beta_1^{\mathcal{MA}}(\tau)$, and $\bar{c}^{\mathcal{A}}(\beta,\tau) < c \leq c_2^{\mathcal{MA}}(\tau)$), the buyer sources from supplier F under both regimes, as shown in Figure 2.6(b). In this case, recall that the government charges a higher carbon price under CCA compared to CBAM. This enables both the government and the buyer to maintain the same profits under CCA as under CBAM, but it hurts supplier F, as it requires more investment in emission abatement. However, when the government cannot effectively use the carbon price to mitigate the impact of τ, particularly when the carbon price is capped, or when τ is high, supplier F may benefit from CCA. In such a case, the presence of τ allows supplier F to enjoy both a higher profit margin and strong demand. Overall, while incorporating τ tends to be more beneficial for supplier D, it can be detrimental to supplier F in certain situations.

Combining the preferences of the government and the buyer, we can further investigate whether incentive alignment between these two parties can be achieved, as characterized in Corollary 2.5.

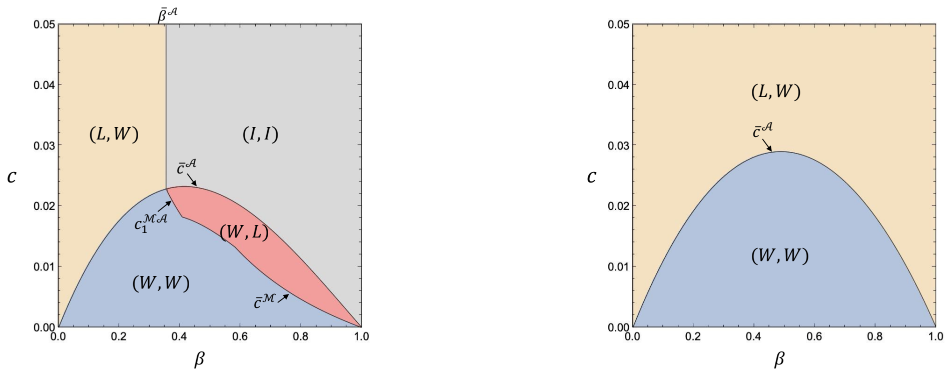
Corollary 2.5 *Compared with CBAM, CCA can lead to:*

(i) A win-win outcome when either $\tau \leq \frac{7}{10}$ *and* $c \leq min\{\bar{c}^{\mathcal{A}}(\beta,\tau), max\{\bar{c}^{\mathcal{M}}(\beta), \bar{c}_1^{\mathcal{MA}}(\beta,\tau)\}\}$, *or* $\tau > \frac{7}{10}$ *and* $c \leq \bar{c}^{\mathcal{A}}(\beta,\tau)$.

(ii) A win-loss outcome when $\tau \leq \frac{7}{10}$, $\beta > \bar{\beta}^{\mathcal{A}}(\tau)$ *and* $max\{\bar{c}^{\mathcal{M}}(\beta), c_1^{\mathcal{MA}}(\beta,\tau)\} < c \leq \bar{c}^{\mathcal{A}}(\beta,\tau)$.

(iii) An indifferent-indifferent outcome when $\tau \leq \frac{7}{10}$, $\beta > \bar{\beta}^{\mathcal{A}}(\tau)$ *and* $\bar{c}^{\mathcal{A}}(\beta,\tau) < c \leq c_5^{\mathcal{A}}(\tau)$.

(iv) A loss-win outcome otherwise.



(a) $\tau = 0.4$ (b) $\tau = 0.8$

Figure 2.7: Impact of CCA on the Government and Buyer

Note: In the above figure, (W,W), (W,L), (L,W), and (I,I) represent the win-win, win-lose, lose-win, and indifferent-indifferent outcomes for the government and buyer, respectively.

Corollary 2.5 indicates CCA can benefit either the government, the buyer, or both parties, depending on the characteristics of supplier D, e.g., the investment cost coefficient (β) and the production cost (c), as illustrated in Figure 2.7. Specifically, when

c is low, incorporating τ results in a win-win outcome for both the government and the buyer. In this scenario, the buyer sources from supplier D under both regimes, and the government sets a lower carbon price under CCA compared to CBAM. This benefits both the buyer and the government, as the government's social welfare is more closely tied to the profits of supply chain participants, including the buyer, suppliers, and consumers, all of whom benefit from a lower carbon price. However, when τ is low and β is high, the introduction of τ induces the buyer to switch its sourcing strategy from supplier F to supplier D if c is moderate. This shift creates a divergence in outcomes between the two parties; that is, while the government gains from the additional revenue generated by supplier D's profits, the buyer faces higher procurement costs due to supplier D's higher unit cost c. In contrast to this result, when c is relatively high, the influence of τ is mitigated by endogenous adjustments in the carbon price. As a result, both the government and the buyer remain indifferent between regime $\mathcal{M}$ and regime $\mathcal{A}$. In other scenarios, where the government's ability to adjust the carbon price is constrained, CCA is detrimental to the government but beneficial to the buyer, leading to a not-surprisingly lose-win outcome.

2.5.3 Impact on Carbon Emissions

In this subsection, we compare the supplier's optimal technology investment level and total carbon emissions under regime $\mathcal{M}$ and regime $\mathcal{A}$. Then, we can obtain the following:

Corollary 2.6 *Comparing the supplier's technology investment level and total carbon emissions under CBAM and CCA, the following statements hold:*

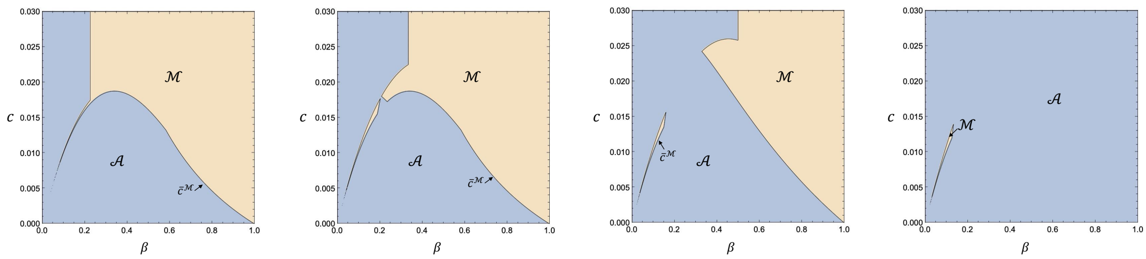
(i) The supplier's technology investment level under CCA is always higher than that under CBAM.

(ii) It is possible that the total carbon emissions under CCA are higher than those under CBAM.

Corollary 2.6(i) indicates CCA always performs better than CBAM in encouraging the supplier's investment in emission abatement. Specifically, when c is low (i.e.,

$c \leq \bar{c}^{\mathcal{M}}(\beta)$), the buyer purchases from supplier D regardless of the regime. In this case, supplier D benefits from the lower carbon price set by the government under CCA relative to CBAM. Although the lower carbon price diminishes supplier D's incentive to invest in emission abatement, the introduction of τ provides an additional incentive for investment. When c is intermediate (i.e., $\bar{c}^{\mathcal{M}}(\beta) < c \leq \bar{c}^{\mathcal{A}}(\beta, \tau)$), the buyer switches from supplier F under CBAM to supplier D under CCA. Consequently, supplier D enhances its investment in abatement efforts due to lower production costs. When both c and β are large (i.e., $\beta > \bar{\beta}^{\mathcal{A}}(\tau)$ and $\bar{c}^{\mathcal{A}}(\beta, \tau) < c \leq c_5^{\mathcal{A}}(\tau)$), the buyer sources from supplier F under both regimes. To maintain consistent carbon tax revenue under CCA compared to CBAM, the government increases the carbon price. This compels supplier F to enhance its investment in carbon abatement. In other cases, although the carbon price reaches the upper bound and remains the same under both regimes, the introduction of τ under CCA incentivizes supplier F to engage in emission reduction activities.

Nevertheless, although suppliers enhance their investment in carbon abatement under CCA compared to CBAM, Corollary 2.6(ii) further indicates that total carbon emissions may not necessarily decrease under CCA, as illustrated in Figure 2.8. This is because total carbon emissions are contingent upon both the level of technology investment and market demand. Here, three distinct regions are worth taking into account. First, when c is low (i.e., $c \leq \bar{c}^{\mathcal{M}}(\beta)$), the buyer sources from supplier D under both regimes. Although introducing τ strengthens supplier D's incentive to invest, the lower carbon price under CCA stimulates demand, leading to higher total emissions under CCA compared to CBAM. Second, when c is intermediate (i.e., $\bar{c}^{\mathcal{M}}(\beta) < c \leq \bar{c}^{\mathcal{A}}(\beta, \tau)$), the buyer transitions from relying on supplier F under CBAM to supplier D under CCA. Within this regime $\mathcal{A}$, a low c and β can enhance the emission abatement efforts of supplier D, whereas a high c and β tend to diminish demand, both contributing to a reduction in total carbon emissions. Conversely, when c and β are moderate, insufficient abatement combined with a not small demand leads to an increase in total emissions when the buyer sources from supplier D. Third, when the carbon price reaches its upper bound, the introduction of τ incentivizes the supplier to invest more in emission abatement. However, this also reduces the unit carbon tax, which in turn encourages consumers to increase their purchases. Consequently, the heightened demand leads to greater carbon emissions.



(a) $\tau = 0.1$ (b) $\tau = 0.4$ (c) $\tau = 0.6$ (d) $\tau = 0.8$

Figure 2.8: Comparison of The Total Carbon Emission Between CBAM and CCA

Note: Here, regime $\mathcal{M}$ or $\mathcal{A}$ refers to cases in which total carbon emissions are higher.

2.6 Extensions

In this section, we extend our baseline model to explore two key issues. First, we examine how the government's heightened concern regarding carbon emissions may influence its determination of carbon pricing, and how this, in turn, affects the buyer's sourcing strategy as well as the supply chain stakeholders' preferences for CBAM and CCA. Second, we incorporate consumer concern for carbon emissions to analyze how consumers' environmental awareness impacts both the buyer's sourcing strategy and the government's carbon pricing decision under CBAM.

2.6.1 Impact of Government's Concern on Carbon Emissions

So far, we have focused on the extreme case where the government exhibits no concern for carbon emissions, i.e., $\lambda = 0$. In this section, we address the situation where the government's concern, denoted by λ, is positive. Notably, the weight λ does not influence the equilibrium outcomes for any given carbon price, thereby ensuring that Lemmas 2.1 and 2.2, Propositions 2.1 and 2.3 continue to hold. However, it is worth noting that this weight impacts the government's carbon price decision via its effect on the social welfare function (2.7) only when the buyer is incentivized to source from supplier D, i.e., when c is small. Thus, to avoid repetitive analysis, our subsequent analysis will focus exclusively on the impact of the weight λ in the context of sourcing from supplier D. We begin by considering the case of $\lambda \to \infty$ and obtain the following:

Proposition 2.5 *When the weight assigned to the total carbon emission λ is sufficiently high (i.e., $\lambda \to \infty$), the following statements hold:*

(i) The government's optimal carbon price, which incentivizes the buyer to source from supplier D, is set at the upper bound, regardless of CBAM or CCA.

(ii) The buyer always sources from supplier F, regardless of CBAM or CCA.

(iii) The government prefers CBAM, while the buyer and supplier F prefer CCA.

Proposition 2.5(i) shows that when the government places substantial emphasis on carbon emissions, it will charge a sufficiently high carbon price to incentivize supplier D to increase investment in emission abatement. This outcome is a natural consequence of Lemma 2.1, which states that a higher carbon price would hurt all the supply chain players. It also leads to the result in Proposition 2.5(ii), indicating that when the government places significant concerns on the environment, the buyer consistently prefers supplier F. This is because the buyer benefits from selecting supplier F, who faces a lower carbon price and has lower production costs compared to supplier D.

This dynamic further influences the preference of supply chain participants regarding the two regimes. That is, when the government exhibits heightened concern for environmental issues, it creates a divergence in incentives between the government and firms, as shown in Proposition 2.5(iii). Specifically, the government favors CBAM, whereas both the buyer and supplier F prefer CCA. This contrasts with the scenario in which the government is not concerned about environmental issues, where it tends to prefer CCA over CBAM. The primary reason for this difference is that the government's focus on environmental concerns leads to a shift in the buyer's sourcing strategy. Specifically, when the government has no environmental concerns, the buyer prefers supplier D under both regimes. However, when the government places significant emphasis on environmental protection, the buyer tends to select supplier F under both CBAM and CCA. In this latter case, the carbon tax revenue becomes crucial for the government. However, the introduction of τ under CCA reduces carbon tax revenue, making it less beneficial for social welfare compared to CBAM. Conversely, for both the buyer and supplier F, incorporating τ decreases the unit carbon tax cost across the supply chain, thereby reducing the purchasing cost for consumers and stimulating demand. Consequently, both the buyer and supplier F prefer CCA over CBAM. Next, we turn to the case of $\lambda \to 0$ and obtain the following proposition.

Proposition 2.6 *When the investment cost coefficient β is high but the weight assigned to the total carbon emission λ is sufficiently small (i.e., $\lambda \to 0$), the following statements hold:*

(i) The government's optimal carbon price, which incentivizes the buyer to source from supplier D, is equivalent to the carbon price set in the absence of λ.

(ii) The buyer is more likely to source from supplier F compared to the scenario in the absence of λ, regardless of CBAM or CCA.

(iii) In the region where the buyer sources from supplier D under both CBAM and CCA, the preferences of supply chain players are identical to those obtained under an environmentally indifferent government.

Unlike the straightforward result of $\lambda \to \infty$ presented in Proposition 2.5(i), the case of $\lambda \to 0$ in Proposition 2.6(i) is more nuanced. Specifically, the introduction of λ does not affect the equilibrium carbon price that induces the buyer to source from supplier D. To explain this, we make two observations. First, as highlighted in Propositions 2.2 and 2.4, when the buyer is incentivized to source from supplier D, the government's social welfare becomes more sensitive to the profits of supply chain participants, all of whom prefer a lower carbon price. Second, while a higher carbon price enables suppliers to reduce carbon emissions, the impact on the government's social welfare is insignificant due to a high β and a low λ. These two observations lead to a boundary solution where the government imposes the lowest feasible carbon price, which remains unaffected by λ.

Proposition 2.6(ii) shows that compared to the case of $\lambda = 0$, the likelihood that the buyer sources from supplier D decreases. The finding reveals that the government's emphasis on environmental protection tends to steer the buyer toward foreign suppliers instead of domestic ones. This is because although the optimal carbon price that induces the buyer to source from supplier D is not influenced by λ, the government's social welfare is negatively impacted by total carbon emissions. As such, the government sets a lower carbon price to encourage the buyer to source from supplier F and reduces the buyer's reliance on supplier D, especially when its production cost is high. Consequently, under both regimes, the area in which the buyer purchases from supplier D shrinks.

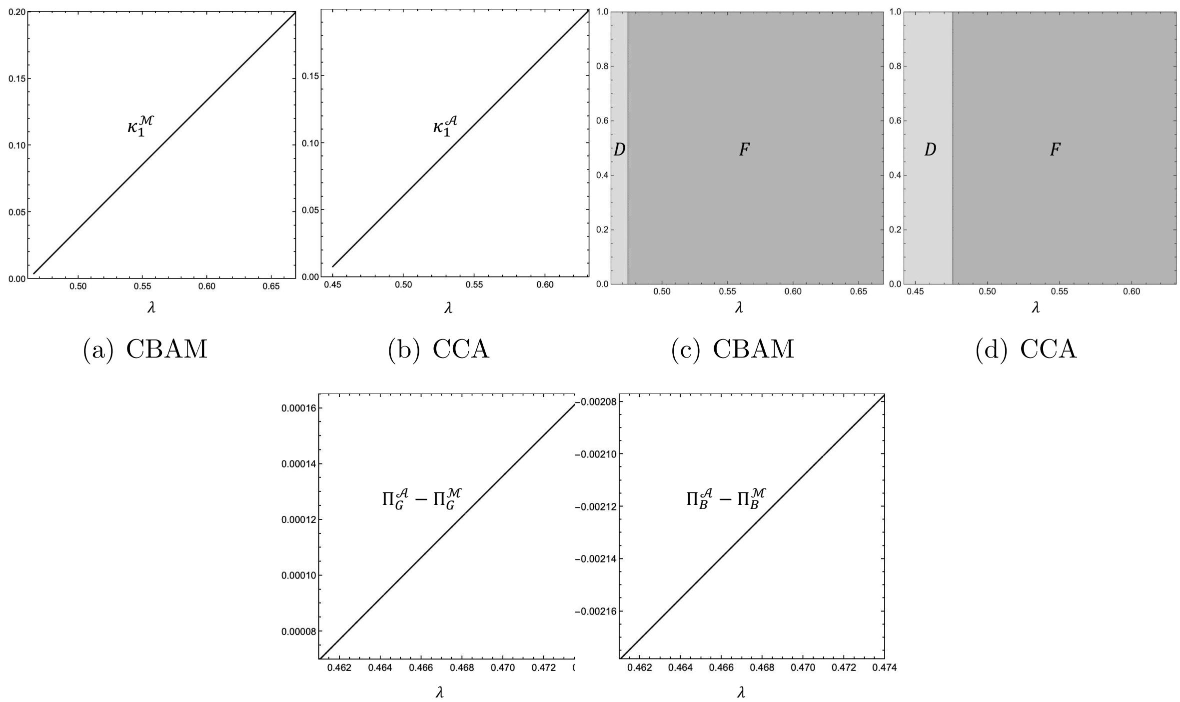
Proposition 2.6(iii) demonstrates that when supplier D remains the buyer's preferred choice under both regulatory regimes, the preferences of supply chain participants mirror those observed in a context where the government exhibits environmental indifference. For the firms involved, the carbon price is independent of λ, indicating that the government's level of environmental concern does not influence the preferences of either the buyer or supplier D with respect to CBAM and CCA. Likewise, for the government, the effect of λ is negligible, resulting in a regime preference that remains consistent with that in the environmentally indifferent scenario.

Up to now, we have analyzed the two extreme cases, namely, $\lambda \to \infty$ and $\lambda \to 0$, to examine the impact of the government's environmental concern λ on the equilibrium outcome and comparative results. However, when λ takes an intermediate value, the analysis becomes intractable due to its complex effects on the government's social welfare given in (2.7). Therefore, we resort to numerical studies to investigate how the government's environmental concern λ influences the equilibrium outcome and the comparative results outlined in Propositions 2.5 and 2.6. In our numerical studies, we vary the parameters c and β from 0.1 to 0.9 with a step length of 0.2. Similarly, for the specific baseline τ, we also vary it from 0.1 to 0.9 with the same step size, as the carbon emission intensity differs significantly across industries. For instance, sectors such as steel and food and beverage manufacturing are characterized by high carbon emission intensity, whereas industries like computers, electronic equipment, and textiles exhibit relatively lower carbon emissions.

We observe that the effects of λ on the previous analytical outcomes are similar by analyzing various combinations of these parameter values. Here is a sample of our results. For instance, examine the scenario when $c = 0.01$, $\beta = 0.2$, and $\tau = 0.1$. The numerical outcomes are illustrated in Figure 2.9. First, recall that under both CBAM and CCA, the optimal carbon price set by the government for supplier D reaches its maximum as $\lambda \to \infty$, and its minimum as $\lambda \to 0$. Here, when λ takes an intermediate value, the optimal carbon price also assumes an intermediate level. As illustrated in Figure 2.9(a) and (b), a greater emphasis on environmental concerns prompts the government to impose a higher carbon price to reduce total carbon emissions. Second, regardless of the regime adopted, the buyer is inclined to purchase from supplier D only when λ is relatively small, as shown in Figure 2.9(c) and (d). Moreover, similar to the scenario in which the government is indifferent to environmental issues (see Corollary 2.1), CCA increases the likelihood that the buyer will source from supplier D.

Third, Figures 2.9(e) and (f) demonstrate that when the government is concerned with the environment, and the buyer sources from supplier D under both CBAM and CCA, the government tends to prefer CCA, whereas the buyer shows a stronger preference for CBAM. This stands in contrast to the scenario where the government is indifferent to environmental issues, in which case both the government and the buyer prefer CCA. The underlying reason may be that introducing τ under CCA increases the total carbon emissions, which negatively impacts social welfare for a government that prioritizes environmental protection. To mitigate this adverse effect, the government imposes a higher carbon price under CCA than CBAM, thereby reducing total carbon emissions. While this approach benefits the government, it is detrimental to the buyer. Furthermore, Figure 2.9(e) and (f) also indicate that as λ increases, the government's preference for CCA becomes more pronounced, while the buyer's preference for CBAM diminishes. This is because, as the government cares more about the environment, the impact of λ on total carbon emissions becomes increasingly significant, whereas the effect of τ becomes relatively negligible.

Alternatively, although introducing τ leads the government to impose a higher carbon price under CCA than under CBAM, this difference gradually diminishes as λ increases. Such a trend benefits supply chain players, including the buyer, supplier D, and consumers. Therefore, whether it is the government that values supplier D's profits and consumer welfare, or the domestic buyer, their preference for the CCA becomes increasingly strong as the government places greater emphasis on environmental concerns.



(a) CBAM (b) CCA (c) CBAM (d) CCA

(e) (f)

Figure 2.9: Impact of Government's Environmental Concern

2.6.2 Impact of the Consumers' Concern on Carbon Emissions

In the basic model, consumer environmental consciousness is not taken into account. Nonetheless, in practice, consumers are becoming increasingly environmentally conscious (Cohen and Munoz 2017). A survey conducted by the Carbon Trust in 2020 revealed that 23% of consumers pay attention to GHG emissions when purchasing products (CarbonTrust 2020). Consumers are willing to pay a premium for low-carbon products, incentivizing firms to proactively work on carbon emission reduction (Lanz et al. 2018, Schwirplies et al. 2019). Thus, it is also reasonable to consider that consumers are environmentally conscious and care about the product's carbon emissions. Their intention to buy is negatively affected by the product's carbon emissions. Specifically, the consumer's utility from consuming the product sourced from supplier i can be written as $u = v - \gamma e_i - p_i, i \in \{D, F\}$, where $\gamma(> 0)$ measures the degree of consumers' environmental concern. Naturally, a larger γ implies consumers are more concerned about the environment. All other settings remain consistent with those in the baseline model.[4] For ease of notation, we use the superscript "^" to denote the equilibrium outcomes when consumers care about carbon emissions and the carbon price κ is given, which are presented in Table 2.4. The following proposition presents the equilibrium sourcing strategy under CBAM.[5]

Table 2.4: Equilibrium Outcomes Under CBAM for a Given Carbon Price κ When Consumers Concern About Carbon Emissions

Supplier F	$\hat{e}_F^{\mathcal{M}} = \frac{8-(\kappa+\gamma)}{8-(\kappa+\gamma)^2}$	$\hat{w}_F^{\mathcal{M}} = \frac{4(1-(\kappa+\gamma))}{8-(\kappa+\gamma)^2}$	$\hat{q}_F^{\mathcal{M}} = \frac{2(1-(\kappa+\gamma))}{8-(\kappa+\gamma)^2}$
	$\hat{p}_F^{\mathcal{M}} = \frac{2(\kappa+\gamma)-(\kappa+\gamma)^2+6}{8-(\kappa+\gamma)^2}$	$\hat{\pi}_F^{\mathcal{M}} = \frac{(1-(\kappa+\gamma))^2}{8-(\kappa+\gamma)^2}$	$\hat{\Pi}_B^{\mathcal{M}} = \frac{4(1-(\kappa+\gamma))^2}{(8-(\kappa+\gamma)^2)^2}$
	$\hat{U}_F^{\mathcal{M}} = \frac{2(1-(\kappa+\gamma))^2}{\left(8-(\kappa+\gamma)^2\right)^2}$	$\hat{C}_F^{\mathcal{M}} = \frac{2(8-(\kappa+\gamma))(1-(\kappa+\gamma))}{\left(8-(\kappa+\gamma)^2\right)^2}$	$\hat{T}_F^{\mathcal{M}} = \frac{2\kappa(8-(\kappa+\gamma))(1-(\kappa+\gamma))}{\left(8-(\kappa+\gamma)^2\right)^2}$
Supplier D	$\hat{e}_D^{\mathcal{M}} = \frac{8\beta-(1-c)(\kappa+\gamma)}{8\beta-(\kappa+\gamma)^2}$	$\hat{w}_D^{\mathcal{M}} = \frac{4\beta(1+c)+4\beta(\kappa+\gamma)-(\kappa+\gamma)^2}{8\beta-(\kappa+\gamma)^2}$	$\hat{q}_D^{\mathcal{M}} = \frac{2\beta(1-c-(\kappa+\gamma))}{8\beta-(\kappa+\gamma)^2}$
	$\hat{p}_D^{\mathcal{M}} = \frac{2\beta(\kappa+\gamma)+2\beta(c+3)-(\kappa+\gamma)(c+(\kappa+\gamma))}{8\beta-(\kappa+\gamma)^2}$	$\hat{\pi}_D^{\mathcal{M}} = \frac{\beta(1-c-(\kappa+\gamma))^2}{8\beta-(\kappa+\gamma)^2}$	$\hat{\Pi}_B^{\mathcal{M}} = \frac{4\beta^2(1-c-(\kappa+\gamma))^2}{(8\beta-(\kappa+\gamma)^2)^2}$
	$\hat{U}_D^{\mathcal{M}} = \frac{2\beta^2(1-c-(\kappa+\gamma))^2}{(8\beta-(\kappa+\gamma)^2)^2}$	$\hat{C}_D^{\mathcal{M}} = \frac{2\beta(1-c-(\kappa+\gamma))(8\beta-(1-c)(\kappa+\gamma))}{\left(8\beta-(\kappa+\gamma)^2\right)^2}$	$\hat{T}_D^{\mathcal{M}} = \frac{2\beta\kappa(1-c-(\kappa+\gamma))(8\beta-(1-c)(\kappa+\gamma))}{\left(8\beta-(\kappa+\gamma)^2\right)^2}$

Proposition 2.7 *Under CBAM, when consumers care about carbon emissions, let $c_{\gamma 1}^{\mathcal{M}}(\beta, \kappa, \gamma)$ and $\kappa_{\gamma 1}^{\mathcal{M}}(\gamma)$ be thresholds defined in Table A.1. Given the carbon price κ, it is optimal for the buyer to source from a domestic supplier if and only if $c \leq c_{\gamma 1}^{\mathcal{M}}(\beta, \kappa, \gamma)$. Moreover, $c_{\gamma 1}^{\mathcal{M}}(\beta, \kappa, \gamma) > c_1^{\mathcal{M}}(\beta, \kappa)$ if $\kappa < \kappa_{\gamma 1}^{\mathcal{M}}(\gamma)$, implying that the buyer is more likely to source from a domestic supplier when consumers are concerned about carbon emissions than when they are not.*

Proposition 2.7 demonstrates that, under a low carbon price, the likelihood of the buyer sourcing from the domestic supplier increases when consumers care about

[4] Again, to avoid the trivial case where the firm is willing to invest in completely eliminating carbon emissions, we assume that $\kappa + \gamma < \beta < 1$ and $c < 1 - (\kappa + \gamma)$.

[5] Since the impact of consumers' environmental concern on supply chain performance is similar under both CBAM and CCA, we focus on CBAM as a representative case in our analysis.

carbon emissions, compared to when they do not. It is worth noting that the difference in equilibrium outcomes shown in Table 2.4 between $\gamma = 0$ and $\gamma > 0$ is that the term $\gamma + \kappa$ replaces κ in most expressions, except for the total carbon tax. This is because both the consumer's environmental concern γ and the carbon price κ essentially affect demand. In other words, the effect of consumers' environmental concern γ can be interpreted as an increase in the carbon price κ. Recall from Proposition 2.1 that when c is in an intermediate range and β is large, as κ increases, the buyer's sourcing preferences first shift from the foreign supplier to the domestic supplier, and then back to the foreign supplier. Therefore, consumers' concern for the environment increases the buyer's likelihood of purchasing from the domestic supplier when κ is relatively small. However, as κ becomes larger, the buyer tends to prefer the foreign supplier again, so the likelihood of purchasing from the domestic supplier decreases. In the following proposition, we examine the impact of consumers' environmental awareness on the equilibrium carbon price as well as the performance of supply chain members.

Proposition 2.8 *When consumers are environmentally concerned, under CBAM, there exist a threshold $\bar{c}^{\mathcal{M}}_{\gamma}(\beta, \gamma)$ defined in Table A.1 such that, in equilibrium, the optimal carbon price $\hat{\kappa}^{\mathcal{M}*}$ provided by the government satisfies:*[6]

$$\hat{\kappa}^{\mathcal{M}*} = \begin{cases} \kappa^{\mathcal{M}}_{\gamma 1}, & \text{if } c \leq \bar{c}^{\mathcal{M}}_{\gamma}(\beta, \gamma), \\ \kappa^{\mathcal{M}}_{\gamma 2}, & \text{Otherwise}. \end{cases} \tag{2.10}$$

Proposition 2.8 indicates that, compared to the case where consumers do not care about carbon emission, increased consumer environmental awareness induces the government to set a lower carbon price, irrespective of whether the domestic or foreign supplier is selected (i.e., $\kappa^{\mathcal{M}}_{\gamma 1} < \kappa^{\mathcal{M}}_{1}$ and $\kappa^{\mathcal{M}}_{\gamma 2} < 5 - \sqrt{23}$). Recall from Proposition 2.7 that consumers' environmental concern γ can be interpreted as an increase in the carbon price κ. Consequently, the government sets a lower carbon price to offset the impact of γ when consumers are environmentally conscious. The subsequent corollary contrasts the government's social welfare and the buyer's profit

[6] It is worth noting that our comparison does not include cases where the optimal carbon price is a boundary solution (i.e., $\beta - \gamma$ or $1 - c - \gamma$ (β or $1 - c$) when consumers care (do not care) about carbon emission.

between cases in which consumers exhibit environmental concern and those in which they do not.

Corollary 2.7 *Compared to the case where consumers have no concerns about carbon emissions, the following statements hold:*

(i) The government's welfare is strictly lower when consumers exhibit concern for carbon emissions, and it decreases with the degree of consumer concern γ*.*

(ii) The buyer is indifferent between the two cases if $c \leq \bar{c}_{\gamma}^{\mathcal{M}}(\beta, \gamma)$*; otherwise, the buyer's profit is strictly lower, and it decreases with the degree of consumer concern* γ*.*

Corollary 2.7 further shows that increased consumer environmental concern could backfire, adversely affecting the government, the buyer sourcing from the foreign supplier (i.e., $c > \bar{c}_{\gamma}^{\mathcal{M}}$), while leaving the buyer sourcing from the domestic supplier unaffected (i.e., $c \leq \bar{c}_{\gamma}^{\mathcal{M}}$). Moreover, in cases where the government or buyer is worse off, their welfare or profit declines as consumers care more about carbon emissions. Intuitively, higher carbon emissions from suppliers diminish the purchasing willingness of environmentally conscious consumers, thereby leading to a decrease in demand. This demand reduction naturally hurts the government, and the buyer sourcing from a foreign supplier. However, the profit of the buyer purchasing from the domestic supplier remains unaffected. This is because the government can fully offset the impact of γ for the buyer sourcing from a domestic supplier by lowering the carbon price, but cannot do so for the buyer sourcing from a foreign supplier. Specifically, when the buyer sources from a foreign supplier, the government's social welfare is mainly influenced by carbon tax revenue, where κ cannot be replaced by $\gamma + \kappa$. However, when the buyer purchases from the domestic supplier, carbon tax revenue does not affect the government's carbon pricing, as the government prioritizes the profits of supply chain members and always chooses the lowest carbon price. Therefore, for the buyer, the impact of increased consumer environmental concern is fully offset by the government's lower carbon price.

2.7 Conclusions

To explore the effectiveness of different carbon border tax regulations, namely, CBAM and CCA, we characterize the optimal levels of technology investment, wholesale pricing, carbon pricing decisions, and the corresponding performance metrics (i.e., expected profit, social welfare, and the amount of carbon emissions) related to both CBAM and CCA. Although both regulations aim to enhance domestic sourcing and reduce carbon emissions, they differ subtly in their mechanisms. That is, the introduction of a specified baseline under CCA serves as a subsidy to mitigate the effects of the carbon price. This nuanced distinction leads to both similarities and differences in the results observed under these two carbon border tax regulations.

First, we find that CCA is more effective than CBAM in encouraging the buyer to source from the domestic supplier. By redirecting demand to local producers, CCA helps sustain and create domestic employment opportunities, particularly in carbon-intensive sectors vulnerable to foreign competition. Second, our analysis reveals that when the domestic supplier's production cost is low, CCA can generate a win-win situation for both the government and the buyer compared to CBAM, thereby enhancing both profit and welfare. Moreover, when the specified baseline is low, the domestic supplier's investment cost coefficient is high, and its production cost is intermediate, CCA can lead to an indifference-indifference outcome for both parties, resulting in identical levels of profit and welfare. Lastly, CCA is always more effective than CCA in incentivizing emission abatement; however, total carbon emissions under CCA are not necessarily lower.

Our findings offer a cautionary message to regulators regarding the design and implementation of carbon border adjustment mechanisms. The results underscore the need for policymakers to conduct a thorough examination of market characteristics, including industry-specific emission baselines, as well as the technological investments and production capacities of domestic suppliers. Such careful consideration is crucial for achieving both environmental effectiveness and economic viability in regulatory efforts.

Chapter 3

Impact of International Commercial Terms on Global Sourcing Strategies

3.1 Introduction

Over the past twenty years, global supply chains have experienced significant expansion, driven largely by free trade agreements (FTAs) and the gradual removal of international trade barriers (Dong and Kouvelis 2020). According to the Office of the United States Trade Representative, the U.S. has signed 14 FTAs with a total of 20 countries. In addition, more than 100 nations, including Brazil, Myanmar, and Cambodia, benefit from zero tariffs under the Generalized System of Preferences (GSP 2020). Similarly, the EU-Vietnam Free Trade Agreement removes tariffs on 99% of traded goods between the European Union and Vietnam (European Commission 2020). Despite such liberalization, recent years have seen a rise in trade tensions among major global manufacturing powers. Countries like China (28.7% of global manufacturing output), the United States (16.8%), and the European Union (9%) have increasingly become targets of retaliatory tariffs. For example, in 2018, the United States imposed Section 232 tariffs of 25% on steel and 10% on aluminum from the EU, prompting immediate retaliatory actions. By May 2025, the escalation of the US-China trade conflict had led the United States to impose a combined tariff rate of 30% on imports from China, while China responded by levying a 10% duty on goods originating from the United States as a countermeasure (Lim and Kiderlin 2025). These developments imply that firms sourcing from countries facing trade barriers with their home market, while selling to domestic customers, may incur significant costs due to high import tariffs. For example, a 10% tariff rate implies that a product valued at $10 would incur an additional $1 in tariffs, which inevitably increases the total cost of the transaction (Clarke 2025).

Naturally, sourcing exclusively from suppliers located in free trade areas can help mitigate the tariff costs. Following the initial rounds of increasing tariffs by the Trump administration in 2018 and 2019, many small and medium-sized enterprises (SMEs) were among the most proactive in adapting their sourcing strategies. For example, Lay-n-Go, a small business specializing in cosmetic bags and drawstring carriers, shifted all production from manufacturers in China to those in Cambodia, which requires the development of an entirely new supply chain (Peck 2025). In a similar vein, Sarah Wells, the founder of a designer bag company, began relocating the production of her bags from China to a new manufacturer in Phnom Penh in February 2025, as Cambodia's 10% tariff rate presented a significantly more favorable alternative to the 145%, and later 30%, tariff rates imposed on goods imported from China (Yurkevich 2025).

However, such a sourcing strategy is subject to a rising number of supply-related issues. Primarily, political unrest and labor strikes contribute to higher supply risks and potential shortages. For example, in 2019, 30,000 workers in more than 70 (out of the 115) export-manufacturing firms located along the Mexican border went on strike (Montes 2019). Second, the inadequate infrastructure in the supply chain has endangered supply stability. Take power shortages as an example. In June 2023, heatwaves and droughts in Vietnam caused surges in electricity demand, leading to repeated power outages and the subsequent production disruption among factories in northern industrial zones (Thanh et al. 2023). To mitigate such negative impact of supply chain risks, supplier diversification such as sourcing from suppliers both within and outside the free trade areas has been adopted in spite of the cost of tariffs. For example, Anna Griffin, who operates a small business in Atlanta, has shifted some production to a factory in Malaysia following the Trump administration's imposition of steep tariffs on Chinese goods in 2025. Nevertheless, the majority of her manufacturing remains with suppliers in China (Jeyaretnam 2025). In another example, Kim Vaccarella, CEO and founder of Bogg Bag—a company specializing in perforated plastic bags—reported that, in response to the impact of high tariffs, she and her team visited factories in Vietnam and Sri Lanka in January 2025 to seek new suppliers and reduce Bogg Bag's production scale in China (Smith 2025).

In the present global trade environment, suppliers operating within free trade areas are exempt from tariffs, while those outside these areas incur significant tariff costs. In the meantime, cross-border procurement is often associated with high freight charges, particularly for SMEs, which incur much higher freight costs than larger firms, which are better equipped to manage fluctuations, according to Peter Sand, chief analyst at Xeneta, the world's largest ocean and air freight rate analytics platform (Jeyaretnam 2025). For instance, in 2022, freight charges accounted for as much as 19% of the total import value of furniture and 17% for large household appliances (Puri and Shrosbree 2025). Recently, freight costs surged by 572% over 19 months during the COVID-19 pandemic and by 250% over the first seven months of 2024 due to disruptions in the Suez and Panama canals (Shen and Stein 2024). Overall, both tariffs and freight charges can each account for approximately 10%∼30% of the total value of imported goods. According to Detwal et al. (2023), freight cost is one of the two most critical factors influencing the selection of vendor International Commercial Terms (Incoterms) during the shipment of pharmaceutical goods.

The rules of Incoterms determine the allocation of responsibilities between a buyer and a supplier concerning the freight charges and tariff in the foreign trade contract (Lloyds Bank 2023). The commonly adopted ones are the following three trade contracts specified by Incoterms: (1) Ex-Works (EXW), in which the buyer bears both the tariff and freight charge, (2) Delivered-at-Place (DAP), in which the buyer bears the tariff while the supplier bears the freight charge, and (3) Delivered Duty Paid (DDP), in which the supplier bears both the tariff and freight charge. For instance, VPN Advertising, which has manufacturing facilities in Vietnam, and Jinsui, whose production is based in China, are both manufacturers of paper packaging. Their products are primarily exported to North America and Western Europe. They arrange shipments through logistics providers such as UPS and FedEx, which offer a range of trade contracts, including EXW, DAP, and DDP (Jinsui 2025a, VPN 2025a). Table 3.1 summarizes the aforementioned three trade contracts.

Table 3.1: Definition of Global Trade Terms Considered in The Paper

Trade Contract	Definition (Lloyds Bank 2023)
EXW	The buyer is responsible for both tariffs and freight charges.
DAP	The buyer assumes tariffs while the supplier bears freight charges.
DDP	The supplier is responsible for both tariffs and freight charges.

Undoubtedly, the allocation of responsibilities for tariffs and freight charges between buyers and suppliers, as delineated by various Incoterms, significantly impacts the pricing and ordering decisions of supply chain parties. These in turn affects the buyer's sourcing strategy. Despite their importance, the impact of Incoterms on the overall supply chain performance remains underexplored in the existing literature. This motivates us to conduct a comprehensive analysis to better understand the implications of trade contract specifications in global sourcing. Specifically, we are interested in examining the following research questions: (1) how do trade contracts defined by Incoterms impact the optimal pricing and ordering decisions of supply chain parties? (2) what are the preferences of buyers and suppliers over trade contracts that differ in the allocation of tariff and freight responsibilities? (3) how do tariffs and supply disruption risks affect the buyer's sourcing strategy and the resulting supply chain performance? and (4) how does competition in the shipping market affect the performance of supply chain parties?

To address the above research questions, we study a global procurement setting involving a domestic buyer who purchases from two overseas suppliers. One supplier, situated outside the free trade area, is dependable but faces high tariffs. In contrast, the other supplier, located within the free trade area, benefits from tariff exemptions but is less reliable. We designate the first as the RT supplier and the second as the UE supplier. The purchased products are transported to the buyer through a common logistics service provider (LSP). Depending on who bears the cost of tariff and freight charge, we have three trade contracts specified by Incoterms, EXW, DAP, and DDP. We then derive the equilibrium outcomes under three trade contracts, and show that the buyer always prefers dual sourcing under EXW and may choose to single source from the UE supplier under DAP and DDP. Below, we highlight some main findings.

First, one may intuit that a firm is less willing to undertake tariff when its rate becomes higher. Interestingly, our result shows that a buyer might benefit from bearing both tariffs and freight charges when the tariff rate is high. This outcome stems from the buyer's need to balance profits from sourcing via the RT supplier (RT channel) and the UE supplier (UE channel). Specifically, regarding the RT channel, the buyer who is responsible for fewer types of costs (e.g., from EXW to DAP to DDP) always bears a marginal cost disadvantage. Regarding the UE channel, when the tariff rate is low, the buyer benefits from a marginal cost advantage when moving from EXW to DAP to DDP. Consequently, given a low tariff rate, the buyer slightly reduces orders in the RT channel and increases orders in the UE channel when switching from EXW to DAP to DDP, which benefits the buyer under DDP by enjoying a marginal cost advantage in the UE channel. This advantage persists when the tariff rate is in a moderate range, but the buyer is worse off under DDP due to the substantial increase in its order from the UE supplier. With a further increase in the tariff rate, the buyer is hurt under DDP by facing a substantial marginal cost disadvantage from both channels. Lastly, when the tariff rate is sufficiently large, the buyer solely sources from the UE channel under DAP and DDP, which hurts the buyer due to the lack of a reliable supply source. The trade contract preferences of other supply chain members are unaffected by the tariff rate. Particularly, both the LSP and the RT supplier always prefer EXW, while the UE supplier always prefers DDP.

Second, the tariff rate and disruption risk have non-trivial impacts on the system performance. In particular, under EXW, the buyer is able to transfer the entire tariff burden to the RT supplier. Hence, as the tariff rate increases, the profit of the RT supplier decreases, while the profits of other parties remain unchanged. By contrast, under DAP, a higher tariff rate hurts both the RT supplier and the LSP but benefits the UE supplier because a higher tariff rate can intensify supplier competition. The buyer's profit, however, exhibits a non-monotonic relationship with the tariff rate, as it needs to balance gains and losses across two sourcing channels. Under DDP, the impact of a higher tariff rate mirrors that observed under DAP, except that the RT supplier increases the wholesale price to cover higher tariff costs. We further show that under all three trade contracts, an improvement in supplier reliability intensifies the competition between suppliers. This benefits the profit of the buyer and the LSP, while hurting the profit of the RT supplier. Somewhat surprisingly, when supply uncertainty is low, an increase in the reliability of the UE supplier is detrimental to the supplier itself due to the intensified competition.

Moreover, when there exists competition among LSPs in the logistic industry, our analysis reveals that the existence of a single-sourcing region induces the LSPs to undercut their freight charges aggressively. This competition leads to a dual-sourcing equilibrium, which always benefits both the buyer and the RT supplier, but hurts the UE supplier if the tariff rate is high. In our baseline model, the tariff is levied on the purchasing cost. As an extension, we further consider the scenario where tariffs are levied on both purchasing costs and freight charges. Most results from the baseline model continue to hold, except that a single-sourcing strategy emerges in equilibrium when the tariff rate is high. We show that the buyer prefers the tariff basis that involves fewer cost components as the tariff rate increases. Additionally, we examine a hypothetical trade contract, where the buyer bears the freight charges while the supplier undertakes the tariffs, and find that the profits of the buyer, the UE supplier, and the LSP under this case are the same as those under EXW, whereas the RT supplier's profit is lower than that under EXW.

The remainder of this paper is structured as follows. Section 3.2 provides a review of the relevant literature. In Section 3.3, we present our model along with the underlying assumptions. Section 3.4 derives the equilibria and analyzes supply chain parties' preferences over trade contracts specified by Incoterms. Section 3.5 analyzes the impact of the tariff rate and the disruption probability on the overall supply chain performance. We discuss several model extensions in Section 3.6, and conclude the paper in Section 3.7. All the proofs presented in the appendices.

3.2 Literature Review

Our research mainly contributes to three streams of literature: impact of trade policies on global sourcing strategy, supply risk management, and cross-border logistics.

First, our paper is related to the board literature on global sourcing and procurement; see, e.g., Feng and Lu (2012), Kayış et al. (2013), Hu and Qi (2018), Shao et al. (2020), Chen et al. (2022b), Turcic et al. (2023), and Gheibi et al. (2023). For example, Wang et al. (2011), Cui and Lu (2019), and Lai et al. (2021) respectively study how non-tariff barriers regulation, local content requirement policy, and international taxation affect firms' sourcing decisions.

Particularly, we contribute to the stream that investigates the impact of trade policies on global sourcing strategy. The studies concerning tariffs are most relevant to our paper. For example, Kouvelis et al. (2004) develop a modeling framework to analyze how government subsidies, tariffs, and regional trade regulations influence the manufacturing and distribution networks of global firms. Hsu and Zhu (2011) examine the effects of China's export-oriented policies, which include tax and tariff considerations, on optimal supply chain decisions for firms producing in China but serving both domestic and international markets. In their study of manufacturing reshoring and offshore supply dependence, Chen and Hu (2017) utilize the FOB basis, where customs duties are applied only to purchase prices. Meanwhile, Xu et al. (2018) explore how China's value-added tax export refund policies affect a multinational firm's choice between consignment and turnkey procurement outsourcing strategies. More recently, Dong and Kouvelis (2020) review recent studies regarding the implications of tariffs for global supply chain network configuration and propose four future research directions: tariff uncertainty, product interdependence, competition, and decentralized supply chain. Kouvelis et al. (2022) further impose tariffs at both the raw-material and finished-goods levels to study a reshoring problem under domestic market competition and tariff uncertainty. While earlier studies assume that the buyer bears the tariff costs, our paper focuses on scenarios where the supplier is accountable for the tariff, which is common practice in some developed regions such as the U.S. and Europe. We examine how changes in the party responsible for paying tariffs and freight charges give rise to EXW, DAP, and DDP trade contracts as defined by Incoterms. We then investigate how the tariff rate and disruption risk affect the incentives of the buyer and suppliers to bear tariff and freight charges in an international supply chain.

Second, our study also contributes to the body of research on supply risk management (e.g., Bitran and Gilbert 1994, Ang et al. 2017, Feng et al. 2022). Earlier works such as Parlar and Perry (1996) and Gürler and Parlar (1997) have discussed the benefits of using supply diversification to reduce the risks of supply disruptions. Later, more research pays attention to the disruption issue with one reliable and one unreliable supplier; see Tomlin (2006) and Wang et al. (2010) for a comprehensive review. The papers particularly related to our research are those that study the sourcing decision. Dada et al. (2007) find that, within a newsvendor framework, cost generally outweighs reliability as the primary factor in supplier selection. Hu and Kostamis (2015) demonstrate that it can be optimal for manufacturers to procure certain quantities from less reliable suppliers if their effective costs are lower than those of reliable suppliers. In a similar vein, we show that the competitiveness of cost is more significant than reliability, but our study differs from the above works in two ways. First, while their research primarily emphasizes production costs, our study incorporates tariff costs as a key factor influencing the buyer's dual sourcing strategy. Second, their studies consider a single-stage sourcing problem, but our work studies a three-stage Stackelberg game with sourcing being the last stage, which is influenced by the decisions of previous players and the gaming interaction between different stages of the system. Recently, Shan et al. (2022) focus on examining the effect of correlated disruptions among unreliable suppliers under responsive pricing. We differ by studying how trade contracts affect a buyer's sourcing decision between a reliable and an unreliable supplier.

Finally, the previously mentioned research mainly focuses on the strategic choices of buyers and suppliers, whereas LSPs, who set freight charges, also hold a crucial role in the global procurement process. From this viewpoint, our study also connects to the research on cross-border logistics. Lim et al. (2008) investigate a practical freight allocation issue within a commercial context, where the shipper negotiates contracts with carriers with exogenous freight rates. Lu et al. (2017) investigate a newsvendor-type shipper transporting a seasonal product whose freight charge is exogenously given via a sea carrier. By contrast, we analyze the pricing decisions of the LSPs, i.e., endogenous freight charges. More recently, Chen et al. (2019) examine cash-flow dynamics within a single supply chain featuring an active third-party logistics provider (3PL). Their findings show that 3PL leadership can be more effective than manufacturer leadership. Lu et al. (2020) examine a transportation procurement setting with a shipper and two competing carriers characterized by differences in speed and freight rates. Unlike their work, which focuses on competition, we explore both common and dedicated LSPs in the presence of suppliers' tariff discrepancy and disruption risk. In contrast to that under LSP competition, where only a dual-sourcing strategy is viable, we show that when the tariff rate is high, a single-sourcing strategy could arise with a common LSP.

3.3 Model Setup

We consider a three-tier global supply chain consisting of a domestic buyer, a logistics service provider, a reliable supplier located outside a free trade area, and an unreliable supplier situated within a free trade area. Figure 3.1 depicts the structure of this three-tier global supply chain. In what follows, we will describe the role, decisions, and profit objectives of each participant.

Suppliers:[1] We have two suppliers, one **r**eliable with a high **t**ariff rate, referred to as the RT supplier, and the other **u**nreliable with tariff **e**xemption, referred to as the UE supplier. Assume the high tariff rate is denoted by $\tau \in (0, 1)$. Alternatively,

[1]Note that there are totally ten representative scenarios regarding the two suppliers based on the combinations of their reliability levels and tariff rates. In this study, we focus on the most interesting case, while the other nine cases are trivial. Specifically, when two suppliers exhibit identical levels of reliability and tariff rates, the buyer selects one of them randomly with equal probability. When two suppliers have the same reliability level (tariff rate) but one outperforms the other in tariff rate (reliability), the buyer chooses the supplier that is more advantageous. Clearly, when one supplier is reliable with tariff exemption while the other is unreliable with a high tariff rate, the buyer sole sources from the reliable supplier with tariff exemption.

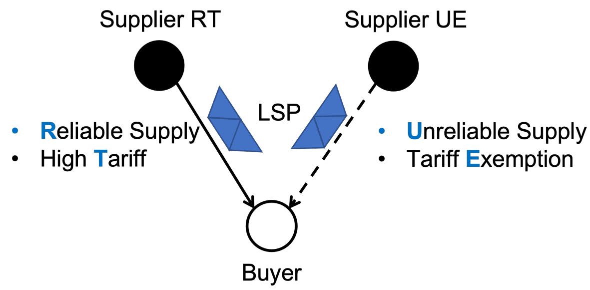


Figure 3.1: Supply Chain Structure

τ can be interpreted as the tariff disparity between the RT and the UE supplier. The RT supplier faces no disruption risk and can fully deliver the buyer's ordering quantity q_{RT}. However, the UE supplier is subject to disruption risk and cannot always fulfill the ordering quantity q_{UE}. The disruption occurs with probability $\psi \in (0,1)$, under which the delivery quantity is 0. Otherwise, the disruption does not occur with probability $1-\psi$ and the delivery quantity is q_{UE}. The loss of the entire order is justified if a strike or natural disaster occurs (see, e.g., Babich et al. 2007). The two suppliers aim to secure the buyer's orders by determining their unit wholesale prices $w_i, i \in \{RT, UE\}$. To focus on examining the impact of tariffs, we assume the two suppliers have the same production cost, which is normalized to 0 without loss of generality.

Buyer: The buyer has two sources to buy the products, one from the RT supplier, which we call the RT channel, and the other from the UE supplier, which we call the UE channel. The inverse demand function of the buyer is

$$p = \begin{cases} a - bq_{RT}, & \text{with probability } \psi, \\ a - b(q_{RT} + q_{UE}), & \text{with probability } 1-\psi, \end{cases} \tag{3.1}$$

where p is the market-clearing price, a captures the maximum willingness to pay, and b denotes the quantity sensitivity satisfying $b > 0$. The buyer compensates suppliers based on the quantity delivered. This type of deterministic inverse demand function is frequently employed in operations research literature addressing supply-side risks. (see, e.g., Tang and Kouvelis 2011, Hu and Kostamis 2015) .

Logistics Service Provider: We assume a common LSP provides the logistics service to the two suppliers and determines the unit freight charge v_i for each supplier $i, i \in \{RT, UE\}$. This assumption is consistent with practice. Major logistics companies, such as FedEx and UPS, provide reliable delivery services to over 200 countries and regions worldwide (FedEx 2025, UPS 2025). Maersk, the world's largest container shipping company, handles approximately one-fifth of the global shipping containers (Baldwin 2021). These LSPs can simultaneously serve suppliers located in different countries by offering varying freight rates and providing line-specific service contracts (Barrios 2018a, Kazliner 2020). For example, UPS collaborates with paper packaging manufacturers such as VPN Advertising and Jinsui, while Maersk partners with home furniture trading firms such as INDOCHINA and Reiz. These companies have production facilities in China or Vietnam, primarily exporting to North America and Western Europe (INDOCHINA 2025, Jinsui 2025b, Reiz 2025, VPN 2025b). Again, to single out the pure impact of tariffs, we normalize the LSP's unit delivery cost for the two suppliers to zero. If the delivery cost is different between the two suppliers, our main results qualitatively hold. We further extend to the setting with channel dedicated LSPs in Section 3.6.1.

Tariff: An important aspect of this paper is that the domestic buyer's purchases from overseas suppliers incur import tariffs and customs clearance fees. Regarding the cost basis on which the tariff is calculated, two commonly observed tariff calculation bases are *Free on Board* (FOB), in which the tariff imposed on the imported goods is levied on the purchasing cost only; and *Cost Insurance Freight* (CIF), in which the tariff imposed on the imported goods is levied on the purchasing cost plus freight charge (Zonos 2023). The former is often applied by the United States, whereas the latter is often adopted by the EU (Chen and Hu 2017). In our main context, we focus on tariffs calculated on an FOB basis. To account for regional differences in practice, we also examine the CIF based tariff and compare the preferences of supply chain partie between FOB- and CIF- based tariff in Section 3.6.2. Then, under FOB based tariff, depending on which party bears the tariff and freight charge, we have three common trade contracts specified by Incoterms: EXW, DAP,

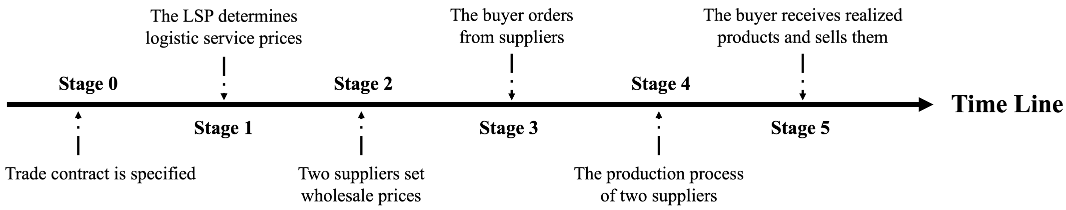


Figure 3.2: Sequence of Events

and DDP.[2] Specifically, under EXW contract, the buyer is responsible for tariff and freight charge; under DAP contract, the buyer bears tariff while the supplier pays for freight charges; and under DDP contract, the suppliers bear both costs. For clarity, we denote EXW, DAP, and DDP trade contracts by the superscripts E, A, and D, respectively, throughout the paper.

Sequence of Events: It is worth noting that Xeneta—the world's largest ocean and air freight rate benchmarking platform—indicates that the supplier and LSP typically determine the freight charge before the supplier and the buyer finalize their sales contract, since the freight charge can influence the parameters of the trade contract between the two parties (Barrios 2018b). Consistent with this practice, our study considers the following six-stage sequence of events; see Figure 3.2 for the illustration. First, the trade contract (EXW, DAP, and DDP) is specified. Next, the LSP acts as the Stackelberg leader and determines a unit freight charge v_i to supplier i, aligned with that in the existing literature (see, e.g., Chen et al. 2019), $i \in \{RT, UE\}$. Then, given v_i, the two suppliers simultaneously engage in price competition by determining their respective wholesale prices w_i. Subsequently, the buyer places orders q_i with each supplier i. The RT supplier produces as planned, while the UE supplier may face disruption with probability ψ. Finally, he buyer arranges transportation of the available products through the LSP before selling them in the market.Table B.1 in Appendix B.2 summarizes the notations used in the paper.

[2]We do not examine the case where the buyer bears the freight cost while the supplier bears the tariff, as such a contract is currently not observed in trade practice. In reality, DDP is the only Incoterm under which the seller (i.e., supplier) assumes responsibility for tariffs; however, this also requires the seller to manage the entire transportation process. For completeness, we analyze this hypothetical case in Section 3.6.3 to generate additional insights and enhance the prescriptive value of our study.

Profit Functions Under FOB Based Tariff: We characterize each player's profit function under FOB based tariff, where the tariff is only levied on the purchasing price. The LSP's goal is to maximize its expected profit Π_L by deciding a unit freight charge v_i for supplier $i \in \{RT, UE\}$. Therefore, under each trade contract $j \in \{E, A, D\}$, the LSP's expected profit can be derived as:

$$\Pi_L^j = v_{RT}^j q_{RT}^j + (1-\psi) v_{UE}^j q_{UE}^j,\ j \in \{E, A, D\}. \tag{3.2}$$

The two suppliers determine their unit wholesale prices w_i simultaneously to maximize their respective expected profit $\Pi_i, i \in \{RT, UE\}$. As the trade contract varies, the RT supplier's expected profit functions change and can be written as follows:

$$\Pi_{RT} = \begin{cases} w_{RT}^E q_{RT}^E, & \text{under EXW,} \\ (w_{RT}^A - v_{RT}^A) q_{RT}^A, & \text{under DAP,} \\ \left[(1-\tau) w_{RT}^D - v_{RT}^D\right] q_{RT}^D, & \text{under DDP.} \end{cases} \tag{3.3}$$

By contrast, the UE supplier who is exempted from tariffs has the identical expected profit under DAP and DDP. We can derive the UE supplier's expected profit functions as follows:

$$\Pi_{UE} = \begin{cases} (1-\psi) w_{UE}^E q_{UE}^E, & \text{under EXW,} \\ (1-\psi)(w_{UE}^A - v_{UE}^A) q_{UE}^A, & \text{under DAP,} \\ (1-\psi)(w_{UE}^D - v_{UE}^D) q_{UE}^D, & \text{under DDP.} \end{cases} \tag{3.4}$$

Next, we turn to the buyer whose profit also depends on the specific form of the trade contract. The buyer's expected profit consists of two terms: expected total revenue R^j and expected total purchasing costs $C_{RT}^j + C_{UE}^j$, where $j \in \{E, A, D\}$. We further denote the case with disruption by "d", and with no-disruption by "n". The expected revenue function is identical under either contract, i.e., $R^j = \psi p_d^j q_{RT}^j + (1-\psi) p_n^j (q_{RT}^j + q_{UE}^j)$. However, the expected cost function depends on the trade scenarios, which can be written as follows:

$$C^j_{RT} + C^j_{UE} = \begin{cases} \left[v^E_{RT} + (1+\tau)w^E_{RT}\right] q^E_{RT} + (1-\psi)(v^E_{UE} + w^E_{UE})q^E_{UE}, & \text{under EXW,} \\ (1+\tau)w^A_{RT}q^A_{RT} + (1-\psi)w^A_{UE}q^A_{UE}, & \text{under DAP,} \\ w^D_{RT}q^D_{RT} + (1-\psi)w^D_{UE}q^D_{UE}, & \text{under DDP.} \end{cases} \tag{3.5}$$

Let Π_B denote the expected profit function of the buyer, which can be written as follows:

$$\Pi^j_B = R^j - (C^j_{RT} + C^j_{UE}), j \in \{E, A, D\}. \tag{3.6}$$

3.4 Analysis Under FOB Based Tariff

In this section, we examine the supply chain parties' optimal pricing and ordering decisions and the buyer's sourcing strategy under each trade contract by considering the FOB based tariff, in which the tariff is only calculated on the purchasing price. We analyze the decisions of the four supply chain parties via backward induction to derive the subgame perfect Nash equilibrium (SPNE) outcomes. Specifically, we first study the buyer's sourcing decision given the wholesale prices and freight charges, then examine the suppliers' wholesale price competition, and finally analyze the LSP's freight charge decisions. For expositional brevity, we omit the subgame analyses from the main text and refer readers to the proof of Proposition 3.1 in Appendix B.1, where the final equilibrium outcomes are provided in Table B.3.

Given the final equilibrium outcomes, we proceed to first discuss the buyer's equilibrium sourcing decisions in Proposition 3.1 and then identify the underlying effects that drive the equilibrium outcomes in Propositions 3.2 and 3.3. We further characterize the supply chain members' preference over different trade contracts in Propositions 3.4, 3.5, and Corollary 3.1. Finally, we examine the incentive alignment among supply chain parties in Corollary 3.2. In the following proposition, we present the buyer's equilibrium sourcing strategy under each trade contract, as illustrated by Figure 3.3.

Proposition 3.1 *Under FOB based tariff, let $\bar{\tau}_2^f[\psi]$*[3] *and $\bar{\tau}_3^f[\psi]$ be thresholds defined in Table B.2. The buyer's equilibrium sourcing strategy under each trade contract is given as follows:*

(i) Under EXW, the buyer always adopts dual sourcing.

(ii) Under DAP, the buyer adopts dual sourcing if and only if (iff) $\tau < min\{\bar{\tau}_2^f[\psi], 1\}$; otherwise, it single sources from the UE supplier.

(iii) Under DDP, the buyer adopts dual sourcing iff $\tau < \bar{\tau}_3^f[\psi]$; otherwise, it single sources from the UE supplier.

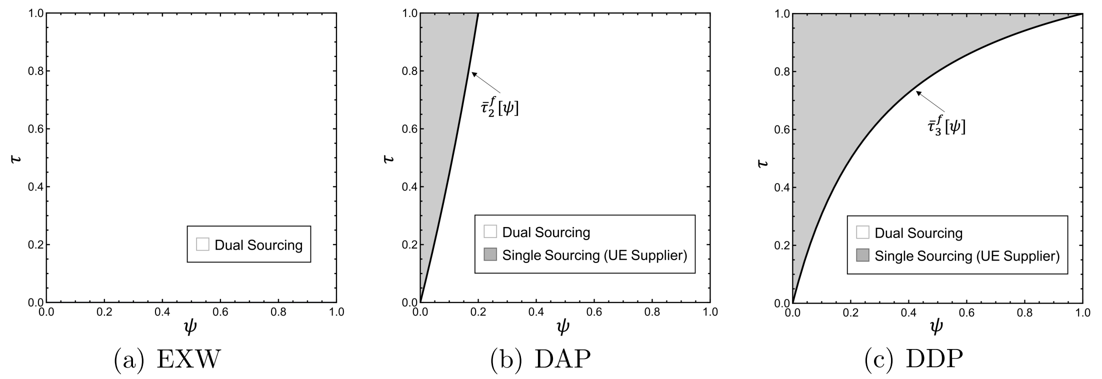


Figure 3.3: Buyer's Equilibrium Sourcing Strategy Under FOB Based Tariff

Note: In the subsequent figures, we always use the grey region to indicate single sourcing from the UE supplier, and the white region to represent dual sourcing.

Tariff cost and reliability can be seen as two dimensions in measuring a supplier's competitiveness. In our model, the former is more beneficial to the UE supplier, whereas the latter is an advantage of the RT supplier. Proposition 3.1(ii) and (iii) show that when the tariff cost is heavy (i.e., τ is high), it is optimal for the buyer to single source from the UE supplier to enjoy a lower purchasing cost, albeit facing potential supply disruption. By contrast, it is never optimal for the buyer to source solely from the RT supplier. This statement aligns with the conventional wisdom in sourcing literature (e.g., Dada et al. 2007 and Dong et al. 2022) regarding supplier

[3] We remark that: In the main model, the notations with "–" are the thresholds for the buyer's equilibrium sourcing strategy, while the notations without "–" are the thresholds for different effects and the buyer's preference on trade contracts.

selection, where tariff costs are prioritized over reliability. Consequently, when making procurement decisions, the buyer typically chooses the lower-cost supplier first, then evaluates the addition of a second supplier who offers higher reliability but at a greater cost. This is consistent with the currently observed real-world impact of high tariffs: as the tariff rate increases, many SMEs shift part of their sourcing from higher-tariff but more reliable countries and regions (e.g., China) to lower-tariff but potentially less reliable places (e.g., Malaysia or Vietnam), as illustrated by the case of Bogg Bag mentioned in Section 3.1. Additionally, as noted in part (i), the buyer consistently sources from both suppliers under EXW; the reasons for this are explained in detail in the discussion of the subsequent proposition.

Our three-tier supply chain consists of the RT channel and the UE channel, with the former revealing the role of tariff and the latter unfolding the impact of reliability. We first analyze the RT channel to understand how tariff takes effect in the final equilibrium. Specifically, given the SPNE outcomes, we compare the buyer's marginal procurement cost and order quantity as well as the marginal profits of the RT supplier and the LSP under each trade contract in Proposition 3.2.

Proposition 3.2 *For the RT channel, when the trade contract changes from EXW to DAP to DDP, the following statements hold:*

(i) The equilibrium marginal profits of the LSP and the RT supplier both decrease (i.e., $v_{RT}^{E*} > v_{RT}^{A*} > v_{RT}^{D*}$ and $w_{RT}^{E*} > w_{RT}^{A*} - v_{RT}^{A*} \geq (1-\tau)w_{RT}^{D*} - v_{RT}^{D*}$).

(ii) The buyer's equilibrium marginal procurement cost increases (i.e., $v_{RT}^{E*} + (1+\tau)w_{RT}^{E*} < (1+\tau)w_{RT}^{A*} \leq w_{RT}^{D*}$).

(iii) The buyer's equilibrium order quantity decreases (i.e., $q_{RT}^{E*} > q_{RT}^{A*} \geq q_{RT}^{D*}$).

Proposition 3.2 shows that the marginal profits of the LSP and the RT supplier and the order quantity of the buyer all decrease when the trade contract switches from EXW to DAP to DDP. Conversely, the buyer's marginal procurement cost rises. To understand this result, we first define a *triple marginalization* effect in a three-tier supply chain that leads to an increase in the buyer's unit purchasing cost, analogous to the classic double marginalization effect in a bilateral supply chain.

This adverse impact is further amplified by tariffs within our three-tier supply chain, a phenomenon we term the *intensified triple marginalization* effect. Specifically, the RT supplier increases the wholesale price to offset the additional freight charge when the trade contract switches from EXW to DAP, and further increases the wholesale price to cover the additional tariff cost when switching from DAP to DDP. In both scenarios, the tariff applied to the purchase price (i.e., $\tau w_{RT} q_{RT}$) rises, thereby intensifying the triple marginalization effect. In summary, this intensified triple marginalization is least pronounced under EXW, resulting in a lower wholesale price from the RT supplier. This can be used to explain why the dual-sourcing strategy is the unique equilibrium under EXW as stated in Proposition 3.1(i). This has useful managerial implications for RT suppliers, who always prefer EXW, as stated in Proposition 3.5. It suggests that a reliable supplier facing high tariff costs can incorporate a new perspective into its decision-making by negotiating the type of trade contract with the buyer. For example, in the two cases mentioned earlier, Bogg Bag terminated its cooperation with Chinese manufacturers after the imposition of U.S. tariff rates on Chinese imports, which increased to as high as 145% in April 2025 (Smith 2025). By contrast, Anna Griffin's small business continued to source from both China and Malaysia, opting to bear the high tariff costs (Jeyaretnam 2025). While multiple factors may underlie such decisions, one possible explanation is the consideration of different trade contracts, as revealed by our study. As Griffin noted, "SMEs with employees are being forced, like it or not, to bear the burden of these tariffs." (Jeyaretnam 2025). This reflects the limited flexibility and bargaining power that many SMEs face in global supply chains. High-cost suppliers may leverage this situation to negotiate the adoption of specific trade contracts with SMEs.

In addition, from EXW to DDP, the LSP reduces freight charges to both mitigate the aggravation of the triple marginalization effect and amplify orders in the RT channel, and the RT supplier's marginal profit decreases due to the increased responsibility to cover both tariff and freight charge, as shown in Proposition 3.2(i). Part (ii) indicates that the aggravation of the triple marginalization effect naturally increases the buyer's marginal procurement cost. Part (iii) directly follows from part (ii), as increased procurement costs lower the buyer's inclination to place larger orders. Additionally, there are two important points worth highlighting. First, the buyer undertakes the tariff when switching from EXW to DAP, while the supplier bears the tariff when moving from DAP to DDP. This encourages the supplier further to push up the wholesale price in the latter case, where the effect of triple marginalization intensifies more sensitively than that in the former case. This can be used to explain the underlying effects in the subsequent analyses. Second, when $\tau = 0$, the buyer is indifferent among EXW, DAP, and DDP since there are no tariff costs, and suppliers can fully pass the freight charges to the buyer via the wholesale price.

To better understand how tariffs affect the entire supply chain, we next take a closer look at the UE channel, which is indirectly affected by the tariff due to its competition with the RT channel for the buyer's order allocation. Parallel to Proposition 3.2, we illustrate how different trade contracts affect the buyer's marginal procurement cost and order quantity as well as the marginal profits of the UE supplier and the LSP in the UE channel, as summarized in Proposition 3.3 below.

Proposition 3.3 *For the UE channel, when the trade contract switches from EXW to DAP to DDP, the following statements hold:*

(i) The UE supplier's equilibrium marginal profit increases (i.e., $w_{UE}^{E*} < w_{UE}^{A*} - v_{UE}^{A*} \leq w_{UE}^{D*} - v_{UE}^{D*}$).

(ii) From EXW to DAP, the LSP's equilibrium marginal profit decreases (i.e., $v_{UE}^{E*} \geq v_{UE}^{A*}$). From DAP to DDP, the LSP's equilibrium marginal profit increases (i.e., $v_{UE}^{A*} \leq v_{UE}^{D*}$) iff $\tau > \tau_1^f[\psi]$.

(iii) From EXW to DAP, the buyer's equilibrium marginal procurement cost increases (i.e., $v_{UE}^{E*}+w_{UE}^{E*} < w_{UE}^{A*}$) iff $\psi < \psi_1^f$ and $\tau > \tau_2^f[\psi]$. From DAP to DDP, the buyer's equilibrium marginal procurement cost increases (i.e., $w_{UE}^{A*} \leq w_{UE}^{D*}$) iff $\tau > \tau_3^f[\psi]$.

(iv) The buyer's equilibrium order quantity increases (i.e., $q_{UE}^{E*} < q_{UE}^{A*} \leq q_{UE}^{D*}$).

Recall that the supplier is not responsible for the freight charge under EXW but needs to bear it under DDP. Proposition 3.3(i) shows that shifting from EXW to

DDP improves the UE supplier's marginal profit. This is because such shifting intensifies the triple marginalization effect, impelling the buyer to reduce its order in the RT channel. Consequently, the buyer has to order more in the UE channel. This enables the UE supplier to charge a higher wholesale price w_{UE} since the buyer is more likely to buy from it, a phenomenon we refer to as the *exploitation effect*.

Proposition 3.3(ii) shows that the LSP's profit margin declines when the trade contract switches from (1) EXW to DAP or (2) from DAP to DDP under a low tariff. By contrast, it increases when the trade contract shifts from DAP to DDP and the tariff rate is high. The underlying reasons are as follows. First, note that a high tariff rate aggravates the triple marginalization effect. Second, recall from Proposition 3.2 that the triple marginalization effect intensifies more sensitively to the tariff rate when the trade contract switches from DAP to DDP than that from EXW to DAP. On the one hand, when the intensified triple marginalization effect is significant (i.e., switching from DAP to DDP under a high tariff), the buyer has less incentive to buy from the RT channel and relies more on sourcing from the UE channel. This enables the LSP to increase v_{UE} to improve its profit earned in the UE channel, which we refer to as the *incitement effect*. On the other hand, when the intensified triple marginalization is moderate (i.e., switching from either EXW to DAP, or from DAP to DDP under a low tariff), the buyer still opts to buy from both channels. In such a situation, the LSP has an incentive to balance the profit earned between the RT and the UE channel by adjusting its freight charges, which in turn indirectly affects the buyer's order decisions. Specifically, by lowering v_{UE}, the LSP can incentivize the RT supplier to reduce its wholesale price w_{RT} to attract more orders from the buyer, an action we refer to as the *alleviation effect*. Table 3.2 summarizes the aforementioned three effects.

Proposition 3.3(iii) states that the buyer may incur a marginal procurement cost advantage or disadvantage in the UE channel as the trade contract varies, which is caused by a combination of the exploitation, the alleviation and the incitement effects. Lastly, the buyer reallocates orders between the two channels to maximize profit, with order quantities consistently rising as the trade term shifts from EXW to DDP, as demonstrated in Proposition 3.3(iv). In what follows, we elaborate on how

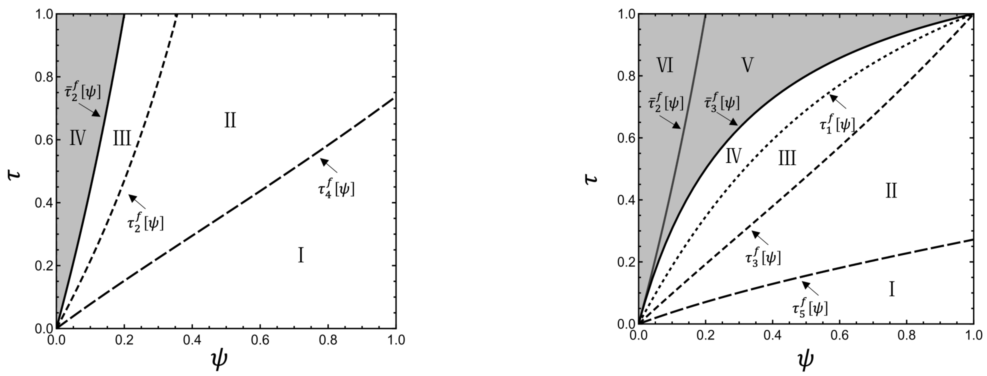
Table 3.2: Three Effects in The UE Channel

Effect	Initiator	Mechanism
Exploitation effect (EXW to DAP to DDP $\forall \tau$)	UE Supplier	UE supplier increases w_{UE} since the buyer is more likely to buy from it.
Incitement effect (DAP to DDP and $\tau > \tau_1^f[\psi]$)	LSP	LSP plays up the UE channel by gradually increasing v_{UE}.
Alleviation effect (EXW to DAP $\forall \tau$) (DAP to DDP and $\tau \leq \tau_1^f[\psi]$)	LSP	LSP downplays the UE channel by gradually reducing v_{UE}.

these effects affect the buyer's profits through the adjustment of the order quantities in Proposition 3.4.

Proposition 3.4 *When the trade contract changes from EXW to DAP, the buyer's equilibrium profit increases (i.e.,* $\Pi_B^E \leq \Pi_B^A$*) iff* $\tau \leq \tau_4^f[\psi]$*. When the trade contract switches from DAP to DDP, the buyer's equilibrium profit increases (i.e.,* $\Pi_B^A \leq \Pi_B^D$*) iff* $\tau \leq \tau_5^f[\psi]$*. Moreover,* $\tau_4^f[\psi] > \tau_5^f[\psi]$*, whose detailed expressions are provided in Table B.2 in Appendix B.2.*

When the tariff rate is large, one may expect that the buyer is unwilling to undertake the tariff and the freight charge, because the higher the tariff, the worse the buyer's profit should be. By contrast, Proposition 3.4 indicates that this action could actually benefit the buyer. To understand, we plot Figure 3.4 to identify several regions used for explanations.



(a) From EXW to DAP

(b) From DAP to DDP

Figure 3.4: Regions Corresponding to Each Effect Under FOB Based Tariff

We start our discussions when the trade contract switches from EXW to DAP; see Figure 3.4(a). When comparing the equilibrium outcomes under EXW and DAP, note that in the RT channel the buyer always has a lower marginal procurement cost in EXW. Regarding the buyer's marginal procurement cost in the UE channel, it can be seen as the sum of the marginal profit of the LSP and the UE supplier, with a decrease in the former and an increase in the latter corresponding to the alleviation effect and exploitation effect, respectively. Hence, in the UE channel, these two effects lead to the difference in the buyer's marginal procurement cost under EXW and DAP, which further induces the buyer to adjust orders and ultimately leads to different preferences. Specifically, when $\tau < \tau_4^f[\psi]$ (i.e., region I), the UE channel has a lower marginal procurement cost in DAP because the alleviation effect has a higher impact than the exploitation effect. In this scenario, when the buyer shifts from EXW to DAP, it slightly decreases the order quantity from the RT channel while increasing it in the UE channel, thereby leveraging the cost advantage of the UE channel to enhance profits. This behavior explains why the buyer has less motivation to take on extra trading duties in region I.

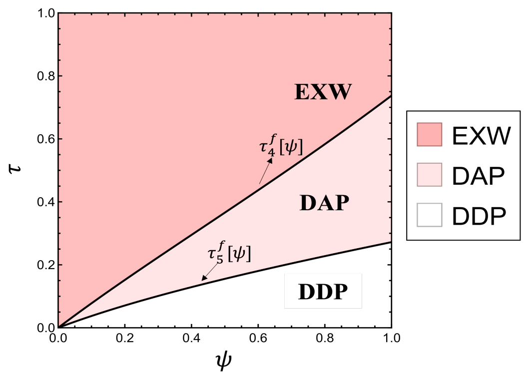
Conversely, when $\tau \geq \tau_4^f[\psi]$, the buyer is consistently worse off under DAP, albeit for different reasons. Particularly, when $\tau_4^f[\psi] \leq \tau < \tau_2^f[\psi]$ (i.e., region II), the UE channel continues to enjoy a marginal procurement cost advantage because the alleviation effect still has a greater impact compared with the exploitation effect. However, the substantial reduction in orders from the RT channel, combined with the increase in orders from the UE channel, harms the buyer, as it retains a large portion of orders in the risk-prone UE channel. When $\tau_2^f[\psi] \leq \tau < \bar{\tau}_2^f[\psi]$ (i.e., region III), unlike previous regions, the exploitation effect becomes dominant, causing the UE channel to face a marginal procurement cost disadvantage under DAP compared to EXW. Consequently, the combined marginal cost disadvantages of both channels reduce the buyer's profits. Finally, when $\tau \geq \bar{\tau}_2^f[\psi]$ (i.e., region IV), the buyer switches from dual sourcing to solely sourcing from the UE channel, which negatively impacts the buyer due to the absence of a reliable supply source.

On the other hand, a comparison of the equilibrium outcomes under DAP and DDP shows that the RT channel has a lower marginal procurement cost under DAP, and the UE channel's marginal cost is jointly affected by all the aforementioned three effects. The interpretations of regions I, II, and III in Figure 3.4(b) align respectively with those observed in the transition from EXW to DAP. Additionally, there are three further regions—IV, V, and VI—where the buyer consistently experiences disadvantages under DDP. Specifically, when $\tau_1^f[\psi] \leq \tau < \bar{\tau}_3^f[\psi]$ (i.e., region IV), the incitement effect appears, which raises the UE channel's marginal procurement cost in DDP as compared to DAP. It follows that the negative impacts of both the incitement effect and the exploitation effect simultaneously aggravate the marginal procurement cost disadvantage of the UE channel. As a result, the buyer faces higher marginal costs in both channels, which negatively impacts its profits. Finally, when converting from DAP to DDP, the buyer suffers profit loss in region V due to the absence of the RT supplier, and DAP is equivalent to DDP in region VI as the buyer only sources from the UE channel with no tariff cost under both trade contracts.

The previous comparisons were made between pairs of trade contracts, namely, EXW and DAP, DAP and DDP. Building on these discussions, Corollary 3.1 identifies the buyer's most preferred trade contract among the three.

Corollary 3.1 *The buyer prefers DDP contract if $\tau \leq \tau_5^f[\psi]$, DAP contract if $\tau_5^f[\psi] < \tau \leq \tau_4^f[\psi]$, and EXW contract if $\tau > \tau_4^f[\psi]$. In other words, as the tariff rate increases, the buyer is more willing to bear the tariff and freight charge. Moreover, the buyer always dual sources under its most preferred trade contract.*

Corollary 3.1 together with Proposition 3.1 reveal two interesting insights: (1) Under the buyer's most preferred trade contract, it always adopts dual sourcing; and (2) the buyer tends to bear both the tariff and freight charge as the tariff rate τ increases; see Figure 3.5(a). These outcomes can be directly inferred from Proposition 3.4. Specifically, when τ is small (i.e., $\tau < \tau_5^f[\psi]$), the buyer gains higher profits under DDP by slightly decreasing the quantity of the RT channel with marginal costs disadvantage and increasing the quantity of the UE channel where the exploitation effect is less significant than the alleviation effect. When τ is intermediate (i.e., $\tau_5^f[\psi] \leq \tau < \tau_4^f[\psi]$), the buyer's profit declines under DDP because allocating a significant portion of orders to the unreliable supplier negatively impacts returns. When τ is large (i.e., $\tau > \tau_4^f[\psi]$), the reason for the loss of profits in regions II, III, and IV in Figure 3.4(a) under DAP is driven by the significant adjustment of quantity, greater impact of the exploitation effect and single sourcing from the UE channel, respectively. Alternatively, if we interpret the optimal decision from the dimension of the supply uncertainty reflected by the disruption probability ψ, the buyer tends to assume more duty as the UE supplier becomes more reliable. This aligns with several real-world cases, where the recent imposition of U.S. tariffs on Chinese goods has substantially increased the tariff costs for U.S. buyers sourcing from China, yet many have chosen to bear these additional costs themselves. For example, Jim Umlauf, owner of 4Knines, who has been exploring alternatives to Chinese manufacturing since 2018, reported that his company has undertaken the additional costs of importing raw materials from China since the imposition of a 25% tariff (CHINA NEWS 2025). In another example, Alyssa Chambers, founder of NOVA Essence Inside Out, a producer of candles and wellness products, indicated her intention to temporarily bear the tariff costs imposed on the Chinese-made candle jars and candles that are essential to her business (Picchi 2025).



(a) Buyer' Preference over Three Trade Contracts

Trade Contract	Incentive Alignment
EXW	Buyer, LSP, and RT supplier
DAP	/
DDP	Buyer, and UE supplier

(b) Supply Chain Members' Incentive Alignment

Figure 3.5: Supply Chain Members' Preference over Three Trade Contracts Under FOB Based Tariff

Next, we discuss the preferences of the LSP and suppliers by comparing their equilibrium profits under each trade contract.

Proposition 3.5 *When the trade contract changes from EXW to DAP to DDP, the equilibrium profits of the LSP and the RT supplier both decrease (i.e.,* $\Pi_L^E >$

$\Pi_L^A \geq \Pi_L^D$ *and* $\Pi_{RT}^E > \Pi_{RT}^A \geq \Pi_{RT}^D$*), while that of the UE supplier increases (i.e.,* $\Pi_{UE}^E < \Pi_{UE}^A \leq \Pi_{UE}^D$*).*

A close look at Proposition 3.5 reveals that the LSP and the RT supplier are always better off if the buyer is responsible for the tariff and freight charge. By contrast, the UE supplier consistently experiences reduced profits when the buyer assumes responsibility for both costs. The intuition is straightforward. Recall from Proposition 3.2 that under EXW contract where the RT supplier takes no cost, the aggravation of the triple marginalization effect caused by tariffs is the weakest, which benefits both the LSP and the RT supplier but hurts the UE supplier as its rival becomes more competitive. This suggests that the UE supplier's preference is always opposite to those of the LSP and the RT supplier. Besides, DAP and DDP are equivalent when the tariff rate is high, as the optimal sourcing strategy is single sourcing from the UE supplier which is independent of tariffs.

Corollary 3.2 *When* $\tau > \tau_4^f[\psi]$*, the buyer, the LSP, and the RT supplier prefer EXW, and their incentives are aligned. When* $\tau < \tau_5^f[\psi]$*, both the buyer and the UE supplier prefer DDP, and their incentives are aligned.*

By integrating the preferences of the buyer, the LSP, and the suppliers, Corollary 3.2 and Figure 3.5(b) indicate that when the tariff rate is low, the buyer and the UE supplier share aligned incentives in selecting a trade contract, i.e., DDP, while given a high tariff rate, the incentive of the buyer, the LSP, and the RT supplier can be aligned in selecting a trade contract, i.e., EXW. This result suggests that by setting the tariff rate within a reasonable range, the policymaker can align the incentive of the domestic buyer with the supplier located in the free trade area and thus facilitate the import country to conduct business within free trade areas.

3.5 Impact of Tariff Rate and Disruption Probability

In this section, we examine the impact of the tariff rate and supply uncertainty on system performance under FOB based tariff. We begin by analyzing how the tariff rate, τ, and the disruption probability, ψ, influence the buyer's preference for trade contracts (i.e., Proposition 3.6). We then investigate the effect of τ on equilibrium wholesale prices (i.e., Proposition 3.7), equilibrium quantities (i.e., Corollary 3.3), and overall supply chain performance (i.e., Proposition 3.8). Finally, we discuss the effects of ψ on equilibrium wholesale prices and the profits of each supply chain party (i.e., Propositions 3.9 and 3.10, respectively).

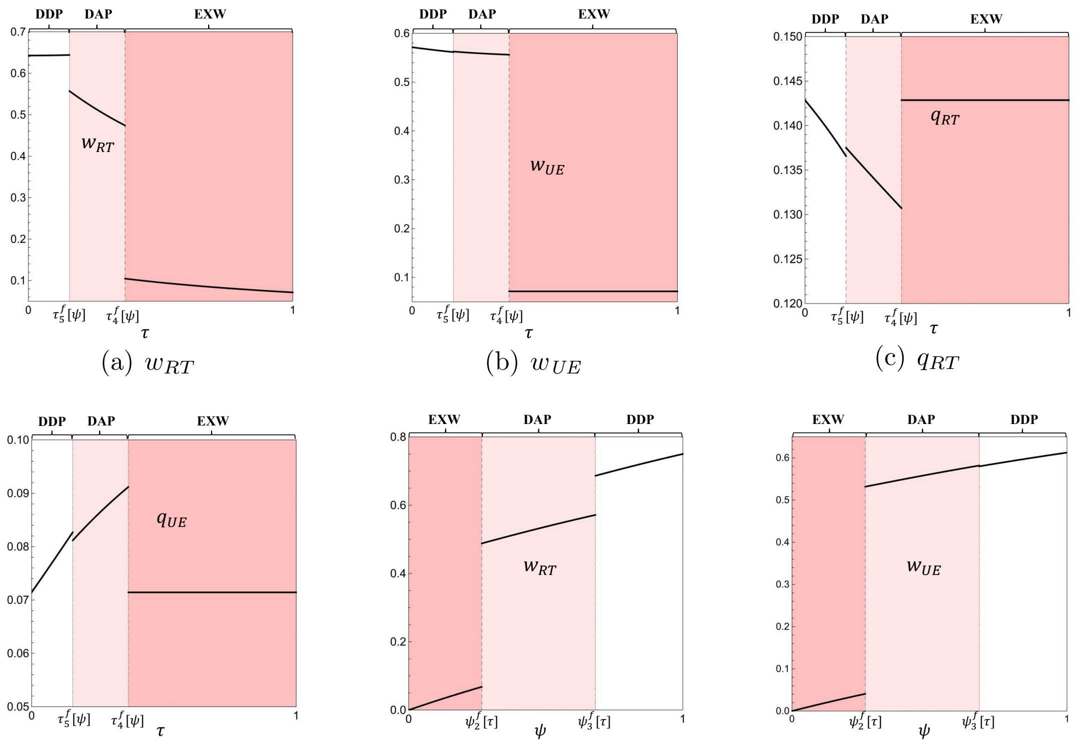
Proposition 3.6 *Under FOB based tariff, the following statements hold:*

(i) As the tariff rate τ increases, the buyer's preference region for the DDP contract shrinks; the preference region for the DAP contract first enlarges and then shrinks; and the preference region for the EXW contract first enlarges and then remains unchanged.

(ii) As the disruption probability ψ increases, the buyer's preference regions for the DAP and DDP contracts enlarge while that for the EXW contract shrinks.

Proposition 3.6(i) shows that as the tariff rate increases, the buyer becomes less inclined to choose DDP, exhibits a non-monotonic preference for DAP—first increasing and then decreasing—and is weakly more likely to select EXW. This result follows directly from our main finding that a higher tariff rate makes the buyer more inclined to bear the tariff cost and freight charge. The non-monotonicity of the buyer's preference for DAP is because, although the relative profitability of DAP compared to DDP increases with a higher tariff rate, the buyer's growing preference for EXW ultimately reduces the attractiveness of DAP. Moreover, the condition for the buyer to prefer DDP (i.e., $\tau < \tau_5^f[\psi]$) can be rewritten in terms of the disruption probability ψ, requiring ψ to exceed a threshold $\psi_3^f[\tau]$. In other words, from the perspective of supply risk (measured by ψ), a less reliable UE supplier makes the buyer more likely to prefer a trade contract with fewer responsibility—namely, DDP—as shown in Proposition 3.6(ii). Next, we discuss how the tariff rate τ affects the equilibrium wholesale price.

Proposition 3.7 *Under FOB based tariff, the RT supplier's equilibrium wholesale price increases with τ for $\tau \leq \tau_5^f[\psi]$ and decreases with τ for $\tau > \tau_5^f[\psi]$, except* *for downward jumps at* $\tau = \tau_5^f[\psi]$ *and* $\tau = \tau_4^f[\psi]$. *The UE supplier's equilibrium wholesale price decreases with* τ *for* $\tau \le \tau_4^f[\psi]$ *and remains constant for* $\tau > \tau_4^f[\psi]$, *except for an upward jump at* $\tau = \tau_5^f[\psi]$ *and a downward jump at* $\tau = \tau_4^f[\psi]$.



(a) w_{RT} (b) w_{UE} (c) q_{RT}

(d) q_{UE} (e) w_{RT} (f) w_{UE}

Figure 3.6: Impact of Tariff Rate τ and Disruption Probability ψ on Equilibrium Wholesale Prices and Order Quantities ($\psi = 0.5$, $\tau = 0.2$)

Recall from Corollary 3.1 that the buyer prefers DDP contract if the tariff rate $\tau \le \tau_5^f[\psi]$, DAP contract if τ falls into the range $(\tau_5^f[\psi], \tau_4^f[\psi]]$, and EXW contract if $\tau > \tau_4^f[\psi]$. Proposition 3.7 then implies that under DAP, the wholesale prices of both suppliers decrease with the tariff rate τ; under DDP, the UE supplier's wholesale price decreases with τ, but the RT supplier's wholesale price increases with τ; see Figures 3.6(a) and 3.6(b). The decrease in both wholesale prices under DAP occurs because a higher tariff rate reduces the buyer's willingness to purchase from the RT channel. As such, the RT supplier lowers its wholesale price to secure order quantity, which further impels the UE supplier to reduce its wholesale price to stay competitive. Consequently, a higher tariff burden on the RT supplier intensifies the competition between the two suppliers, leading to lower wholesale prices for the buyer. By contrast, under DDP, the RT supplier bears the tariff costs, which pressures it to increase the wholesale price as the tariff rate increases.

Proposition 3.7 further reveals that under EXW (i.e., $\tau > \tau_4^f[\psi]$), an increase in the tariff rate τ makes the RT supplier reduce its wholesale price but has no impact on the UE supplier's wholesale price. This is due to the fact that the triple marginalization effect is weakest under EXW. As the tariff rate increases, the RT supplier can absorb the increased marginal procurement cost without substantially reducing its wholesale price, thereby avoiding triggering a price reduction from the UE supplier. It is worth noting that the discontinuity in w_{RT}, w_{UE}, q_{RT}, and q_{UE} at the tariff rate thresholds $\tau_5^f[\psi]$ and $\tau_4^f[\psi]$ arise due to the switch of the buyer's contract preference from DDP to DAP and then from DAP to EXW. Next, we examine how the tariff rate impacts the order quantities allocated to each supplier in the following corollary.

Corollary 3.3 *The equilibrium ordering quantity from the RT supplier (q_{RT}) reaches its maximum and that from the UE supplier (q_{UE}) reaches its minimum when the tariff rate $\tau = \tau_4^f[\psi]$, under which the DAP contract is adopted.*

Corollary 3.3, together with Figures 3.6(c) and 3.6(d), shows that the effect of the tariff rate τ on the buyer's order allocation to each supplier is non-monotonic. In particular, there exists a threshold $\tau_4^f[\psi]$ at which the RT supplier receives its minimum order quantity, while the UE supplier receives its maximum. This result implies that if the tariff rate is set at a reasonable level and combined with a well-designed trade contract, it can reduce domestic buyers' incentives to procure from suppliers outside free trade areas, strengthening relationships with partners in free trade areas. This is consistent with real-world observations, where many developed countries, such as the United States, have appropriately increased tariff rates to reduce domestic buyers' reliance on suppliers outside free trade areas and to strengthen trade relationships with suppliers within free trade areas. For example, since the Trump administration's implementation of tariff policies, the United States imposed tariffs on Chinese goods with rates as high as 145%, which was later negotiated down to 30%. A similar situation occurs between the United States and the EU; in July

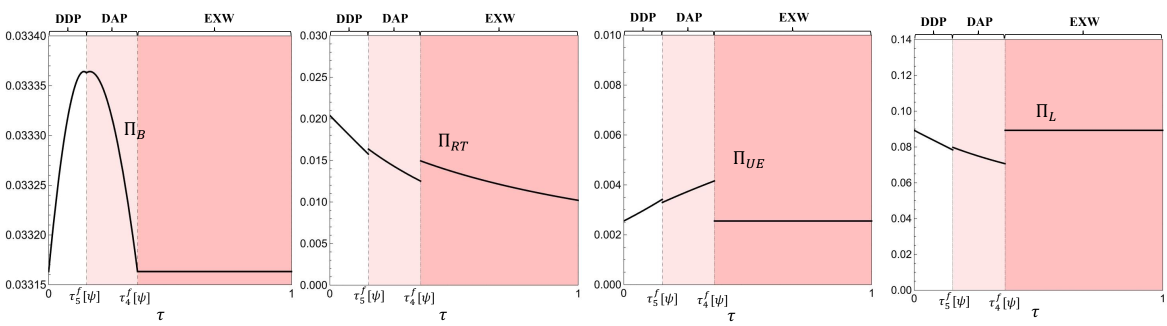
2025, the EU faced a 15% baseline tariff rate on most European goods exported to the U.S., which is half of the 30% import tax rate that the Trump administration previously planned to implement (Lim and Kiderlin 2025). This suggests that higher tariffs are not always beneficial and preferable. By setting tariff rates at an appropriate level, domestic buyers can be incentivized to adjust their preferences for trade contracts and engage in business with partners within free trade areas. This finding also aligns with the recent trend of "ally-sourcing", as appropriately setting tariff rates can help strengthen cooperation with allied countries (Dezenski and Austin 2021). Based on the effects of τ on pricing and quantity decisions, we can further derive its impacts on the profits of the supply chain participants, as summarized in the following proposition.

Proposition 3.8 *Under FOB based tariff, in equilibrium, the following statements hold:*

(i) The buyer's profit is non-monotonic in τ for $\tau \leq \tau_4^f[\psi]$ and remains constant afterwards.

(ii) The RT supplier's profit decreases with τ, except for upward jumps at $\tau = \tau_5^f[\psi]$ and $\tau = \tau_4^f[\psi]$.

(iii) The profit of the UE supplier (LSP) first increases (decreases) in τ for $\tau \leq \tau_4^f[\psi]$ and then remains constant, with downward (upward) jumps at $\tau = \tau_5^f[\psi]$ and $\tau = \tau_4^f[\psi]$.



(a) Buyer (b) RT Supplier (c) UE Supplier (d) LSP

Figure 3.7: Impact of Tariff Rate τ on Equilibrium Profits ($\psi = 0.5$)

Interestingly, Proposition 3.8(i) indicates that under DAP and DDP, the buyer's profit exhibits a non-monotonic relationship with the tariff rate τ, following a unimodal pattern. This is because the buyer must balance its profits from both the RT and UE channels. Specifically, when τ is relatively low, the triple marginalization effect in the RT channel is relatively weak, and the buyer tends to rely more on this channel due to the unreliability of the UE channel. Hence, the buyer places more orders to the RT channel and fewer to the UE channel. While this approach increases the buyer's profits from the RT channel, it reduces its profits from the UE channel. Conversely, when τ is high, the triple marginalization effect in the RT channel is prominent, impelling the buyer to shift more orders toward the UE channel. However, while the buyer's profits from the UE channel are enhanced, this comes at the expense of reduced profits from the RT channel. Consequently, the buyer achieves the maximum profit at a moderate tariff rate, where the buyer effectively balances orders between the two channels and avoids excessive dependence on either channel.

Not surprisingly, under DAP and DDP, as τ increases, the profits of the RT supplier and the LSP decrease, while the UE supplier's profit increases; see Figure 3.7. This is because higher tariffs exacerbate the triple marginalization effect in the RT channel, which naturally hurts the RT supplier as well as the LSP that attempts to mitigate this effect via the alleviation effect. Meanwhile, the intensified triple marginalization effect in the RT channel induces the buyer to shift their sourcing preference toward the UE supplier, thereby benefiting the UE supplier at the expense of hurting its competitor. The discontinuity of Π_{RT}, Π_{UE}, and Π_L at the thresholds $\tau_5^f[\psi]$ and $\tau_4^f[\psi]$ is again due to the buyer's contract preference switching from DDP to DAP, and then from DAP to EXW. At these thresholds, the profits of the RT supplier and LSP experience an upward jump, while the UE supplier's profit experiences a downward jump. This is consistent with the fact that as the trade contract shifts from EXW to DAP to DDP, the profits of the RT supplier and the LSP decrease, whereas the UE supplier's profit increases.

Proposition 3.8 also shows that under EXW, an increase in the tariff rate τ decreases the RT supplier's profit but has no impact on the profits of the buyer, the UE supplier, and the LSP. In other words, although the buyer bears the tariff cost when sourcing from a supplier outside free trade areas, its profit is unaffected by the tariff. Recall from Proposition 3.7 that under EXW, as the tariff rate increases, the RT supplier's reduction in wholesale price fully offsets the additional tariff burden, thereby keeping the buyer's marginal procurement cost and order quantity unchanged. Hence, the buyer benefits from competition between the RT and UE suppliers, with the tariff costs entirely shifted to the RT supplier. Notably, such complete absorption of the tariff impact occurs only under EXW, where the triple marginalization effect is weakest. This allows the RT supplier to fully offset tariff costs by adjusting its wholesale price. We next examine the impact of supply uncertainty, measured by the disruption probability ψ, on the system performance.

Proposition 3.9 *Under FOB based tariff, in equilibrium, the wholesale prices of both the RT and UE suppliers increase with ψ, except at two threshold points. Specifically, the RT supplier's wholesale price experiences upward jumps at $\psi = \psi_2^f[\tau]$ and $\psi = \psi_3^f[\tau]$, while the UE supplier's wholesale price exhibits an upward jump at $\psi = \psi_2^f[\tau]$ and a downward jump at $\psi = \psi_3^f[\tau]$, where the detailed expressions of $\psi_2^f[\tau]$ and $\psi_3^f[\tau]$ are provided in Table B.2 in the Appendix B.2.*

Recall that, in terms of the disruption probability ψ, the buyer prefers EXW if $\psi \leq \psi_2^f[\tau]$, DAP if $\psi_2^f[\tau] < \psi \leq \psi_3^f[\tau]$, and DDP if $\psi > \psi_3^f[\tau]$. Proposition 3.9 shows that under each trade contract, the wholesale prices of both suppliers increase with the disruption probability ψ; see Figures 3.6(e) and 3.6(f). The underlying reason is that a higher disruption probability ψ weakens the UE supplier's bargaining position in securing orders, thereby softening wholesale price competition with the RT supplier. Hence, both suppliers increase their wholesale prices as ψ increases. It is worth noting that the impact of the disruption probability ψ on supplier competition differs from that of the tariff rate τ: an increase in τ can intensify price competition between the two suppliers, particularly under DAP. Last, we examine how the disruption probability affects the profits of supply chain parties and obtain the following:

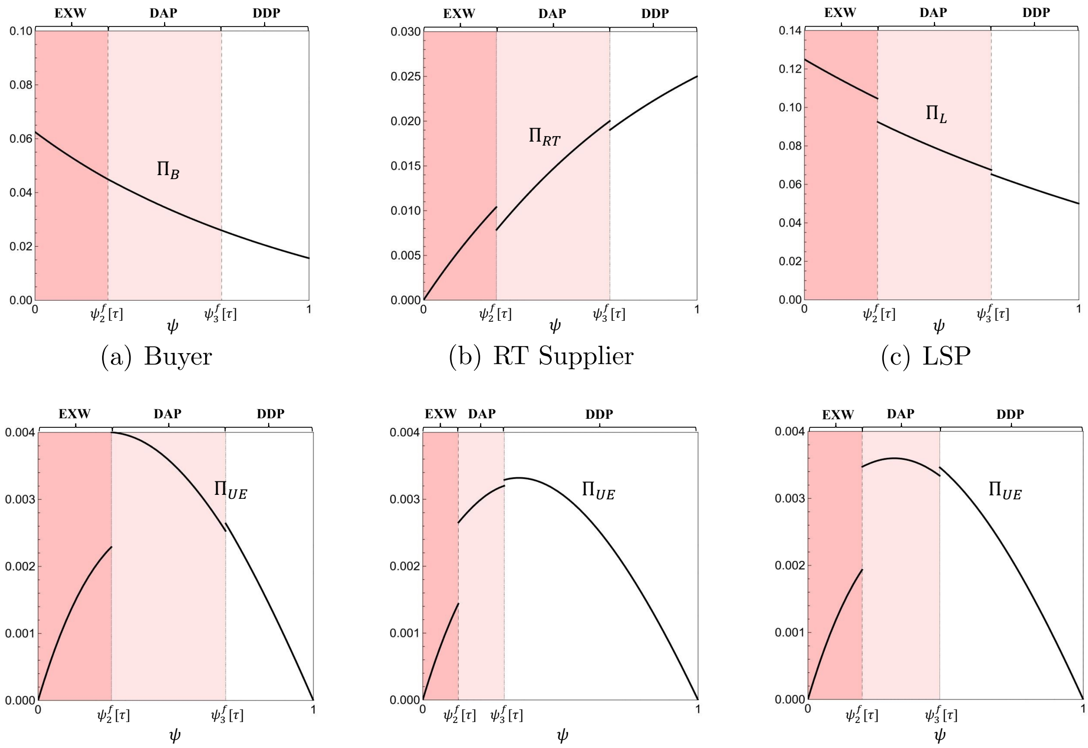
Proposition 3.10 *Under FOB based tariff, in equilibrium, the following statements hold:*

(i) The buyer's profit decreases with the disruption probability ψ.

(ii) The RT supplier's profit increases with ψ, except for downward jumps at $\psi = \psi_2^f[\tau]$ and $\psi = \psi_3^f[\tau]$.

(iii) The UE supplier's profit is non-monotonic in ψ.

(iv) The LSP's profit decreases with ψ, except for the downward jumps at $\psi = \psi_2^f[\tau]$ and $\psi = \psi_3^f[\tau]$.



(a) Buyer (b) RT Supplier (c) LSP

(d) UE Supplier (e) UE Supplier ($\tau = 0.1$) (f) UE Supplier ($\tau = 0.15$)

Figure 3.8: Impact of Disruption Probability ψ on Equilibrium Profits ($\tau = 0.2$)

Proposition 3.10 together with Figure 3.8 yield two key insights. First, for any given trade contract, an increase in the disruption probability ψ always reduces the RT supplier's profit. The effect on the UE supplier, however, is much more nuanced. Counterintuitively, when ψ is relatively low, an increase in the disruption probability can improve the UE supplier's profit. This implies that being slightly less reliable may be beneficial for the UE supplier. The underlying reasons are twofold: On the one hand, a reduction in reliability reduces the buyer's willingness to source from the UE supplier. On the other hand, as shown in Proposition 3.9, lower reliability softens the UE supplier's wholesale price competition with the RT supplier, allowing both suppliers to increase their wholesale prices. Consequently, as ψ increases, the RT supplier benefits from a higher profit margin, while the UE supplier can also benefit if its reliability remains relatively high (i.e., ψ is still low). As ψ keeps increasing and becomes sufficiently large, the adverse effect of reduced delivered quantity arising from disruption dominates and the UE supplier's profit decreases. The above results tend to be reflected in real-world observations, where improvements in reliability do not necessarily result in higher profits, particularly in highly competitive markets. For example, Vietnamese garment enterprises, facing stricter quality standards and increasing competition in the global market, have improved their reliability to meet international buyers' expectations. Yet, this has also intensified price competition from manufacturers in other countries such as Bangladesh and China, ultimately pressuring their profit margins (Viet Nam News 2023).

Second, the profits of the buyer and the LSP, generated through both the RT and UE channels, decrease as ψ increases. A higher disruption probability ψ reduces the expected deliverable quantity from the UE channel, which inevitably harms the profitability of both parties. The underlying reason is that as ψ increases, the competition between suppliers weakens, leading to an increase in the buyer's procurement cost and thus a decrease in its profitability. It is worth noting that the impact of ψ on the buyer's profit differs from that of the tariff rate τ, where the buyer's profit is unimodal in τ. Again, the discontinuity in Π_{RT}, Π_{UE}, and Π_L at the thresholds $\psi_2^f[\tau]$ and $\psi_3^f[\tau]$ is due to the buyer's switching in trade contract preference—from EXW to DAP, and then from DAP to DDP.

3.6 Discussions

In this section, we extend our baseline model to three scenarios. First, we introduce competition in the LSP market and analyze its implications for overall system performance in Section 3.6.1. Second, we extend the FOB based tariff calculation to a CIF based tariff calculation in Section 3.6.2. We then examine the preferences of supply chain parties and the government over the two tariff bases. Last, we explore a hypothetical trade contract, in which the buyer bears the freight cost while the supplier takes care of the tariff under FOB based tariff in Section 3.6.3.

3.6.1 Dedicated LSPs Under FOB Based Tariff

In the baseline model, we assume that a common LSP transports products for both UE and RT channels. It is noteworthy that the U.S. government has made efforts to promote competition in the logistics industry (J. Lynch 2021). Here, we consider another setting in which each channel has a dedicated LSP and both channels compete for the buyer's orders under FOB based tariff. Analogous to the baseline model, we normalize the unit delivery cost of both LSPs to zero to single out the pure effect of tariffs.[4] Let $\hat{\Pi}_{Lk}$ denote the expected profit of LSP k, $k \in \{1, 2\}$, which can be written as

$$\hat{\Pi}_{L1} = \hat{v}_{RT}\hat{q}_{RT} \quad \text{and} \quad \hat{\Pi}_{L2} = (1-\psi)\hat{v}_{UE}\hat{q}_{UE}. \tag{3.7}$$

Under this setting, the two LSPs decide their respective freight charge $v_i, i \in \{RT, UE\}$ in the first stage. The remaining game sequences are the same as those in the baseline model. For ease of notation, we use the superscript $\hat{}$ to denote the equilibrium outcomes with dedicated LSPs, which are presented in the proof of Proposition 3.11 in Appendix B.1. The following proposition presents the equilibrium sourcing strategy and the optimal freight charges under LSP competition.

Proposition 3.11 *Under FOB based tariff, the competition between LSPs under a given trade contract undercuts freight charges to their marginal cost, and the buyer always adopts dual sourcing.*

Recall from previous discussions that, given wholesale prices and freight charges, the buyer's sourcing decision in stage 3 of the game is as follows: if the prices of one channel are high, the buyer will single source from the other channel; otherwise, the buyer adopts dual sourcing.[5] Under competition, both LSPs have incentives to

[4] Our results also qualitatively hold when both LSPs have the same marginal cost c, with $c < a(1-\tau)$ ensuring nonnegative profits across all the three trade contracts. By contrast, when there exists a cost difference between the two LSPs, the buyer may single source from the chain with a lower marginal cost.

[5] We refer interested readers to the proof of Proposition 3.1 and Figure B.5 in Appendix B.1 for the detailed derivation and equilibrium analysis.

induce the buyer to solely source from their dedicated channel. This induces them to undercut freight charges with each other until reaching their marginal cost. However, this results in a dual-sourcing equilibrium in which order allocation between suppliers is arbitrary. This finding is significant because, if the buyer consistently relied on dual sourcing, freight charges would not be driven down to marginal cost. The intense price competition among logistics service providers only occurs due to the presence of a single-sourcing region. That is, driven by the buyer's potential adoption of single sourcing, both LSPs are incentivized to grab the entire market by lowering their prices to marginal cost. Next, we evaluate the impact of LSP competition on the supply chain parties.

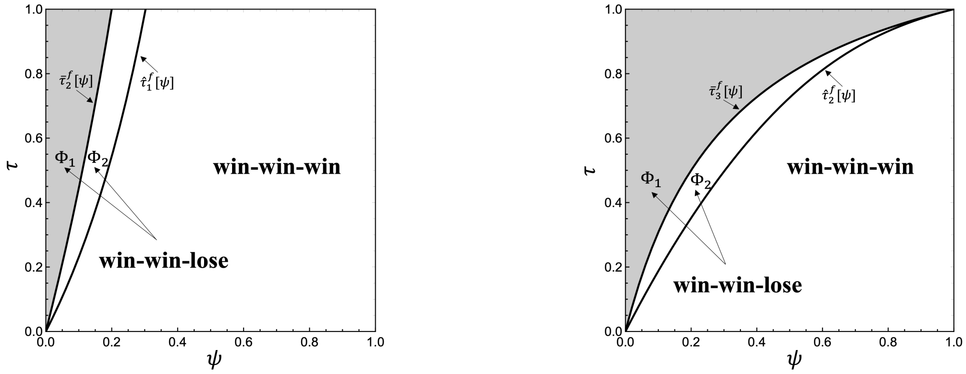
Proposition 3.12 *Under FOB based tariff, let $\hat{\tau}_1^f[\psi]$ and $\hat{\tau}_2^f[\psi]$ be thresholds defined in Table B.2. In a competitive LSP market, the following statements hold:*

(i) For a given trade contract, the buyer and the RT supplier are always better off under LSP competition (i.e., $\hat{\Pi}_B^j > \Pi_B^j$ and $\hat{\Pi}_{RT}^j > \Pi_{RT}^j, j \in \{E, A, D\}$).

(ii) Whether the UE supplier is better off under LSP competition depends on the adopted trade contract. Specifically,

1. *when EXW is adopted, the UE supplier is always better off (i.e., $\hat{\Pi}_{UE}^E > \Pi_{UE}^E$).*
2. *when DAP is adopted, the UE supplier is better off (i.e., $\hat{\Pi}_{UE}^A > \Pi_{UE}^A$) iff $\tau < min\{\hat{\tau}_1^f[\psi], 1\}$.*
3. *when DDP is adopted, the UE supplier is better off (i.e., $\hat{\Pi}_{UE}^D > \Pi_{UE}^D$) iff $\tau < \hat{\tau}_2^f[\psi]$.*

Proposition 3.12 reveals that, in most situations, competition benefits all supply chain members except dedicated LSPs whose freight charges are competed down. This result is intuitive, as the buyer and suppliers now incur lower freight charges. Proposition 3.12 further shows that competition can harm the UE supplier when the tariff rate is high under DAP and DDP. Recall that without competition, a high tariff rate can lead to the buyer single sourcing from the UE supplier under



(a) *DAP* (b) *DDP*

Figure 3.9: Impact of LSP Competition on Buyer, RT Supplier and UE Supplier Under FOB Based Tariff

DAP and DDP (i.e., region Φ_1 in Figure 3.9). By contrast, under LSP competition, dual sourcing becomes the unique equilibrium. Clearly, capturing the entire order volume is more profitable for the UE supplier, even with a higher freight charge. Our analysis also identifies a second scenario in which the LSP competition is harmful to the UE supplier even though dual sourcing remains the equilibrium (i.e., region Φ_2 in Figure 3.9). This is because, in addition to lowering freight charges, competition also mitigates the negative impact of the intensified triple marginalization effect in the RT channel, especially when the tariff rate is high. Meanwhile, the alleviation effect in the UE channel disappears once dedicated LSPs are unable to optimize across the two revenue streams. As a result, the UE supplier loses its competitive edge, while its rival RT supplier becomes more competitive, leading to a profit loss for the UE supplier. To summarize, promoting LSP competition can be an effective policy instrument for governments to reduce freight charges, which in general benefits the buyer and suppliers, particularly when the tariff rate is relatively low.

3.6.2 Impact of Tariff Calculation Basis on System Performance

In this section, we examine CIF, where the tariff is levied on the purchasing price as well as the freight charge. The final equilibrium outcomes are presented in Table B.4. Most of the previous results under FOB based tariff continue to hold under

CIF based tariff. Particularly, the buyer's preference over three trade contracts is given in the following corollary.

Corollary 3.4 *Under CIF based tariff, let $\bar{\tau}_1^c[\psi]$, $\tau_5^c[\psi]$, and $\tau_6^c[\psi]$ be thresholds defined in Table B.2. The buyer adopts dual sourcing iff $\tau \leq \bar{\tau}_1^c[\psi]$, under which the buyer prefers DDP contract if $\tau \leq \tau_6^c[\psi]$, prefers DAP contract if $\tau_6^c[\psi] < \tau \leq \tau_5^c[\psi]$, and prefers EXW contract if $\tau_5^c[\psi] < \tau \leq \bar{\tau}_1^c[\psi]$. Otherwise, the buyer finds it more advantageous to adopt a single-sourcing strategy.*

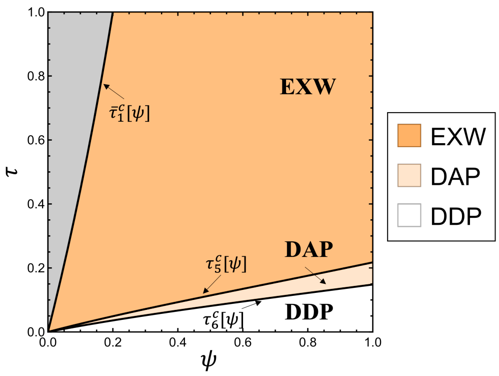


Figure 3.10: Buyer's Preference over Three Trade Contracts Under CIF Based Tariff

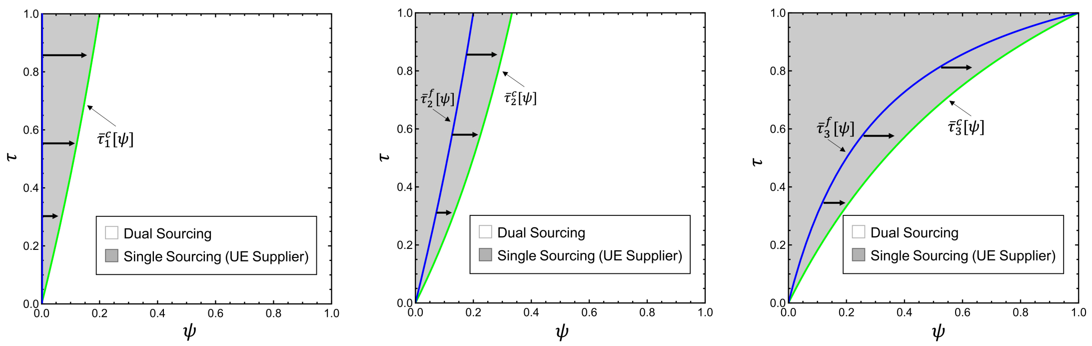
The different tariff calculation bases also lead to some qualitative changes. First, under CIF based tariff, when the tariff rate is high, the LSP's marginal profit in the UE channel also increases when comparing the equilibrium outcomes under EXW and DAP. That is, under CIF based tariff, the incitement effect not only occurs when the trade contract switches from DAP to DDP but also appears when it switches from EXW to DAP, which is in contrast to that under FOB based tariff. Second, we find that the single-sourcing strategy emerges in equilibrium under CIF based tariff; see Figure 3.10 for the illustration. This result is in sharp contrast to that under FOB based tariff, in which single sourcing cannot occur given the most preferred trade contract (see Corollary 3.1). This is because when the tariff rate is high, the intensified triple marginalization effect induces a single-sourcing strategy to occur under each trade contract.

Next, we compare the equilibria under FOB- and CIF-based tariff. We first compare the buyer's equilibrium sourcing strategies under each basis in Corollary 3.5, then focus on the supply chain members' preference over tariff calculation bases in Corollary 3.6, Propositions 3.13 and 3.14.

Corollary 3.5 *Comparing the buyer's equilibrium sourcing strategies between FOB- and CIF-based tariff, the following statements hold:*

(i) Given individual trade contract, $\bar{\tau}_i^c[\psi] < \bar{\tau}_i^f[\psi], i \in \{1, 2, 3\}$*, implying that single sourcing from the UE supplier is more possible under CIF based tariff.*

(ii) Given the most preferred trade contract, the buyer always adopts dual sourcing under FOB based tariff. However, there exists a region (e.g., $\tau > \bar{\tau}_1^c[\psi]$*) where the buyer opts for a single-sourcing strategy under CIF based tariff.*



(a) EXW (b) DAP (c) DDP

Figure 3.11: Comparison of Buyer's Equilibrium Sourcing Strategy Under FOB- and CIF-based Tariff

Corollary 3.5(i) shows that the buyer under CIF based tariff cannot use dual sourcing as frequently as it does under FOB based tariff. Moreover, as seen in Figure 3.11, for each trade contract, the boundary between the single-sourcing and dual-sourcing strategy moves to the right compared to the similar line under FOB based tariff. Alternatively, the scope for adopting a dual-sourcing strategy becomes narrower. The underlying reason is that the calculation of tariffs is also related to freight charges under CIF based tariff, which aggravates the triple marginalization effect in the RT channel due to the increased tariffs and further increases the difference between the buyer's marginal procurement cost in the two channels compared to the corresponding one under FOB based tariff. It turns out that the buyer tends to reduce orders in the RT channel and even solely source from the UE channel under CIF based tariff compared to FOB based tariff. The buyer's preferences under each trade contract directly lead to part (ii), which are also depicted by Figures 3.5 and 3.10. Specifically, the sole-sourcing region becomes larger under CIF based tariff even if we consider the buyer's most preferred trade contract between the two tariff calculation bases. Alternatively, only under the condition that CIF is adopted and the tariff rate is relatively high, the buyer gives up purchasing from the RT supplier and solely relies on the partner within the free trade areas.

We now examine how the buyer's preference differs under FOB- and CIF-based tariff. Note that we only compare the buyer's most preferred trade contract under each tariff calculation basis. In general, all the three trade contracts are practically available for the trade parties, but each focal country usually adopts one tariff calculation basis, such as FOB or CIF. Therefore, we evaluate the buyer's preference between FOB- and CIF-based tariff by assuming that all three contracts are available for the buyer to adopt.

Corollary 3.6 *Comparing the buyer's most preferred trade contract between FOB- and CIF-based tariff, there exist thresholds $\tau_4^f[\psi], \tau_5^f[\psi], \tau_6^c[\psi]$ and $\tau_1[\psi]$ (whose expressions are the same as those in previous propositions) such that*

(i) CIF coupled with DDP is adopted (i.e., $\widetilde{\Pi}_B^D > \Pi_B^D$) iff $\tau \le \tau_6^c[\psi]$.

(ii) CIF coupled with DAP is adopted (i.e., $\widetilde{\Pi}_B^A \ge \Pi_B^D$) iff $\tau_6^c[\psi] < \tau \le \tau_1[\psi]$.

(iii) FOB coupled with DDP is adopted (i.e., $\Pi_B^D > \widetilde{\Pi}_B^A$) iff $\tau_1[\psi] < \tau \le \tau_5^f[\psi]$.

(iv) FOB coupled with DAP and CIF coupled with EXW are both equally preferred (i.e., $\Pi_B^A = \widetilde{\Pi}_B^E$) iff $\tau_5^f[\psi] < \tau \le \tau_4^f[\psi]$.

(v) FOB coupled with EXW is adopted (i.e., $\Pi_B^E > \widetilde{\Pi}_B^E$) iff $\tau > \tau_4^f[\psi]$.

Proposition 3.13 *The buyer strictly prefers CIF iff $\tau \le \tau_1[\psi]$, and strictly prefers FOB iff $\tau_1[\psi] < \tau \le \tau_5^f[\psi]$ or $\tau > \tau_4^f[\psi]$. Otherwise, the buyer is indifferent between FOB- and CIF-based tariff.*

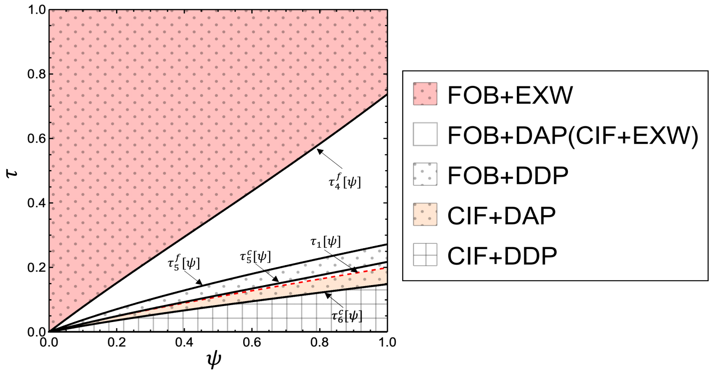


Figure 3.12: Buyer's Most Preferred Trade Contract by Comparing FOB- and CIF-based Tariff

Corollary 3.6 and Proposition 3.13 jointly characterize the buyer's preference under six possible combinations of tariff basis and trade contract, as depicted in Figure 3.12, which gives rise to an interesting result: when the tariff rate is low, the buyer prefers CIF; when the tariff rate is high, the buyer prefers FOB. Note that both the switching from FOB to CIF and from EXW to DDP result in an intensified triple marginalization effect in the RT channel. The difference is that the former is due to the new component of the tariff basis (i.e., freight charge), while the latter is attributed to an increase in the wholesale price of the tariff basis. Therefore, when moving from FOB to CIF, the previous three effects continue to hold. To be specific, when the tariff rate τ is small, CIF is adopted since the buyer can reduce the order volume of the RT channel with a marginal cost disadvantage and increase the quantity of the UE channel where the alleviation effect has a higher impact than the exploitation effect. However, with the increase in tariff rate, the alleviation effect is overwhelmed by the incitement effect. Under CIF based tariff, the exploitation effect, together with the incitement effect, is detrimental to the buyer by increasing marginal procurement costs in the UE channel. Thus, the buyer is hurt because both channels face higher marginal costs under CIF based tariff as compared to that under FOB based tariff. An alternative explanation is that, as τ increases, the impact of the tariff basis becomes more significant. Given a low τ, the tariff basis can contain more cost components, i.e., CIF is adopted. However, the cost becomes too high to be profitable for the buyer with the increase of τ. Thus, the buyer shifts to a more moderate basis, i.e., FOB, where the tariff basis consists of fewer cost components. These insights provide useful guidance to policymakers on how to help domestic firms improve their profits. Specifically, CIF is preferable by the domestic buyer if the country imposes low tariffs, and FOB is favorable otherwise.

In the following proposition, we compare the other parties' preferences between the two tariff calculation bases. Note that the LSP and the RT supplier always prefer EXW while the UE supplier prefers DDP under both FOB- and CIF-based tariff.

Proposition 3.14 *Given the most preferred trade contract of the LSP, the RT supplier and the UE supplier under FOB- and CIF-based tariff, we have the following:*

(i) The RT supplier and the LSP are better off under FOB based tariff (i.e., $\Pi_{RT}^{E} > \widetilde{\Pi}_{RT}^{E}$ *and* $\Pi_{L}^{E} > \widetilde{\Pi}_{L}^{E}$*).*

(ii) The UE supplier is better off under CIF based tariff (i.e., $\widetilde{\Pi}_{UE}^{D} > \Pi_{UE}^{D}$*).*

In contrast to the buyer, whose preference between FOB and CIF depends on the tariff rate (see Proposition 3.13), Proposition 3.14 shows that the preferences of other supply chain members are not influenced by the tariff rate. Specifically, the LSP and the RT supplier favor FOB, while the UE supplier prefers CIF. Intuitively, CIF adds freight charges to the tariff basis, which is detrimental to the RT channel but beneficial for the UE channel, rendering the latter more competitive as the UE supplier is unrelated to tariffs. This leads to different preferences over tariff calculation bases for both suppliers. Although the LSP can improve profits from the UE channel through the alleviation effect and the incitement effect, such adjustment cannot make up for the profit loss from the RT channel caused by the intensified triple marginalization effect under CIF based tariff. As such, the LSP always prefers FOB.

3.6.3 Contract H

In this section, we examine a hypothetical trade contract where the buyer is responsible for the freight cost, while the supplier undertakes the tariff, under both FOB- and CIF-based tariff. For ease of reference, we term this setting as Contract

H. Table 3.3 summarizes the expected profit function of each player in contract H under both FOB- and CIF-based tariff. By backward induction, we are able to fully derive the equilibrium results under FOB- and CIF-based tariff, which are presented in the proof of Corollary 3.7 in Appendix B.1. The following corollary characterizes the buyer's most preferred trade contract among the four.

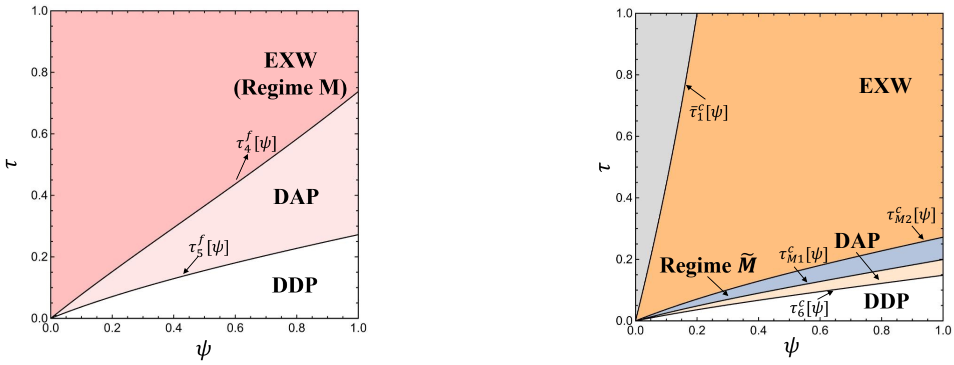
Corollary 3.7 *Under FOB based tariff, the profits of the buyer, the UE supplier, and the LSP under contract H are the same as those under EXW, while the profit of the RT supplier is lower than that under EXW.*

Table 3.3: Expected Profit Functions in Contract H

	Contract H Under FOB Based Tariff		Contract H Under CIF Based Tariff
Π_{RT}^H	$(1-\tau)w_{RT}^H q_{RT}^H$	$\widetilde{\Pi}_{RT}^H$	$((1-\tau)\widetilde{w}_{RT}^H - \tau\widetilde{v}_{RT}^H)\widetilde{q}_{RT}^H$
Π_{UE}^H	$(1-\psi)w_{UE}^H q_{UE}^H$	$\widetilde{\Pi}_{UE}^H$	$(1-\psi)\widetilde{w}_{UE}^H\widetilde{q}_{UE}^H$
Π_L^H	$v_{RT}^H q_{RT}^H + (1-\psi)v_{UE}^H q_{UE}^H$	$\widetilde{\Pi}_L^H$	$\widetilde{v}_{RT}^H\widetilde{q}_{RT}^H + (1-\psi)\widetilde{v}_{UE}^H\widetilde{q}_{UE}^H$
Π_B^H	$R^H - (C_{RT}^H + C_{UE}^H)$	$\widetilde{\Pi}_B^H$	$\widetilde{R}^H - (\widetilde{C}_{RT}^H + \widetilde{C}_{UE}^H)$
R^H	$\psi p_d^H q_{RT}^H + (1-\psi)p_n^H(q_{RT}^H + q_{UE}^H)$	$\widetilde{R}^H$	$\psi\widetilde{p}_d^H\widetilde{q}_{RT}^H + (1-\psi)\widetilde{p}_n^H(\widetilde{q}_{RT}^H + \widetilde{q}_{UE}^H)$
C_{RT}^H	$(w_{RT}^H + v_{RT}^H)q_{RT}^H$	$\widetilde{C}_{RT}^H$	$(\widetilde{w}_{RT}^H + \widetilde{v}_{RT}^H)\widetilde{q}_{RT}^H$
C_{UE}^H	$(1-\psi)(w_{UE}^H + v_{UE}^H)q_{UE}^H$	$\widetilde{C}_{UE}^H$	$(1-\psi)(\widetilde{w}_{UE}^H + \widetilde{v}_{UE}^H)\widetilde{q}_{UE}^H$

Corollary 3.7 shows that under FOB based tariff, the profits for the buyer, the UE supplier, and the LSP under contract H are the same as those under EXW, but the profit of the RT supplier is lower than that under EXW. The underlying reasons are as follows: When switching from EXW to contract H, the RT supplier incurs additional tariff costs, while the UE supplier is exempted from tariffs. This compels the RT supplier to increase the wholesale price to cover this extra cost. We can show that the tariff cost is entirely transferred to the buyer in the RT channel. Thus, both the marginal procurement cost and the order quantity for the buyer remain unchanged across the two contracts. Thus, the buyer, the LSP, and the UE supplier earn the same profit under EXW and contract H. However, compared to EXW, the RT supplier has a lower profit under contract H. This is because the RT supplier incurs greater tariff costs, despite being able to charge a higher wholesale price. Note that when comparing contract H with DAP, in the former only the RT

supplier bears tariffs, whereas in the latter both suppliers are responsible for freight charges. Consequently, under DAP, both suppliers have incentives to increase their wholesale prices, which weakens price competition between them relative to contract H. This reduced competition, in turn, intensifies the triple marginalization effect in the RT channel when transitioning from contract H to DAP.



(a) FOB (b) CIF

Figure 3.13: Buyer's Preference over Four Trade Contracts Under FOB- and CIF-based Tariff

Corollary 3.8 *Under CIF based tariff, let* $\bar{\tau}_1^c[\psi]$, $\tau_{H1}^c[\psi]$, $\tau_{H2}^c[\psi]$ *and* $\tau_6^c[\psi]$ *be thresholds defined in Table B.2. The buyer prefers DDP contract iff* $\tau \leq \tau_6^c[\psi]$*, DAP contract iff* $\tau_6^c[\psi] < \tau \leq \tau_{H1}^c[\psi]$*, contract* H *iff* $\tau_{H1}^c[\psi] < \tau \leq \tau_{H2}^c[\psi]$*, and EXW contract iff* $\tau_{H2}^c[\psi] < \tau \leq \bar{\tau}_1^c[\psi]$*. Otherwise, the buyer adopts single sourcing. Moreover, the LSP and the RT supplier always prefer EXW, whereas the UE supplier always prefers DDP.*

Corollary 3.8 yields the following insights under CIF based tariff: (1) An increase in the tariff rate shifts the buyer's trade contract preference from DDP to DAP, then to contract H, and finally to EXW (see Figure 3.13); and (2) the LSP and the RT supplier are always better off under EXW, whereas the UE supplier always obtains the highest profits under DDP. The underlying reason is that, under CIF based tariff, the triple marginalization effect in the RT channel is intensified, both when the contract switches from EXW to contract H and when it switches from contract H to DAP. Unlike that under FOB based tariff, the tariff is levied on both purchasing cost and freight charge under CIF based tariff. Therefore, under CIF based tariff, when switching from EXW to contract H, the RT supplier is compelled to raise the wholesale price to cover the increased tariff cost. This exacerbates the triple marginalization effect in the RT channel. Consequently, the buyer faces a marginal procurement cost disadvantage in the RT channel under contract H compared to EXW. This differs from FOB based tariff, where the buyer's marginal procurement cost in the RT channel remains unchanged when switching from EXW to contract H. Similar to the case of switching from contract H to DAP under FOB based tariff, the triple marginalization effect in the RT channel intensifies when switching from contract H to DAP under CIF based tariff, due to weakened competition among suppliers bearing freight charges.

Combining these observations, we can conclude that under CIF based tariff, when switching from EXW to contract H to DAP, the triple marginalization effect in the RT channel intensifies. Thus, the trade-off among the exploitation effect, the alleviation effect, and the incitement effect, as defined in the main paper for the contract transition from EXW to DAP to DDP, continues to apply in this context. Consequently, as the tariff rate increases, the buyer's contract preference shifts from DAP to contract H and then to EXW under CIF based tariff. Notably, contract H functions as an intermediate contract between EXW and DDP, as switching from contract H to DDP requires the supplier to bear additional freight charges. Thus, we can obtain that the LSP and the RT supplier always prefer EXW, while the UE supplier always prefers DDP.

3.7 Conclusions

This paper studies supply chain parties' preference for different trade contracts (i.e., EXW, DAP, DDP) specified by Incoterms, focusing on who should bear freight charges and import tariffs. Below, we highlight our key results and their corresponding managerial implications.

First, regarding the buyer's preference for the trade contract, we find that as the tariff rate increases, the buyer becomes more willing to bear both the freight charge and the tariff. Notably, DDP has been one of the most widely adopted trade contracts for cross-border trade among buyers in recent years (Callarman 2019). Besides the fact that buyers bear less risk as the suppliers assume delivery responsibility, our results suggest that the low tariff rate under FTAs is an important factor for buyers to choose DDP. The newly imposed U.S. tariffs on goods from China have considerably raised the tariff burden for U.S. importers. In practice, many SME buyers have chosen to bear these higher tariff costs themselves (CHINA NEWS 2025, Picchi 2025), which is consistent with our analytical finding. Therefore, buyers should tailor-make their trade contract decisions in alignment with the prevailing tariff environment to safeguard profitability.

Second, our results indicate that under disruption risks, the buyer tends to select a lower-cost supplier before considering incorporating a more reliable, albeit higher-cost, supplier into the supplier base. This implies that the buyer can utilize a dual-sourcing strategy, leveraging the higher-cost but more reliable supplier as a safeguard to mitigate disruptions from the lower-cost, less reliable supplier. We further show that the buyer always adopts dual sourcing under EXW, which is preferred by the reliable supplier located outside the free trade area. This outcome suggests that reliable suppliers located outside the free trade area facing substantial tariff burdens may enhance their strategic decision-making by engaging in trade contract negotiations, particularly given that SME buyers often operate under narrow profit margins and have limited bargaining power.

Third, we investigate the impact of disruption risk on supply chain performance and find that, contrary to our intuition, a supplier may be worse off as its reliability increases. This occurs because the improvement in the reliability of one supplier could pressurize its competitor to lower the wholesale price. This, in turn, intensifies the price competition between the two suppliers and reduces the reliable supplier's profit. Such a result corroborates the observation that improvements in reliability do not necessarily translate into higher profits, particularly in highly competitive markets (Viet Nam News 2023). Thus, this finding provides a crucial managerial insight for unreliable suppliers located in a free trade area in international trade: the supplier should recognize that the effect of its reliability is influenced by both the reliability and costs of its rivals when competing for orders.

Moreover, we identify a tariff rate at which the sourcing quantity from the reliable supplier located outside the free trade area is the smallest while that from the unreliable supplier located in a free trade area is the largest. This is aligned with the observation that the U.S. has appropriately raised its tariff rates to reduce domestic buyers' reliance on suppliers outside the free trade areas (Lim and Kiderlin 2025). Note that countries that have FTAs with each other can be seen as allies. This finding also echoes a recent policy called ally-sourcing (Dezenski and Austin 2021). It indicates that if the tariff rate is set at an appropriate level, the domestic buyer can be incentivized to switch its preference over the trade contract and conduct business with partners in the free trade areas, which strengthens the cooperation with allies. This might be regarded as a short-term strategy on how policymakers can keep business with partners in free trade areas and reduce reliance on suppliers outside free trade areas, which is achievable by tailor-make the tariff rate.

Finally, we highlight policy insights concerning LSP competition from the policymaker's perspective. Apart from the tariff issue, the globalized supply chain is also grappling with high freight charges. According to UNCTAD's Review of Maritime Transport (UNCTAD 2021), freight costs have experienced a significant increase since 2020. White House officials argued in 2021 that the lack of competition allowed LSPs to exploit the COVID-19 pandemic by raising freight charges. Consequently, U.S. policymakers have enacted the Ocean Shipping Reform Act to increase competition among LSPs in the maritime industry (Windward 2025). Our findings suggest that this move could be effective and lead to a dual-sourcing equilibrium; it would benefit both the buyer and the reliable supplier located outside the free trade area, but it may hurt the unreliable supplier located in a free trade area if the tariff rate is high.

Chapter 4

Summary and Future Work

We focus on the impact of two tariff-associated regulations on global sourcing. In the first part, we begin by exploring how two types of carbon border regulations, namely CBAM and CCA, influence buyers' sourcing preferences and the carbon emissions of their suppliers. We show that CCA tends to be more effective than CBAM in steering buyers toward domestic sourcing, which contributes positively to national employment levels and strengthens the local economy. Moreover, when the cost of domestic production remains low, CCA can lead to outcomes that are beneficial both for the buyer and society. In contrast, when production expenses are moderate and the financial burden of investing in emission reduction is substantial, the differences in performance between the two regulatory approaches become negligible. We also find that although CCA generally results in greater investment in reducing emissions compared with CBAM, its effectiveness in lowering total emissions is not guaranteed. Taken together, these findings suggest that policy effectiveness depends heavily on how well regulatory frameworks are matched with the cost characteristics of suppliers, especially when aiming to balance economic benefits with environmental impact. Admittedly, our model has certain limitations that open up opportunities for future research. First, we consider a single buyer in our framework, whereas in reality, multiple buyers often compete for a limited low-carbon supply. This competition could significantly influence sourcing strategies and shift bargaining power in the supply chain. For instance, in a carbon-constrained environment, large multinational buyers might secure green inputs through long-term contracts, while small and medium-sized enterprises could face greater difficulty accessing low-emission suppliers and may be disproportionately affected by carbon border policies. Future extensions could incorporate a multi-buyer game-theoretic model to examine how buyers with varying sizes, bargaining power, and sustainability goals respond under different regulatory scenarios. Second, our model captures cost asymmetry between two suppliers but does not account for uncertainty in supply availability. In practical global supply chains, especially those involving international suppliers, there are risks such as political instability, climate-related disruptions, or technological failures that can affect supply reliability. For example, a foreign supplier with low production costs might have a higher probability of delivery failure due to geopolitical tensions or infrastructure weaknesses. Introducing stochastic elements or scenario-based disruptions into the model could help evaluate how buyers adjust sourcing decisions under risk, and whether policies like CBAM or CCA are more resilient in uncertain environments.

We then investigate how supply chain participants evaluate different trade contracts defined by Incoterms—specifically EXW, DAP, and DDP—with an emphasis on the allocation of responsibility for freight costs and import duties. Our results show that: (1) Under a common LSP, the buyer may prefer to bear both tariffs and freight charges when the tariff rate is high; and (2) higher disruption risks generally reduce the profits of both the buyer and the logistics service provider, while potentially benefiting the less reliable supplier within free trade areas. As a direction for future research, one promising extension is to treat the tariff rate, which is currently an exogenous parameter in our thesis, as a variable that fluctuates over time. In practice, tariff rates often change due to factors such as trade negotiations, geopolitical developments, or retaliatory trade actions. For example, temporary tariffs imposed by the United States on steel and aluminum imports, or newly introduced environmental compliance tariffs targeting exports from certain developing countries, can create significant uncertainty for global buyers. Incorporating tariff volatility into the model would allow for a more realistic analysis of how buyers adapt their sourcing strategies and trade contract choices in a changing policy landscape. Another promising direction for future research is to consider the scenario where two separate LSPs adopt different Incoterms. While a common LSP would naturally apply the same Incoterm to both suppliers, allowing different Incoterms for separate LSPs could lead to new insights regarding sourcing strategies, cost structures, and supply chain coordination. A more comprehensive comparison may help better understand the role of dedicated LSPs and their associated impacts on global sourcing.

Appendix A

Appendix for Chapter 2

A.1 Proofs of Statements

A.1.1 Proof of Lemma 2.1

In the final stage, suppose the buyer sources from supplier F under CBAM. The buyer determines the optimal retail price p_F by solving the following maximization problem: $\max_{p_F} \pi_B = (p_F - w_F - \kappa e_F)q_F$, where $q_F = 1 - p_F$. Taking the first-order condition (FOC) with respect to p_F and solving for p_F, we obtain the optimal retail price: $p_F^* = \frac{1}{2}(1 + w_F + \kappa e_F)$. Given p_F^*, supplier F chooses the optimal wholesale price w_F and emission intensity e_F to maximize profits under CBAM: $\max_{w_F, e_F} \pi_F = w_F q_F - (1 - e_F)^2 = \frac{1}{2} w_F(1 - w_F - \kappa e_F) - (1 - e_F)^2$. Taking the FOC with respect to w_F and e_F and solving the resulting equations, the optimal solutions are given by $w_F^* = \frac{4(1-\kappa)}{8-\kappa^2}$ and $e_F^* = \frac{8-\kappa}{8-\kappa^2}$, respectively. Similarly, consider the case where the buyer sources from supplier D. The buyer's profit maximization problem is given by $\max_{p_D} \pi_B = (p_D - w_D)q_D$ and supplier D's profit maximization problem is given by $\max_{w_D, e_D} \pi_D = (w_D - c - \kappa e_D)q_D - \beta(1 - e_D)^2$. Similarly, the optimal retail price, wholesale price, and emission intensity can be derived following the same approach as above. If $\kappa < \beta < 1$ and $c < 1 - \kappa$, the results are given by $e_D^{\mathcal{M}} = \frac{8\beta-(1-c)\kappa}{8\beta-\kappa^2}$, $w_D^{\mathcal{M}} = \frac{4\beta(1+c+\kappa)-\kappa^2}{8\beta-\kappa^2}$, and $p_D^{\mathcal{M}} = 1 - \frac{2\beta(1-c-\kappa)}{8\beta-\kappa^2}$. All the equilibrium outcomes under CBAM for a given κ are summarized in Table 2.2.

When the buyer sources from supplier F, taking the second derivative of $1 - e_F$

with respect to κ yields $\frac{\partial^2(1-e_F)}{\partial\kappa^2} = \frac{2(\kappa^3-24\kappa^2+24\kappa-64)}{(8-\kappa^2)^3} < 0$, which implies that $1-e_F$ is a concave function of κ. Then, differentiating $1-e_F$ with respect to κ yields $\frac{\partial(1-e_F)}{\partial\kappa} = \frac{\kappa^2-16\kappa+8}{(8-\kappa^2)^2} > 0$ for $\kappa < 2(4-\sqrt{14})$, which indicates that $1-e_F$ is unimodal in κ. Similarly, differentiating T_F with respect to κ yields $\frac{\partial T_F}{\partial\kappa} = \frac{2(\kappa^2-16\kappa+8)(\kappa^2-2\kappa+8)}{(8-\kappa^2)^3} > 0$ for $\kappa < 2(4-\sqrt{14})$, which indicates that T_F is unimodal in κ. In addition, we have the following monotonicity results for other variables with respect to κ: $\frac{\partial w_F}{\partial\kappa} = -\frac{4(\kappa^2-2\kappa+8)}{(8-\kappa^2)^2} < 0$, and $\frac{\partial p_F}{\partial\kappa} = \frac{2(\kappa^2-2\kappa+8)}{(8-\kappa^2)^2} > 0$, $\frac{\partial q_F}{\partial\kappa} = -\frac{2(\kappa^2-2\kappa+8)}{(8-\kappa^2)^2} < 0$, $\frac{\partial\pi_F}{\partial\kappa} = -\frac{2(8-\kappa)(1-\kappa)}{(8-\kappa^2)^2} < 0$, $\frac{\partial\Pi_B}{\partial\kappa} = -\frac{8(1-\kappa)(\kappa^2-2\kappa+8)}{(8-\kappa^2)^3} < 0$, $\frac{\partial U_F}{\partial\kappa} = -\frac{4(1-\kappa)(\kappa^2-2\kappa+8)}{(8-\kappa^2)^3} < 0$, $\frac{\partial C_F}{\partial\kappa} = \frac{2(2\kappa^3-27\kappa^2+48\kappa-72)}{(8-\kappa^2)^3} < 0$. Similarly, when the buyer sources from supplier D, the comparative statics of the equilibrium outcomes with respect to κ can be derived in the same manner. The results exhibit analogous properties: the relevant variables are either unimodal or monotonic in κ, consistent with the findings for the case of sourcing from supplier F. $\square$

A.1.2 Proof of Proposition 2.1

Comparing the buyer's profit between sourcing from supplier F and supplier D, we get that

$$\Pi_{BD} - \Pi_{BF} = \frac{4\beta^2(8-\kappa^2)^2(1-c-\kappa)^2 - 4(1-\kappa)^2(8\beta-\kappa^2)^2}{(8-\kappa^2)^2(8\beta-\kappa^2)^2}.$$

We get that the sufficient and necessary condition for $\Pi_{BD} - \Pi_{BF} \geq 0$ is:

$$c \leq 1-\kappa - \frac{(1-\kappa)(8\beta-\kappa^2)}{\beta(8-\kappa^2)} = \frac{(1-\beta)(1-\kappa)\kappa^2}{\beta(8-\kappa^2)}. \square$$

A.1.3 Proof of Proposition 2.2

By backward induction, in stage 1, the buyer sources from the domestic supplier if $c \leq \frac{(1-\beta)(1-\kappa)\kappa^2}{\beta(8-\kappa^2)}$, which is equal to $f(\kappa) = (1-\beta)\kappa^3 - (1-\beta+c\beta)\kappa^2 + 8\beta c \geq 0$. Solving $f(\kappa) \geq 0$ yields (1) $0 < c < c_2^{\mathcal{M}}(\beta)$ and $\kappa_1^{\mathcal{M}}(\beta, c) \leq \kappa < \beta$, or (2) $c_2^{\mathcal{M}}(\beta) \leq c < c_3^{\mathcal{M}}(\beta)$, $\beta > \beta_1^{\mathcal{M}}$, and $\kappa_1^{\mathcal{M}}(\beta, c) \leq \kappa < \kappa_2^{\mathcal{M}}(\beta, c)$. Define $c_2^{\mathcal{M}}(\beta) = \frac{(1-\beta)^2\beta}{8-\beta^2}$, $c_3^{\mathcal{M}}(\beta)$ is unique and satisfies ${c_3^{\mathcal{M}}}^3\beta^3 + 3{c_3^{\mathcal{M}}}^2\beta^2(1-\beta) - 51c_3^{\mathcal{M}}\beta(1-\beta)^2 + (1-\beta)^3$, $\kappa_1^{\mathcal{M}}$ is unique and satisfies ${\kappa_1^{\mathcal{M}}}^3(1-\beta) - {\kappa_1^{\mathcal{M}}}^2(1-\beta+\beta c) + 8\beta c = 0$, $\kappa_2^{\mathcal{M}}$ is unique and satisfies ${\kappa_2^{\mathcal{M}}}^3(1-\beta) - {\kappa_2^{\mathcal{M}}}^2(1-\beta+\beta c) + 8\beta c = 0$. $\beta_1^{\mathcal{M}}$ is unique and satisfies ${\beta_1^{\mathcal{M}}}^3 - 24\beta_1^{\mathcal{M}} + 16 = 0$. Otherwise, if $f(\kappa) < 0$, the buyer sources from the foreign supplier otherwise.

In stage 0, the government decides the carbon price κ to maximize:

$$S_i^{\mathcal{M}} = \begin{cases} \Pi_B^{\mathcal{M}} + \pi_D^{\mathcal{M}} + U_D^{\mathcal{M}} + T_D^{\mathcal{M}}, & \text{if } f(\kappa) \geq 0, \\ \Pi_B^{\mathcal{M}} + U_F^{\mathcal{M}} + T_F^{\mathcal{M}}, & \text{if } f(\kappa) < 0. \end{cases} \tag{A.1}$$

(1) If $f(\kappa) \geq 0$, differentiating (A.1) with respect to κ yields

$$\begin{aligned} \frac{\mathrm{d}S_D^{\mathcal{M}}}{\mathrm{d}\kappa} &= \frac{2\beta(2\kappa^4(1-c) - 3\kappa^3((1-c)^2+6\beta) + 30\kappa^2\beta(1-c) + 4\beta\kappa((1-c)^2-4\beta) - 48\beta^2(1-c))}{(8\beta-\kappa^2)^3} \\ &< \frac{2\beta(2\beta^2(1-c) - 3\kappa^3((1-c)^2+6\beta) + 30\beta^2(1-c) + 4\beta^2((1-c)^2-4\beta) - 48\beta^2(1-c))}{(8\beta-\kappa^2)^3} \\ &< \frac{2\beta(4\beta^2((c-1)(c+3)-4\beta) - 3\kappa^3((1-c)^2+6\beta))}{(8\beta-\kappa^2)^3} < 0. \end{aligned}$$

This implies that $S_D^{\mathcal{M}}$ is decreasing in κ, which further implies that $\frac{\mathrm{d}f(\kappa)}{\mathrm{d}\kappa}\Big|_{\kappa=\kappa_1^{\mathcal{M}}} < 0$. Thus, $\kappa^{\mathcal{M}*} = \kappa_1^{\mathcal{M}}$ maximizes $S_D^{\mathcal{M}}$ and satisfies $f(\kappa_1^{\mathcal{M}}) \geq 0$, which equals to $c < c_a^{\mathcal{M}}(\beta)$, where $c_a^{\mathcal{M}}(\beta) = \begin{cases} c_2^{\mathcal{M}}(\beta), & \text{if } \beta \leq \beta_1^{\mathcal{M}}, \\ c_3^{\mathcal{M}}(\beta), & \text{if } \beta > \beta_1^{\mathcal{M}}. \end{cases}$.

(2) If $f(\kappa) < 0$, takeing the second derivative of (A.1) with respect to κ yields

$$\frac{\mathrm{d}^2 S_F^{\mathcal{M}}}{\mathrm{d}\kappa^2} = \frac{4(\kappa^5 - 18\kappa^4 + 76\kappa^3 - 354\kappa^2 + 288\kappa - 336)}{(\kappa^2-8)^4} < 0.$$

This implies that $S_F^{\mathcal{M}}$ is concave in κ when $f(\kappa) > 0$. Differentiating (A.1) with respect to κ yields

$$\frac{\mathrm{d}S_F^{\mathcal{M}}}{\mathrm{d}\kappa} = \frac{2((\kappa-10)\kappa+2)((\kappa-2)\kappa+8)}{(8-\kappa^2)^3}.$$

Solving the above equation equals zero and and isolating κ yields the optimal interior solution $\kappa^* = 5-\sqrt{23}$ for $5-\sqrt{23} < \beta < 1$ and $\frac{(44\sqrt{23}-211)(1-\beta)}{5(\sqrt{23}-4)\beta} < c < \sqrt{23}-4$. However, when these conditions are not met, the optimal solution may occur at one of the boundary points. Define $c_b^{\mathcal{M}}(\beta) = \begin{cases} c_2^{\mathcal{M}}(\beta), & \text{if } \beta \leq 5-\sqrt{23}, \\ \frac{(44\sqrt{23}-211)(1-\beta)}{5(\sqrt{23}-4)\beta}, & \text{if } \beta > 5-\sqrt{23}. \end{cases}$.

Considering both the interior and boundary solutions, the optimal value of $\kappa^{\mathcal{M}*}$ can be summarized as follows:

$$\kappa^{\mathcal{M}*} = \begin{cases} \kappa_1^{\mathcal{M}}, & \text{if } c \leq c_b^{\mathcal{M}}(\beta), \\ 5-\sqrt{23}, & \text{if } \beta > 5-\sqrt{23} \text{ and } \frac{(44\sqrt{23}-211)(1-\beta)}{5(\sqrt{23}-4)\beta} < c \leq \sqrt{23}-4, \\ \beta, & \text{if } \beta \leq 5-\sqrt{23} \text{ and } c_2^{\mathcal{M}}(\beta) < c \leq 1-\beta, \\ 1-c, & \textit{Otherwise}. \end{cases} \tag{A.2}$$

(3) Then, we compare the values of $S^{\mathcal{M}}$ for a buyer sourcing from supplier D and supplier F in regions $c \leq c_b^{\mathcal{M}}(\beta)$ and $c_b^{\mathcal{M}}(\beta) < c \leq c_a^{\mathcal{M}}(\beta)$.

Case 1: $c \leq c_b^{\mathcal{M}}(\beta)$.

In this region, the optimal carbon price for both suppliers is $\kappa^{\mathcal{M}*} = \kappa_1^{\mathcal{M}}$. Comparing $S_D^{\mathcal{M}}$ and $S_F^{\mathcal{M}}$ ireduces to comparing $S_D^{\mathcal{M}}(c = c_1^{\mathcal{M}})$ and $S_F^{\mathcal{M}}$. Thus, we get that $S_D^{\mathcal{M}}(c = c_1^{\mathcal{M}}) - S_F^{\mathcal{M}} = \frac{(1-\kappa)^2(8\beta+(2\beta-3)\kappa^2)}{\beta(8-\kappa^2)^2} > 0$ since $\kappa < \beta$. Consequently, when $c \leq c_b^{\mathcal{M}}(\beta)$, we have $S_D^{\mathcal{M}} > S_F^{\mathcal{M}}$.

Case 2: $c_b^{\mathcal{M}}(\beta) < c \leq c_a^{\mathcal{M}}(\beta)$.

In this region, we compare $S_D^{\mathcal{M}}(\kappa^{\mathcal{M}*} = \kappa_1^{\mathcal{M}})$ with $S_F^{\mathcal{M}}(\kappa^{\mathcal{M}*} = 5-\sqrt{23})$. Define $s(c) = S^{\mathcal{M}}(\kappa^{\mathcal{M}*} = \kappa_1^{\mathcal{M}}) - S^{\mathcal{M}}(\kappa^{\mathcal{M}*} = 5-\sqrt{23})$, we get that

$$s(c) = \frac{\beta(1-c-\kappa_1^{\mathcal{M}})(\kappa_1^{\mathcal{M}3} - 3(1-c)\kappa_1^{\mathcal{M}2} + 2\beta\kappa_1^{\mathcal{M}} + 14\beta(1-c))}{(\kappa_1^{\mathcal{M}2} - 8\beta)^2} - \frac{1}{10}$$

Recall that $\frac{\mathrm{d}f(\kappa)}{\mathrm{d}\kappa}\big|_{\kappa=\kappa_1^{\mathcal{M}}} < 0$ and $\frac{\mathrm{d}f(\kappa)}{\mathrm{d}c} = \beta(8-\kappa^2) > 0$. Because $\kappa_1^{\mathcal{M}}$ satisfies the binding constraint $f(\kappa_1^{\mathcal{M}}) = 0$, by using the implicit function theorem, we can show that

$$\frac{\mathrm{d}\kappa_1^{\mathcal{M}}}{\mathrm{d}c} = -\frac{\frac{\mathrm{d}f(\kappa)}{\mathrm{d}c}\big|_{\kappa=\kappa_1^{\mathcal{M}}}}{\frac{\mathrm{d}f(\kappa)}{\mathrm{d}\kappa}\big|_{\kappa=\kappa_1^{\mathcal{M}}}} > 0$$

This implies that $\kappa_1^{\mathcal{M}}$ is increasing in c. Differentiating $s(c)$ with respect to c

yields

$$\frac{\mathrm{d}s(c)}{\mathrm{d}c} = \frac{2\beta(2\kappa_1^{\mathcal{M}^5} + (1-c)\kappa_1^{\mathcal{M}^4}(2\kappa_1^{\mathcal{M}'} - 3) - \kappa_1^{\mathcal{M}^3}(22\beta + 3\kappa_1^{\mathcal{M}'}(6\beta + (1-c)^2)) + 2\beta(1-c)\kappa_1^{\mathcal{M}^2}(15\kappa_1^{\mathcal{M}'} + 19))}{(8\beta - \kappa_1^{\mathcal{M}^2})^3}$$
$$+ \frac{2\beta(4\beta\kappa_1^{\mathcal{M}}(12\beta + \kappa_1^{\mathcal{M}'}((1-c)^2 - 4\beta)) - 16\beta^2(1-c)(3\kappa_1^{\mathcal{M}'} + 7))}{(8\beta - \kappa_1^{\mathcal{M}^2})^3} < -(8 - \kappa_1^{\mathcal{M}})^2\kappa_1^{\mathcal{M}^3}(1 + \kappa_1^{\mathcal{M}'}) < 0.$$

This further implies that $s(c)$ is decreasing in c. Since $s(0) = \frac{19}{160} > 0$ and $s(1 - \kappa_1^{\mathcal{M}}) = -\frac{1}{10} < 0$, there exists an unique $c_4^{\mathcal{M}}$ that satisfies $s(c_4^{\mathcal{M}}) = 0$. Define $\bar{c}^{\mathcal{M}}(\beta) = \begin{cases} c_2^{\mathcal{M}}(\beta), & \text{if } \beta \le \beta_2^{\mathcal{M}}, \\ c_4^{\mathcal{M}}(\beta), & \text{if } \beta > \beta_2^{\mathcal{M}}. \end{cases}$ Therefore, if $c \le \bar{c}^{\mathcal{M}}(\beta)$, the optimal carbon price is $\kappa^{\mathcal{M}*} = \kappa_1^{\mathcal{M}}$, and the buyer sources from the domestic supplier. Otherwise, if $\beta > 5 - \sqrt{23}$ and $\bar{c}^{\mathcal{M}}(\beta) < c \le \sqrt{23} - 4$, the optimal $\kappa^{\mathcal{M}*} = 5 - \sqrt{23}$, and the buyer sources from the foreign supplier. Define $\beta_2^{\mathcal{M}}$ is unique and satisfies $19\beta_2^{\mathcal{M}^4} - 50\beta_2^{\mathcal{M}^3} + 56\beta_2^{\mathcal{M}^2} - 150\beta_2^{\mathcal{M}} + 76 = 0$. □

A.1.4 Proof of Lemma 2.2

The proof of the equilibrium outcomes under CCA closely follows that under CBAM. The key difference lies in the introduction of a lower bound τ on emission intensity. It is straightforward to verify that when τ is sufficiently high, suppliers optimally choose to reduce their emission intensity to this lower bound τ. The remaining analysis proceeds analogously to the CBAM case and is thus omitted for brevity. □

A.1.5 Proof of Proposition 2.3

The proof of the equilibrium sourcing strategy under CCA is similar to that under CBAM, here we omit details. □

A.1.6 Proof of Proposition 2.4

Different from CBAM, the equilibrium carbon price that induces the buyer to source from supplier F depends on the magnitude of τ. Takeing the second derivative of S_F^A with respect to κ yields

$$\begin{aligned}\frac{\mathrm{d}^2 S_F^{\mathcal{M}}}{\mathrm{d}\kappa^2} &= \frac{4(\kappa^5(1-\tau)-3\kappa^4(5(1-\tau)^2+1)+76\kappa^3(1-\tau)-\kappa^2(320(1-\tau)^2+34)+288\kappa(1-\tau)-16(20(1-\tau)^2+1))}{(\kappa^2-8)^4}\\ &< \frac{-\kappa^4(15(1-\tau)^2+2)-2\kappa^2(160(1-\tau)^2-38(1-t)+17)+288\kappa(1-\tau)-16(20(1-\tau)^2+1)}{(\kappa^2-8)^4} < 0.\end{aligned}$$

This implies that $S_F^{\mathcal{M}}$ is concave in κ when $f(\kappa) > 0$. Differentiating (A.1) with respect to κ yields

$$\frac{\mathrm{d}S_F^{\mathcal{M}}}{\mathrm{d}\kappa} = \frac{2\kappa^4(1-\tau)-4\kappa^3(5(1-\tau)^2+1)+60\kappa^2(1-\tau)-8\kappa(20(1-\tau)^2+1)+32(1-\tau)}{(8-\kappa^2)^3}.$$

Solving the above equation equals zero and and isolating κ yields the four potential interior solutions $\kappa^* = 5(1-\tau) \pm \sqrt{25(1-\tau)^2-2}$, and $\kappa^* = \frac{1\pm\sqrt{1-8(1-\tau)^2}}{1-\tau}$. Since we require $0 < \kappa^* < 1$, only two of the candidate solutions qualify as optimal interior solutions. Specifically, $\kappa^* = 5(1-\tau) - \sqrt{25(1-\tau)^2-2}$ satisfies the interior condition when $0 < \tau < \frac{7}{10}$; and $\kappa^* = \frac{1-\sqrt{1-8(1-\tau)^2}}{1-\tau}$ satisfies the interior condition when $\frac{7}{9} < \tau < 1$. Since the derivation of the equilibrium carbon price under CCA closely parallels that under CBAM, we omit the detailed proof for brevity. Define $c_3^{\mathcal{A}}(\beta,\tau) = \frac{(1-\beta)\beta(1-\beta(1-\tau))}{8-\beta^2}$, $c_4^{\mathcal{A}}(\beta,\tau)$ is unique and satisfies $\frac{\beta(1-c_4^{\mathcal{A}}-\kappa_1^{\mathcal{A}}(1-\tau))({\kappa_1^{\mathcal{A}}}^3(1-\tau)-3(1-c_4^{\mathcal{A}}){\kappa_1^{\mathcal{A}}}^2+2\beta\kappa_1^{\mathcal{A}}(1-\tau)+14\beta(1-c_4^{\mathcal{A}}))}{(8\beta-{\kappa_1^{\mathcal{M}}}^2)^2} - \frac{1}{10} = 0$. $\beta_1^{\mathcal{A}}(\tau)$ is unique and satisfies ${\beta_1^{\mathcal{A}}}^4(20(1-\tau)^2+1)-10{\beta_1^{\mathcal{A}}}^3(1-\tau)(5-3\tau)-4{\beta_1^{\mathcal{A}}}^2(5\tau(1+\tau)-16)+30\beta_1^{\mathcal{A}}(4\tau-5)+76 = 0$. $\bar{c}^{\mathcal{A}}(\beta,\tau) = \begin{cases} c_3^{\mathcal{A}}(\beta,\tau), & \text{if } \tau \le \frac{7}{3}-\frac{7\sqrt{70}}{30} \text{ and } \beta \le \beta_1^{\mathcal{A}}(\tau), \\ c_4^{\mathcal{A}}(\beta,\tau), & \text{if } \tau \le \frac{7}{3}-\frac{7\sqrt{70}}{30} \text{ and } \beta > \beta_1^{\mathcal{A}}(\tau), \text{ or } \tau > \frac{7}{3}-\frac{7\sqrt{70}}{30}. \end{cases}$ $\kappa_1^{\mathcal{A}}(\beta,c,\tau)$ is unique and satisfies ${\kappa_1^{\mathcal{A}}}^3((1-\beta)(1-\tau)) - {\kappa_1^{\mathcal{A}}}^2(1-\beta+\beta c)+8\beta c = 0$, $\kappa_2^{\mathcal{A}}(\tau) = 5(1-\tau)-\sqrt{25(1-\tau)^2-2}$, and $\kappa_3^{\mathcal{A}}(\tau) = \frac{1-\sqrt{1-8(1-\tau)^2}}{1-\tau}$. Thus, when $c \le \bar{c}^{\mathcal{A}}(\beta,\tau)$, the optimal carbon price is $\kappa^{\mathcal{A}*} = \kappa_1^{\mathcal{A}}$, and the buyer sources from supplier D. When $c > \bar{c}^{\mathcal{A}}(\beta,\tau)$, the optimal carbon price is $\kappa_2^{\mathcal{A}}$ if $\tau \le \frac{7}{10}, \beta > \bar{\beta}^{\mathcal{A}}(\tau)$ and $\bar{c}^{\mathcal{A}}(\beta,\tau) < c \le c_5^{\mathcal{A}}(\tau)$, and $\kappa_3^{\mathcal{A}}$ if $\tau > \frac{7}{9}, \beta > \bar{\beta}^{\mathcal{A}}(\tau)$ and $\bar{c}^{\mathcal{A}}(\beta,\tau) < c \le c_6^{\mathcal{A}}(\tau)$. $\square$

A.1.7 Proof of Corollary 2.1

It is straightforward to verify that $c_3^{\mathcal{A}}(\beta,\tau) = \frac{(1-\beta)\beta(1-\beta(1-\tau))}{8-\beta^2} > \frac{(1-\beta)^2\beta}{8-\beta^2} = c_2^{\mathcal{M}}(\beta)$. Let $f_1(c)$ denote the quartic polynomial satisfied by $c_4^{\mathcal{M}}(\beta)$, given by $f_1(c) = 25\beta(19\beta-30)(12-7\beta)^2 {c_4^{\mathcal{M}}}^4 + 100(1-\beta)\beta(12-7\beta)(159-98\beta){c_4^{\mathcal{M}}}^3 + 10(1-\beta)^2(\beta(6277\beta-10287)-360){c_4^{\mathcal{M}}}^2 + 40(1-\beta)^3(446\beta+57)c_4^{\mathcal{M}} - 361(1-\beta)^4 = 0$. Let $f_2(c)$ denote the quartic polynomial satisfied by $c_4^{\mathcal{A}}(\beta,\tau)$, given by $25\beta(12-7\beta)^2(19\beta+10(2\beta-3)(\tau-2)\tau-30){c_4^{\mathcal{A}}}^4 + 100(1-\beta)\beta(7\beta-12)(98\beta+15(7\beta-11)(\tau-2)\tau-159){c_4^{\mathcal{A}}}^3 - 10(1-\beta)^2(\beta(-6277\beta+5(\tau-2)\tau(10\beta((\tau-2)\tau-137)+2271)+10287)+360){c_4^{\mathcal{A}}}^2 - 20(\beta-1)^3(\beta(1025(\tau-2)\tau+892)+114)c_4^{\mathcal{A}} - 361(1-\beta)^4 = 0$. Taking the first-order derivative of $f_1(c)$ with respect to c, we show that $\frac{\partial f_1(c)}{\partial c} = 20(2(1-\beta)^3(446\beta+57)+5\beta(19\beta-30)(12-7\beta)^2c^3 - 15\beta(686\beta^3-2975\beta^2+4197\beta-1908)c^2 + (1-\beta)^2(6277\beta^2-10287\beta-360)c) > \frac{20(1-\beta)^3(4655\beta^{10}-26985\beta^9+74137\beta^8-203237\beta^7+462104\beta^6-691724\beta^5+994360\beta^4-1123552\beta^3+657216\beta^2-433664\beta-58368)}{(\beta^2-8)^3} > 0$ since $c < \frac{(1-\beta)^2\beta}{8-\beta^2}$. Hence, $f_1(c)$ is increasing in c. Similarly, taking the first-order derivative of $f_2(c)$ with respect to c, we show that $\frac{\partial f_2(c)}{\partial c} = 20((1-\beta)^3(\beta(1025\tau^2-2050\tau+892)+114)+5\beta(12-7\beta)^2c^3(\beta(20\tau^2-40\tau+19)-30(\tau-1)^2)-15\beta(7\beta^2-19\beta+12)c^2(15(7\beta-11)\tau^2-30(7\beta-11)\tau+98\beta-159)-(\beta-1)^2c(\beta^2(50\tau^4-200\tau^3-6650\tau^2+13700\tau-6277)+3\beta(3785\tau^2-7570\tau+3429)+360)) > 0$ since $c < \frac{(1-\beta)\beta(1-\beta(1-\tau))}{8-\beta^2}$ and $\tau < \frac{1}{30}(70-7\sqrt{70})$. Thus, $f_2(c)$ is increasing in c. Now consider the difference: $\frac{\partial f_1(c)}{\partial c} - \frac{\partial f_2(c)}{\partial c} = 100\beta(\tau-2)\tau(205(\beta-1)^3-10(12-7\beta)^2(2\beta-3)c^3+45(49\beta^3-210\beta^2+293\beta-132)c^2+(\beta-1)^2c(10\beta(\tau^2-2\tau-137)+2271)) > 0$. Since both $f_1(c)$ and $f_2(c)$ are increasing in τ, the fact that $\frac{\partial f_1(c)}{\partial c} > \frac{\partial f_2(c)}{\partial c}$ implies that $f_1(c)$ increases with respect to c at a faster rate than $f_2(c)$. Moreover, noting that $f_1(0) = f_2(0) = -361(1-\beta)^4$, it follows that the root of $f_1(c) = 0$, i.e., $c_4^{\mathcal{M}}(\beta)$, is smaller than the root of $f_2(c)$, i.e., $c_4^{\mathcal{A}}(\beta,\tau)$. Thus, we get that $\bar{c}^{\mathcal{M}}(\beta) < \bar{c}^{\mathcal{A}}(\beta,\tau)$.
□

A.1.8 Proof of Corollary 2.2

Here, there exist four distinct regions based on the sourcing decisions under CBAM and CCA.

(1) If $\tau \le \frac{7}{10}$, $\beta > \bar{\beta}^{\mathcal{A}}(\tau)$ and $\bar{c}^{\mathcal{A}}(\beta,\tau) < c \le c_5^{\mathcal{A}}(\tau)$, then the buyer sources from

supplier F under both CBAM and CCA. In this region, it is straightforward to verify that $S^{\mathcal{M}} = S^{\mathcal{A}} = \frac{1}{10}$.

(2) If $c \leq \bar{c}^{\mathcal{M}}(\beta)$, then the buyer sources from supplier D under both CBAM and CCA. In this case, the corresponding social welfare is given by:

$S^{\mathcal{M}} = \frac{\beta(1-c-\kappa_1^{\mathcal{M}})(\kappa_1^{\mathcal{M}2}(\kappa_1^{\mathcal{M}}-3(1-c))+2\beta(\kappa_1^{\mathcal{M}}+7(1-c)))}{(8\beta-\kappa_1^{\mathcal{M}2})^2}$,

$S^{\mathcal{A}} = \frac{\beta(1-c+\kappa_1^{\mathcal{A}}(1-\tau))(\kappa_1^{\mathcal{A}2}(\kappa_1^{\mathcal{A}}(1-\tau)-3(1-c))+2\beta(7(1-c)+\kappa_1^{\mathcal{A}}(1-\tau)))}{(8\beta-\kappa_1^{\mathcal{A}2})^2}$. Note that for a given κ, both $S^{\mathcal{M}}$ and $S^{\mathcal{A}}$ are decreasing in κ, while $S^{\mathcal{A}}$ is increasing in τ. Moreover, since $c_1^{\mathcal{M}} < c_1^{\mathcal{A}}$, it follows that $\kappa_1^{\mathcal{M}} > \kappa_1^{\mathcal{A}}$. Therefore, we have $S^{\mathcal{A}} > S^{\mathcal{M}}$ in this region.

(3) If $\bar{c}^{\mathcal{M}}(\beta) < c \leq \bar{c}^{\mathcal{A}}(\beta, \tau)$, then the buyer sources from supplier D under both CCA but from supplier F under CBAM. In this case, we have:

$S^{\mathcal{A}} = \frac{\beta(1-c+\kappa_1^{\mathcal{A}}(1-\tau))(\kappa_1^{\mathcal{A}2}(\kappa_1^{\mathcal{A}}(1-\tau)-3(1-c))+2\beta(7(1-c)+\kappa_1^{\mathcal{A}}(1-\tau)))}{(8\beta-\kappa_1^{\mathcal{A}2})^2} < S^{\mathcal{M}} = \frac{1}{10}$.

(4) In the remaining regions, the optimal carbon price is either β or $1-c$. If the optimal price is β, then $S^{\mathcal{A}}(\beta) - S^{\mathcal{M}}(\beta) = -\frac{2\beta\tau(\beta^2+5\beta(\tau-2)+2)}{(8-\beta^2)^2} < 0$ for $c > \sqrt{23}-4$. If the optimal price is β, $S^{\mathcal{A}}(1-c) - S^{\mathcal{M}}(1-c) = \frac{2(c-1)\tau(c(c-5\tau+8)+5\tau-7)}{(7-(c-2)c)^2}$ for $\beta < 5-\sqrt{23}$. Thus, we have $S^{\mathcal{A}} < S^{\mathcal{M}}$. $\square$

A.1.9 Proof of Corollary 2.3

The proof comparing the buyer's preference between CBAM and CCA follows a similar structure to that of the government's preference analysis. Hence, we omit the detaile d. $\square$.

A.1.10 Proof of Corollary 2.4

The proof comparing the buyer's preference between CBAM and CCA follows a similar structure to that of the government's preference analysis. Hence, we omit the detailed proof. $\square$.

A.1.11 Proof of Corollary 2.5

This is directly inferred from Corollaries 2.2 and 2.3. $\square$.

A.1.12 Proof of Corollary 2.6

If $c \leq \bar{c}^{\mathcal{M}}(\beta)$, then the buyer sources from supplier D under both CBAM and CCA. In this case, the corresponding emission intensity are given by: $e_D^{\mathcal{M}} = \frac{8\beta-(1-c)\kappa_1^{\mathcal{M}}}{8\beta-\kappa_1^{\mathcal{M}2}}$, and $e_D^{\mathcal{A}} = \frac{8\beta-\kappa_1^{\mathcal{A}}(1-c)-\kappa_1^{\mathcal{A}2}\tau}{8\beta-\kappa_1^{\mathcal{A}2}}$. Note that $\kappa = \kappa_1^{\mathcal{M}}$ equals to $c = \frac{(1-\beta)\kappa^2(1-\kappa)}{\beta(8-\kappa^2)}$, and $\kappa = \kappa_1^{\mathcal{A}}$ equals to $c = \frac{(1-\beta)\kappa^2(1-\kappa(1-\tau))}{\beta(8-\kappa^2)}$. Thus, we have $1-e_D^{\mathcal{M}} = \frac{(1-\kappa)\kappa}{\beta(8-\kappa^2)} < 1-e_D^{\mathcal{A}} = \frac{\kappa(1-\kappa(1-\tau))}{\beta(\kappa^2-8)}$. The proofs for other cases follow a similar structure and are thus omitted for brevity. $\square$.

A.1.13 Proof of Proposition 2.5∼2.8

The proof for the limiting cases $\lambda \to \infty$, $\lambda \to 0$, and $\gamma > 0$ follow a similar derivation structure to that of the basic model. Hence, we omit the detailed proof. $\square$.

A.2 Summary of Notations

Table A.1: List of Thresholds

Threshold	**Expression**
$\kappa_1^{\mathcal{M}}(\beta, c)$	${\kappa_1^{\mathcal{M}}}^3(1-\beta) - {\kappa_1^{\mathcal{M}}}^2(1-\beta+\beta c) + 8\beta c = 0$
$\kappa_2^{\mathcal{M}}(\beta, c)$	${\kappa_2^{\mathcal{M}}}^3(1-\beta) - {\kappa_2^{\mathcal{M}}}^2(1-\beta+\beta c) + 8\beta c = 0$
$c_1^{\mathcal{M}}(\beta, \kappa)$	$\frac{(1-\beta)(1-\kappa)\kappa^2}{\beta(8-\kappa^2)}$
$c_2^{\mathcal{M}}(\beta)$	$\frac{(1-\beta)^2\beta}{8-\beta^2}$
$c_3^{\mathcal{M}}(\beta)$	${c_3^{\mathcal{M}}}^3\beta^3 + 3{c_3^{\mathcal{M}}}^2\beta^2(1-\beta) - 51c_3^{\mathcal{M}}\beta(1-\beta)^2 + (1-\beta)^3 = 0$
$c_4^{\mathcal{M}}(\beta)$	$\frac{\beta(1-c_4^{\mathcal{M}}-\kappa_1^{\mathcal{M}})({\kappa_1^{\mathcal{M}}}^3-3(1-c_4^{\mathcal{M}}){\kappa_1^{\mathcal{M}}}^2+2\beta\kappa_1^{\mathcal{M}}+14\beta(1-c_4^{\mathcal{M}}))}{(8\beta-{\kappa_1^{\mathcal{M}}}^2)^2} - \frac{1}{10} = 0$
$\beta_1^{\mathcal{M}}$	${\beta_1^{\mathcal{M}}}^3 - 24\beta_1^{\mathcal{M}} + 16 = 0$
$\beta_2^{\mathcal{M}}$	$19{\beta_2^{\mathcal{M}}}^4 - 50{\beta_2^{\mathcal{M}}}^3 + 56{\beta_2^{\mathcal{M}}}^2 - 150\beta_2^{\mathcal{M}} + 76 = 0$
$\bar{c}^{\mathcal{M}}(\beta)$	$\begin{cases} c_2^{\mathcal{M}}(\beta), & \text{if } \beta \leq \beta_2^{\mathcal{M}}, \\ c_4^{\mathcal{M}}(\beta), & \text{if } \beta > \beta_2^{\mathcal{M}}. \end{cases}$
$c_1^{\mathcal{A}}(\beta, \kappa, \tau)$	$\frac{(1-\beta)(1-\kappa+\kappa\tau)\kappa^2}{\beta(8-\kappa^2)}$
$c_2^{\mathcal{A}}(\beta, \kappa, \tau)$	$\frac{\kappa(8(1-\tau)-\kappa)}{8-\kappa^2}$
$c_3^{\mathcal{A}}(\beta, \tau)$	$\frac{(1-\beta)\beta(1-\beta(1-\tau))}{8-\beta^2}$
$c_4^{\mathcal{A}}(\beta, \tau)$	$\frac{\beta(1-c_4^{\mathcal{A}}-\kappa_1^{\mathcal{A}}(1-\tau))({\kappa_1^{\mathcal{A}}}^3(1-\tau)-3(1-c_4^{\mathcal{A}}){\kappa_1^{\mathcal{A}}}^2+2\beta\kappa_1^{\mathcal{A}}(1-\tau)+14\beta(1-c_4^{\mathcal{A}}))}{(8\beta-{\kappa_1^{\mathcal{M}}}^2)^2} - \frac{1}{10} = 0$
$\beta_1^{\mathcal{A}}(\tau)$	${\beta_1^{\mathcal{A}}}^4(20(1-\tau)^2+1)-10{\beta_1^{\mathcal{A}}}^3(1-\tau)(5-3\tau)-4{\beta_1^{\mathcal{A}}}^2(5\tau(1+\tau)-16)+30\beta_1^{\mathcal{A}}(4\tau-5)+76 = 0$
$\bar{c}^{\mathcal{A}}(\beta, \tau)$	$\begin{cases} c_3^{\mathcal{A}}(\beta, \tau), & \text{if } \tau \leq \frac{7}{3} - \frac{7\sqrt{70}}{30} \text{ and } \beta \leq \beta_1^{\mathcal{A}}(\tau), \\ c_4^{\mathcal{A}}(\beta, \tau), & \text{if } \tau \leq \frac{7}{3} - \frac{7\sqrt{70}}{30} \text{ and } \beta > \beta_1^{\mathcal{A}}(\tau), \text{ or } \tau > \frac{7}{3} - \frac{7\sqrt{70}}{30}. \end{cases}$
$\kappa_1^{\mathcal{A}}(\beta, c, \tau)$	${\kappa_1^{\mathcal{A}}}^3((1-\beta)(1-\tau)) - {\kappa_1^{\mathcal{A}}}^2(1-\beta+\beta c) + 8\beta c = 0$
$\kappa_2^{\mathcal{A}}(\tau)$	$5(1-\tau) - \sqrt{25(1-\tau)^2 - 2}$
$\kappa_3^{\mathcal{A}}(\tau)$	$\frac{1-\sqrt{1-8(1-\tau)^2}}{1-\tau}$
$\bar{\beta}^{\mathcal{A}}(\tau)$	$\begin{cases} \kappa_2^{\mathcal{A}}(\tau), & \text{if } \tau \leq \frac{7}{10}, \\ 1, & \text{if } \frac{7}{10} < \tau \leq \frac{7}{9}, \\ \kappa_3^{\mathcal{A}}(\tau), & \text{Otherwise.} \end{cases}$
$c_5^{\mathcal{A}}(\tau)$	$1 - \kappa_2^{\mathcal{A}}$
$c_6^{\mathcal{A}}(\tau)$	$1 - \kappa_3^{\mathcal{A}}$
$c_1^{\mathcal{MA}}(\beta, \tau)$	$\frac{4\beta^2(1-c_1^{\mathcal{MA}}-\kappa_1^{\mathcal{A}}+\kappa_1^{\mathcal{A}}\tau)^2}{(8\beta-{\kappa_1^{\mathcal{A}}}^2)^2} - \frac{1}{25} = 0$
$\beta_1^{\mathcal{MA}}(\tau)$	$\frac{10(1-\tau)-\sqrt{80(\sqrt{23}-4)(\tau-2)\tau+6\sqrt{23}+32}}{10(\tau-2)\tau+\sqrt{23}+6}$
$c_2^{\mathcal{MA}}(\tau)$	$1 - \beta_1^{\mathcal{MA}}$
$c_{\gamma 1}^{\mathcal{M}}(\beta, \kappa, \gamma)$	$\frac{(1-\beta)(1-(\kappa+\gamma))(\kappa+\gamma)^2}{\beta(8-(\kappa+\gamma)^2)}$
$\kappa_{\gamma 1}^{\mathcal{M}}(\beta, c, \gamma)$	${\kappa_{\gamma 1}^{\mathcal{M}}}^3(\beta-1) + {\kappa_{\gamma 1}^{\mathcal{M}}}^2(3\beta\gamma-\beta+\beta c-3\gamma+1) + \kappa_{\gamma 1}^{\mathcal{M}}(3\beta\gamma^2-2\beta\gamma-3\gamma^2+2\beta c\gamma+2\gamma) +$ $\beta\gamma^3 - \beta\gamma^2 - \gamma^3 + \gamma^2 + \beta c\gamma^2 - 8\beta c = 0$
$\kappa_{\gamma 2}^{\mathcal{M}}(\gamma)$	${\kappa_{\gamma 2}^{\mathcal{M}}}^4 + 2{\kappa_{\gamma 2}^{\mathcal{M}}}^3\gamma + {\kappa_{\gamma 2}^{\mathcal{M}}}^2(\gamma^2-24) + \kappa_{\gamma 2}^{\mathcal{M}}(16-24\gamma) - 8\gamma^2 + 8\gamma = 0$
$c_{\gamma 2}^{\mathcal{M}}(\beta, \gamma)$	$\frac{\beta(1-c_{\gamma 2}^{\mathcal{M}}-\gamma-\kappa_{\gamma 1}^{\mathcal{M}})((14\beta-\gamma^2-3{\kappa_{\gamma 1}^{\mathcal{M}}}^2)(1-c_{\gamma 2}^{\mathcal{M}}-\gamma)+\kappa_{\gamma 1}^{\mathcal{M}}(2\beta+\gamma(4c_{\gamma 2}^{\mathcal{M}}+3\gamma-4))+{\kappa_{\gamma 1}^{\mathcal{M}}}^3)}{(8\beta-(\gamma+\kappa_{\gamma 1}^{\mathcal{M}})^2)^2} -$ $\frac{2(1-\gamma-\kappa_{\gamma 2}^{\mathcal{M}})(3(1-\gamma)+\kappa_{\gamma 2}^{\mathcal{M}}(5-\gamma-\kappa_{\gamma 2}^{\mathcal{M}}))}{(8-(\gamma+\kappa_{\gamma 2}^{\mathcal{M}})^2)^2} = 0$
$\bar{c}_{\gamma}^{\mathcal{M}}(\beta, \gamma)$	$\begin{cases} c_2^{\mathcal{M}}(\beta), & \text{if } \beta \leq \beta_2^{\mathcal{M}}, \\ c_{\gamma 2}^{\mathcal{M}}(\beta), & \text{if } \beta > \beta_2^{\mathcal{M}}. \end{cases}$

Table A.2: Equilibrium Outcomes Under CBAM

Decision Variables and Profits	**Sourcing Strategy**
$\kappa_D^{\mathcal{M}} = \kappa_1^{\mathcal{M}}$ $e_D^{\mathcal{M}} = \frac{8\beta-(1-c)\kappa_1^{\mathcal{M}}}{8\beta-\kappa_1^{\mathcal{M}2}}$ $w_D^{\mathcal{M}} = \frac{4\beta(1+c+\kappa_1^{\mathcal{M}})-\kappa_1^{\mathcal{M}2}}{8\beta-\kappa_1^{\mathcal{M}2}}$ $q_D^{\mathcal{M}} = \frac{2\beta(1-c-\kappa_1^{\mathcal{M}})}{8\beta-\kappa_1^{\mathcal{M}2}}$ $p_D^{\mathcal{M}} = 1 - \frac{2\beta(1-c-\kappa_1^{\mathcal{M}})}{8\beta-\kappa_1^{\mathcal{M}2}}$ $\pi_D^{\mathcal{M}} = \frac{\beta(1-c-\kappa_1^{\mathcal{M}})^2}{8\beta-\kappa_1^{\mathcal{M}2}}$ $\Pi_B^{\mathcal{M}} = \frac{4\beta^2(1-c-\kappa_1^{\mathcal{M}})^2}{(8\beta-\kappa_1^{\mathcal{M}2})^2}$ $C_D^{\mathcal{M}} = \frac{2\beta(1-c-\kappa_1^{\mathcal{M}})(8\beta-(1-c)\kappa_1^{\mathcal{M}})}{(8\beta-\kappa_1^{\mathcal{M}2})^2}$ $S^{\mathcal{M}} = \frac{\beta(1-c-\kappa_1^{\mathcal{M}})(\kappa_1^{\mathcal{M}2}(\kappa_1^{\mathcal{M}}-3(1-c))+2\beta(\kappa_1^{\mathcal{M}}+7(1-c)))}{(8\beta-\kappa_1^{\mathcal{M}2})^2}$	Domestic Supplier $c \leq \bar{c}^{\mathcal{M}}(\beta)$
$\kappa_F^{\mathcal{M}} = 5-\sqrt{23}$ $e_F^{\mathcal{M}} = \frac{1}{10}(\sqrt{23}+5)$ $w_F^{\mathcal{M}} = \frac{2}{5}$ $q_F^{\mathcal{M}} = \frac{1}{5}$ $p_F^{\mathcal{M}} = \frac{4}{5}$ $\pi_F^{\mathcal{M}} = \frac{1}{10}(\sqrt{23}-4)$ $\Pi_B^{\mathcal{M}} = \frac{1}{25}$ $C_F^{\mathcal{M}} = \frac{1}{50}(\sqrt{23}+5)$ $S^{\mathcal{M}} = \frac{1}{10}$	Foreign Supplier $\beta > 5-\sqrt{23}$ and $\bar{c}^{\mathcal{M}}(\beta) < c \leq \sqrt{23}-4$
$\kappa_F^{\mathcal{M}} = \beta$ $e_F^{\mathcal{M}} = \frac{8-\beta}{8-\beta^2}$ $w_F^{\mathcal{M}} = \frac{4(1-\beta)}{8-\beta^2}$ $q_F^{\mathcal{M}} = \frac{2(1-\beta)}{8-\beta^2}$ $p_F^{\mathcal{M}} = 1-\frac{2(1-\beta)}{8-\beta^2}$ $\pi_F^{\mathcal{M}} = \frac{(1-\beta)^2}{8-\beta^2}$ $\Pi_B^{\mathcal{M}} = \frac{4(1-\beta)^2}{(8-\beta^2)^2}$ $C_F^{\mathcal{M}} = \frac{2(8-\beta)(1-\beta)}{(8-\beta^2)^2}$ $S^{\mathcal{M}} = \frac{2\beta((\beta-6)\beta+2)+6}{(8-\beta^2)^2}$	Foreign Supplier $\beta \leq 5-\sqrt{23}$ and $\bar{c}^{\mathcal{M}}(\beta) < c \leq 1-\beta$
$\kappa_F^{\mathcal{M}} = 1-c$ $e_F^{\mathcal{M}} = \frac{7+c}{7+2c-c^2}$ $w_F^{\mathcal{M}} = \frac{4c}{7+2c-c^2}$ $q_F^{\mathcal{M}} = \frac{2c}{7+2c-c^2}$ $p_F^{\mathcal{M}} = 1-\frac{2c}{7+2c-c^2}$ $\pi_F^{\mathcal{M}} = \frac{c^2}{7+2c-c^2}$ $\Pi_B^{\mathcal{M}} = \frac{4c^2}{(7+2c-c^2)^2}$ $C_F^{\mathcal{M}} = \frac{2c(7+c)}{(7+2c-c^2)^2}$ $S^{\mathcal{M}} = \frac{2c(7-3c-c^2)}{(7+2c-c^2)^2}$	Foreign Supplier $c > max\{1-\beta, \sqrt{23}-4\}$

Table A.3: Equilibrium Outcomes Under CCA

Decision Variables and Profits	Sourcing Strategy
$\kappa_D^{\mathcal{A}} = \kappa_1^{\mathcal{A}}$ $e_D^{\mathcal{A}} = \frac{8\beta-\kappa_1^{\mathcal{A}}(1-c)-\kappa_1^{\mathcal{A}2}\tau}{8\beta-\kappa_1^{\mathcal{A}2}}$ $w_D^{\mathcal{A}} = \frac{4\beta(1+c+\kappa_1^{\mathcal{A}}-\kappa_1^{\mathcal{A}}\tau)-\kappa_1^{\mathcal{A}2}}{8\beta-\kappa_1^{\mathcal{A}2}}$ $q_D^{\mathcal{A}} = \frac{2\beta(1-c-\kappa_1^{\mathcal{A}}+\kappa_1^{\mathcal{A}}\tau)}{8\beta-\kappa_1^{\mathcal{A}2}}$ $p_D^{\mathcal{A}} = 1 - \frac{2\beta(1-c-\kappa_1^{\mathcal{A}}+\kappa_1^{\mathcal{A}}\tau)}{8\beta-\kappa_1^{\mathcal{A}2}}$ $\pi_D^{\mathcal{A}} = \frac{\beta(1-c-\kappa_1^{\mathcal{A}}+\kappa_1^{\mathcal{A}}\tau)^2}{8\beta-\kappa_1^{\mathcal{A}2}}$ $\Pi_B^{\mathcal{A}} = \frac{4\beta^2(1-c-\kappa_1^{\mathcal{A}}+\kappa_1^{\mathcal{A}}\tau)^2}{(8\beta-\kappa_1^{\mathcal{A}2})^2}$ $C_D^{\mathcal{A}} = \frac{2\beta(1-c-\kappa_1^{\mathcal{A}}+\kappa_1^{\mathcal{A}}\tau)(8\beta-(1-c)\kappa_1^{\mathcal{A}}-\kappa_1^{\mathcal{A}2}\tau)}{(8\beta-\kappa_1^{\mathcal{A}2})^2}$ $S^{\mathcal{A}} = \frac{\beta(1-c+\kappa_1^{\mathcal{A}}(1-\tau))(\kappa_1^{\mathcal{A}2}(\kappa_1^{\mathcal{A}}(1-\tau)-3(1-c))+2\beta(7(1-c)+\kappa_1^{\mathcal{A}}(1-\tau)))}{(8\beta-\kappa_1^{\mathcal{A}2})^2}$	Domestic Supplier $c \leq \bar{c}^{\mathcal{A}}(\beta,\tau)$
$\kappa_F^{\mathcal{A}} = 5(1-\tau) - \sqrt{25(1-\tau)^2-2}$ $e_F^{\mathcal{A}} = \frac{5(1+\tau)+\sqrt{25(1-\tau)^2-2}}{10}$ $w_F^{\mathcal{A}} = \frac{2}{5}$ $q_F^{\mathcal{A}} = \frac{1}{5}$ $p_F^{\mathcal{A}} = \frac{4}{5}$ $\pi_F^{\mathcal{A}} = \frac{(1-\tau)\sqrt{25(1-\tau)^2-2}-5(1-\tau)^2+1}{10}$ $\Pi_B^{\mathcal{A}} = \frac{1}{25}$ $C_F^{\mathcal{A}} = \frac{5(1+\tau)+\sqrt{25(1-\tau)^2-2}}{50}$ $S^{\mathcal{A}} = \frac{1}{10}$	Foreign Supplier $\tau \leq \frac{7}{10}, \beta > \bar{\beta}^{\mathcal{A}}(\tau)$ and $\bar{c}^{\mathcal{A}}(\beta,\tau) <$ $c \leq c_5^{\mathcal{A}}(\tau)$
$\kappa_F^{\mathcal{A}} = \frac{1-\sqrt{8(2-\tau)\tau-7}}{1-\tau}$ $e_F^{\mathcal{A}} = \frac{1+\tau}{2}$ $w_F^{\mathcal{A}} = \frac{\sqrt{8(2-\tau)\tau-7}+1}{4}$ $q_F^{\mathcal{A}} = \frac{\sqrt{8(2-\tau)\tau-7}+1}{8}$ $p_F^{\mathcal{A}} = \frac{7-\sqrt{8(2-\tau)\tau-7}}{8}$ $\pi_F^{\mathcal{A}} = \frac{8(2-\tau)\tau-7+\sqrt{8(2-\tau)\tau}}{16}$ $\Pi_B^{\mathcal{A}} = \frac{4(2-\tau)\tau+\sqrt{8(2-\tau)\tau-7}-3}{32}$ $C_F^{\mathcal{A}} = \frac{(1+\tau)(\sqrt{8(2-\tau)\tau-7}+1)}{16}$ $S^{\mathcal{A}} = \frac{(20\tau(\tau-2)+3\sqrt{8(2-\tau)\tau-7}+23)}{64}$	Foreign Supplier $\tau > \frac{7}{9}, \beta > \bar{\beta}^{\mathcal{A}}(\tau)$ and $\bar{c}^{\mathcal{A}}(\beta,\tau)$ $< c \leq c_6^{\mathcal{A}}(\tau)$
$\kappa_F^{\mathcal{A}} = \beta$ $e_F^{\mathcal{A}} = \frac{8-\beta-\beta^2\tau}{8-\beta^2}$ $w_F^{\mathcal{A}} = \frac{4(1-\beta(1-\tau))}{8-\beta^2}$ $q_F^{\mathcal{A}} = \frac{2(1-\beta(1-\tau))}{8-\beta^2}$ $p_F^{\mathcal{A}} = 1 - \frac{2(1-\beta(1-\tau))}{8-\beta^2}$ $\pi_F^{\mathcal{A}} = \frac{(1-\beta(1-\tau))^2}{8-\beta^2}$ $\Pi_B^{\mathcal{A}} = \frac{4(1-\beta(1-\tau))^2}{(8-\beta^2)^2}$ $C_F^{\mathcal{A}} = \frac{2(1-\beta(1-\tau))(8-\beta-\beta^2\tau)}{(8-\beta^2)^2}$ $S^{\mathcal{A}} = \frac{2(1-\beta(1-\tau))(3-\beta(\beta-5(1-\tau)))}{(8-\beta^2)^2}$	Foreign Supplier $\beta \leq \bar{\beta}^{\mathcal{A}}(\tau)$ and $\bar{c}^{\mathcal{A}}(\beta,\tau) < c \leq 1-\beta$
$\kappa_F^{\mathcal{A}} = 1-c$ $e_F^{\mathcal{A}} = \frac{7+c-(1-c)^2\tau}{7+(2-c)c}$ $w_F^{\mathcal{A}} = \frac{4(c(1-\tau)+\tau)}{7+(2-c)c}$ $q_F^{\mathcal{A}} = \frac{2(c(1-\tau)+\tau)}{7+(2-c)c}$ $p_F^{\mathcal{A}} = 1 - \frac{2(c(1-\tau)+\tau)}{7+(2-c)c}$ $\pi_F^{\mathcal{A}} = \frac{(c(1-\tau)+\tau)^2}{7+(2-c)c}$ $\Pi_B^{\mathcal{A}} = \frac{4(\tau+c(1-\tau))^2}{(7+(2-c)c)^2}$ $C_F^{\mathcal{A}} = \frac{2(c(1-\tau)+\tau)(7+c-(1-c)^2\tau)}{(7+(2-c)c)^2}$ $S^{\mathcal{A}} = \frac{2(c(1-\tau)+\tau)(7-5\tau-c(c-5\tau+3))}{(7+(2-c)c)^2}$	Foreign Supplier $c > max\{c_5^{\mathcal{A}}(\tau), c_6^{\mathcal{A}}(\tau), 1-\beta\}$

Appendix B

Appendix for Chapter 3

B.1 Proofs of Statements

B.1.1 Proof of Proposition 3.1

Taking the derivation under DAP contract as an example. The tariff is paid by the buyer and the freight charge is borne by suppliers. The supply chain parties' profit functions are $\Pi^A_{RT} = q^A_{RT}(w^A_{RT} - v^A_{RT}), \Pi^A_{UE} = (1-\psi)q^A_{UE}(w^A_{UE} - v^A_{UE}), \Pi^A_L = q^A_{RT}v^A_{RT} + (1-\psi)q^A_{UE}v^A_{UE}$, and $\Pi^A_R = \psi p^A_d q^A_{RT} + (1-\psi)p^A_n(q^A_{RT} + q^A_{UE}) - (1+\tau)q^A_{RT}w^A_{RT} - (1-\psi)q^A_{UE}w^A_{UE}$. We analyze the game using backward induction.

According to the first-order conditions (FOCs), given $q^A_{UE} = 0$, if $\partial\Pi^A_R/\partial q^A_{RT} = 0$ and $\partial\Pi^A_R/\partial q^A_{UE} \leq 0$, then $(q^A_{RT}, 0)$ is the buyer's best response. Equivalently, $q^A_{RT} = \frac{a-(1+\tau)w_{RT}}{2b}, q^A_{UE} = 0, (1+\tau)w_{RT} - w_{UE} \leq 0$, and $w_{UE} \leq a$ (region I). Similarly, $(0, q^A_{UE})$ is the buyer's best response if $q^A_{RT} = 0, q^A_{UE} = \frac{a-w_{UE}}{2b}, a\psi - (1+\tau)w_{RT} + (1-\psi)w_{UE} \leq 0$, and $w_{RT} \leq \frac{a}{1+\tau}$(region III). Finally, (q^A_{RT}, q^A_{UE}) is the buyer's best response if $\partial\Pi^A_R/\partial q^A_{RT} = 0$ and $\partial\Pi^A_R/\partial q^A_{UE} = 0$. Equivalently, $q^A_{RT} = \frac{a\psi-(1+\tau)w_{RT}+(1-\psi)w_{UE}}{2b\psi}, q^A_{UE} = \frac{(1+\tau)w_{RT}-w_{UE}}{2b\psi}, (1+\tau)w_{RT} - w_{UE} > 0$, and $a\psi - (1+\tau)w_{RT} + (1-\psi)w_{UE} > 0$ (region II). The division of the plane into three regions is depicted in Figure B.1. To ensure that suppliers can make nonnegative profits, we assume that $0 \leq v_i \leq w_i, i \in \{RT, UE\}$.

We can derive the RT supplier's reaction curve when the UE supplier's wholesale price is given. In region I, the RT supplier's best response wholesale price is

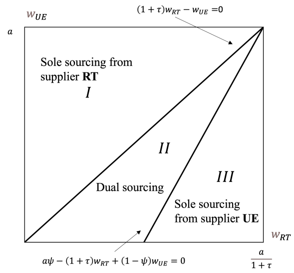


Figure B.1: Buyer's Sourcing Strategy Under DAP

$w^*_{RTA} = \frac{a+(1+\tau)v_{RT}}{2(1+\tau)}$ by maximizing $\frac{(w_{RT}-v_{RT})[a-(1+\tau)w_{RT}]}{2b}$. In region II, the RT supplier's best response wholesale price is $w^*_{RTB} = \frac{a\psi+(1+\tau)v_{RT}+(1-\psi)w_{UE}}{2(1+\tau)}$ by maximizing $\frac{(w_{RT}-v_{RT})[a\psi-(1+\tau)w_{RT}+(1-\psi)w_{UE}]}{2b\psi}$. In region III, the RT supplier receives no order, and the best response wholesale price is $w^*_{RTC} = v_{RT}$. We show that there exists an intersection $(\bar{w}^*_{RT_a}, \bar{w}^*_{UE_a})$ between $w^*_{RTA} = \frac{a+(1+\tau)v_{RT}}{2(1+\tau)}$ and $(1+\tau)w_{RT} - w_{UE} = 0$, where $\bar{w}^*_{RT_a} = \frac{a+(1+\tau)v_{RT}}{2(1+\tau)}$, $\bar{w}^*_{UE_a} = \frac{1}{2}[a + (1+\tau)v_{RT}]$. Besides, there also exists an intersection $(\hat{w}^*_{RT_a}, \hat{w}^*_{UE_a})$ between $w^*_{RTB} = \frac{a\psi+(1+\tau)v_{RT}+(1-\psi)w_{UE}}{2(1+\tau)}$ and $(1+\tau)w_{RT} - w_{UE} = 0$, where $\hat{w}^*_{RT_a} = \frac{a\psi(1+\tau)v_{RT}}{(1+\tau)(1+\psi)}$, and $\hat{w}^*_{UE_a} = \frac{a\psi+(1+\tau)v_{RT}}{1+\psi}$. It is obvious that $\bar{w}^*_{RT_a} - \hat{w}^*_{RT_a} = \frac{(1-\psi)[a-(1+\tau)v_{RT}]}{2(1+\tau)(1+\psi)} > 0$, thus the intersection $(\hat{w}^*_{RT_a}, \hat{w}^*_{UE_a})$ is always in front of the intersection $(\bar{w}^*_{RT_a}, \bar{w}^*_{UE_a})$. In addition, there also exists an intersection $(\widetilde{w}^*_{RT_a}, \widetilde{w}^*_{UE_a})$ between $w^*_{RTB} = \frac{a\psi+(1+\tau)v_{RT}+(1-\psi)w_{UE}}{2(1+\tau)}$ and $a\psi - (1+\tau)w_{RT} + (1-\psi)w_{UE} = 0$, where $\widetilde{w}^*_{RT_a} = v_{RT}$, and $\widetilde{w}^*_{UE_a} = \frac{(1+\tau)v_{RT}-a\psi}{1-\psi}$. If $v_{RT} > \frac{a\psi}{1+\tau}$, $\widetilde{w}^*_{UE_a} > 0$. Otherwise, $\widetilde{w}^*_{UE_a} \leq 0$.

Next, we derive the RT supplier's best response function given any wholesale price set by the UE supplier. Obviously, w^*_{UE} starts from the minimum value v_{UE}, and $0 \leq v_{UE} \leq a$. Note that $\widetilde{w}^*_{UE_a} > 0$ if $v_{RT} > \frac{a\psi}{1+\tau}$. Therefore, we obtain the FOC which satisfies $v_{UE} < \frac{(1+\tau)v_{RT}-a\psi}{1-\psi}$ and $v_{RT} > \frac{a\psi}{1+\tau}$, see Figure B.2(a). Then, if $v_{UE} \geq \frac{(1+\tau)v_{RT}-a\psi}{1-\psi}$, w^*_{UE} is no longer subject to $\widetilde{w}^*_{UE_a}$. Similarly, Figure B.2(b) corresponds to the case where $\frac{(1+\tau)v_{RT}-a\psi}{1-\psi} \leq v_{UE} < \frac{a\psi+(1+\tau)v_{RT}}{1+\psi}$, and Figure B.2(c) corresponds to the case where $\frac{a\psi+(1+\tau)v_{RT}}{1+\psi} \leq v_{UE} < \frac{1}{2}[a + (1+\tau)v_{RT}]$. Otherwise, see Figure B.2(d). We can summarize the results as follows:

If $v_{UE} < \frac{(1+\tau)v_{RT}-a\psi}{1-\psi}$ and $v_{RT} > \frac{a\psi}{1+\tau}$, then

$$w_{RT}^* = \begin{cases} \frac{a+(1+\tau)v_{RT}}{2(1+\tau)}, & w_{UE} \geq \frac{1}{2}[a+(1+\tau)v_{RT}]; \\ \frac{w_{UE}}{1+\tau}, & \frac{a\psi+(1+\tau)v_{RT}}{1+\psi} \leq w_{UE} < \frac{1}{2}[a+(1+\tau)v_{RT}]; \\ \frac{a\psi+(1+\tau)v_{RT}+(1-\psi)w_{UE}}{2(1+\tau)}, & \frac{(1+\tau)v_{RT}-a\psi}{1-\psi} \leq w_{UE} < \frac{a\psi+(1+\tau)v_{RT}}{1+\psi}; \\ v_{RT}, & v_{UE} \leq w_{UE} < \frac{(1+\tau)v_{RT}-a\psi}{1-\psi}. \end{cases}$$

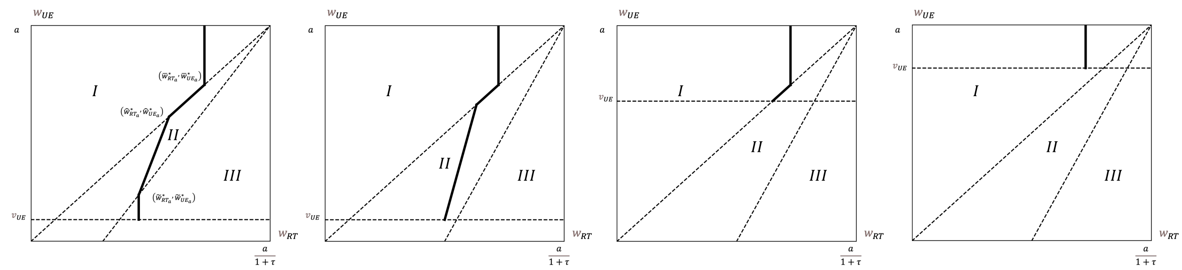
If $\frac{(1+\tau)v_{RT}-a\psi}{1-\psi} \leq v_{UE} < \frac{a\psi+(1+\tau)v_{RT}}{1+\psi}$, then

$$w_{RT}^* = \begin{cases} \frac{a+(1+\tau)v_{RT}}{2(1+\tau)}, & w_{UE} \geq \frac{1}{2}[a+(1+\tau)v_{RT}]; \\ \frac{w_{UE}}{1+\tau}, & \frac{a\psi+(1+\tau)v_{RT}}{1+\psi} \leq w_{UE} < \frac{1}{2}[a+(1+\tau)v_{RT}]; \\ \frac{a\psi+(1+\tau)v_{RT}+(1-\psi)w_{UE}}{2(1+\tau)}, & v_{UE} \leq w_{UE} < \frac{a\psi+(1+\tau)v_{RT}}{1+\psi}. \end{cases}$$

If $\frac{a\psi+(1+\tau)v_{RT}}{1+\psi} \leq v_{UE} < \frac{1}{2}[a+(1+\tau)v_{RT}]$, then

$$w_{RT}^* = \begin{cases} \frac{a+(1+\tau)v_{RT}}{2(1+\tau)}, & w_{UE} \geq \frac{1}{2}[a+(1+\tau)v_{RT}]; \\ \frac{w_{UE}}{1+\tau}, & v_{UE} \leq w_{UE} < \frac{1}{2}[a+(1+\tau)v_{RT}]. \end{cases}$$

If $v_{UE} \geq \frac{1}{2}[a+(1+\tau)v_{RT}]$, then $w_{RT}^* = \frac{a+(1+\tau)v_{RT}}{2(1+\tau)}$.

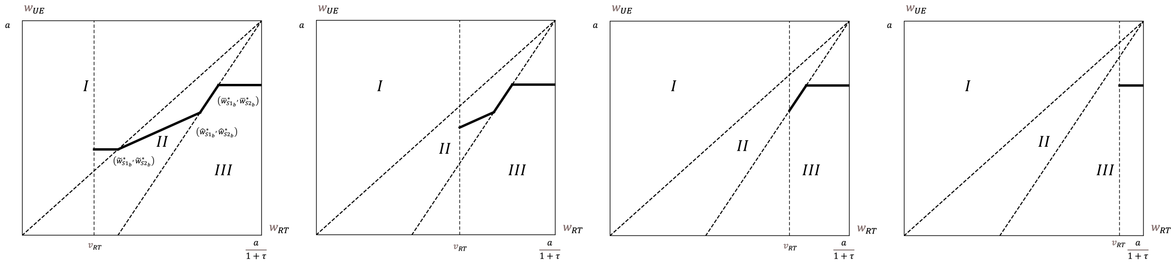


(a) $v_{UE} < \frac{(1+\tau)v_{RT}-a\psi}{1-\psi}$ and $v_{RT} > \frac{a\psi}{1+\tau}$ (b) $\frac{(1+\tau)v_{RT}-a\psi}{1-\psi} \leq v_{UE} < \frac{a\psi+(1+\tau)v_{RT}}{1+\psi}$ (c) $\frac{a\psi+(1+\tau)v_{RT}}{1+\psi} \leq v_{UE} < \frac{a+(1+\tau)v_{RT}}{2}$ (d) $v_{UE} \geq \frac{a+(1+\tau)v_{RT}}{2}$

Figure B.2: RT Supplier's Wholesale Price Best Response Curve Under DAP

Similarly, we derive the UE supplier's best response function for any given wholesale price set by the RT supplier, where w_{RT}^* begins from its minimum value v_{RT}, with $0 \leq v_{RT} \leq \frac{a}{1+\tau}$. We consider four cases in total. Specifically, Figure B.3(a) corresponds to the case where $v_{RT} < \frac{v_{UE}}{1+\tau}$, Figure B.3(b) corresponds to the case where $\frac{v_{UE}}{1+\tau} \leq v_{RT} < \frac{2a\psi+(1-\psi)v_{UE}}{(1+\tau)(1+\psi)}$, and Figure B.3(c) corresponds to $\frac{2a\psi+(1-\psi)v_{UE}}{(1+\tau)(1+\psi)} \leq$

$v_{RT} < \frac{a(1+\psi)+(1-\psi)v_{UE}}{2(1+\tau)}$. Otherwise, see Figure B.3(d).



(a) $v_{RT} < \frac{v_{UE}}{1+\tau}$ (b) $\frac{v_{UE}}{1+\tau} \le v_{RT} < \frac{2a\psi+(1-\psi)v_{UE}}{(1+\tau)(1+\psi)}$ (c) $\frac{2a\psi+(1-\psi)v_{UE}}{(1+\tau)(1+\psi)} \le v_{RT} < \frac{a(1+\psi)+(1-\psi)v_{UE}}{2(1+\tau)}$ (d) $v_{RT} \ge \frac{a(1+\psi)+(1-\psi)v_{UE}}{2(1+\tau)}$

Figure B.3: UE Supplier's Wholesale Price Best Response Curve Under DAP

By intersecting the reaction curves, we get equilibriums shown in Figure B.4 where $0 \le v_{RT} \le \frac{a}{1+\tau}$ and $0 \le v_{UE} \le a$. We can summarize the results as follows (see Figure B.5 where the plane contains five regions) where $0 \le v_{RT} \le \frac{a}{1+\tau}$ and $0 \le v_{UE} \le a$ are required:

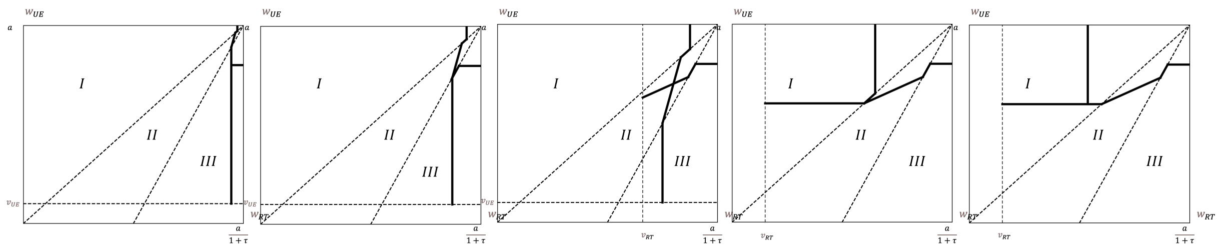
(1) If $v_{RT} \ge \frac{a(1+\psi)+(1-\psi)v_{UE}}{2(1+\tau)}$ (region I), then $w^*_{RT} = v_{RT}$ and $w^*_{UE} = \frac{1}{2}(a + v_{UE})$;

(2) If $\frac{2a\psi+(1-\psi)v_{UE}}{(1+\tau)(1+\psi)} \le v_{RT} < \frac{a(1+\psi)+(1-\psi)v_{UE}}{2(1+\tau)}$ (region II),then $w^*_{RT} = v_{RT}$ and $w^*_{UE} = \frac{(1+\tau)v_{RT}-a\psi}{1-\psi}$;

(3) If $\frac{(1+\psi)v_{UE}-a\psi}{1+\tau} < v_{RT} < \frac{2a\psi+(1-\psi)v_{UE}}{(1+\tau)(1+\psi)}$ (region III), then $w^*_{RT} = \frac{2a\psi+2(1+\tau)v_{RT}+(1-\psi)v_{UE}}{(1+\tau)(\psi+3)}$ and $w^*_{UE} = \frac{a\psi+(1+\tau)v_{RT}+2v_{UE}}{\psi+3}$;

(4) If $\frac{2v_{UE}-a}{1+\tau} < v_{RT} \le \frac{(1+\psi)v_{UE}-a\psi}{1+\tau}$ (region IV), then $w^*_{RT} = \frac{v_{UE}}{1+\tau}$ and $w^*_{UE} = v_{UE}$;

(5) If $v_{RT} \le \frac{2v_{UE}-a}{1+\tau}$ (region V), then $w^*_{RT} = \frac{a+(1+\tau)v_{RT}}{2(1+\tau)}$ and $w^*_{UE} = v_{UE}$.



(a) $v_{RT} \ge \frac{a(1+\psi)+(1-\psi)v_{UE}}{2(1+\tau)}$ (b) $\frac{2a\psi+(1-\psi)v_{UE}}{(1+\tau)(1+\psi)} \le v_{RT} < \frac{a(1+\psi)+(1-\psi)v_{UE}}{2(1+\tau)}$ (c) $\frac{(1+\psi)v_{UE}-a\psi}{1+\tau} < v_{RT} < \frac{2a\psi+(1-\psi)v_{UE}}{(1+\tau)(1+\psi)}$ (d) $\frac{2v_{UE}-a}{1+\tau} < v_{RT} \le \frac{(1+\psi)v_{UE}-a\psi}{1+\tau}$ (e) $v_{RT} \le \frac{2v_{UE}-a}{1+\tau}$

Figure B.4: Suppliers' Optimal Wholesale Prices Under DAP

We get the LSP's best response function regarding the UE supplier's freight charge when the RT supplier's is given. In region I, the LSP's best response freight charge

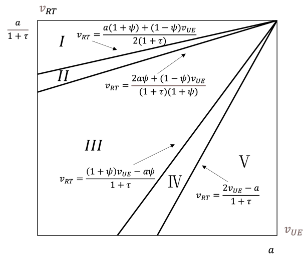


Figure B.5: Five Regions for the LSP Under DAP

towards the UE supplier is $v^*_{UEA} = \frac{a}{2}$ by maximizing $\frac{(1-\psi)v_{UE}(a-v_{UE})}{4b}$. In region II, the LSP's best response freight charge towards the UE supplier is $v^*_{UEB} = \frac{a}{2}$ by maximizing $\frac{v_{UE}[a-(1+\tau)v_{RT}]}{2b}$, where $v_{RT} = \frac{2a\psi+(1-\psi)v_{UE}}{(1+\tau)(1+\psi)}$. In region III, the LSP's best response freight charge towards the UE supplier is $v^*_{UEC} = \frac{a\psi+(\tau+2)v_{RT}}{2(1+\psi)}$ by maximizing $\frac{v_{RT}[2a\psi+(\tau+2)(1-\psi)v_{UE}]+(\psi-1)v_{UE}[(1+\psi)v_{UE}-a\psi]-(1+\tau)(1+\psi)v^2_{RT}}{2b\psi(\psi+3)}$. In region IV, the UE supplier receives no order, and the optimal freight charge is equal to the minimum value in this region, i.e., $v^*_{UED} = \frac{a\psi+(1+\tau)v_{RT}}{1+\psi}$. In region V, the UE supplier receives no order, and the optimal freight charge is equal to the minimum value in this region, i.e., $v^*_{UEE} = \frac{1}{2}[a + (1+\tau)v_{RT}]$.

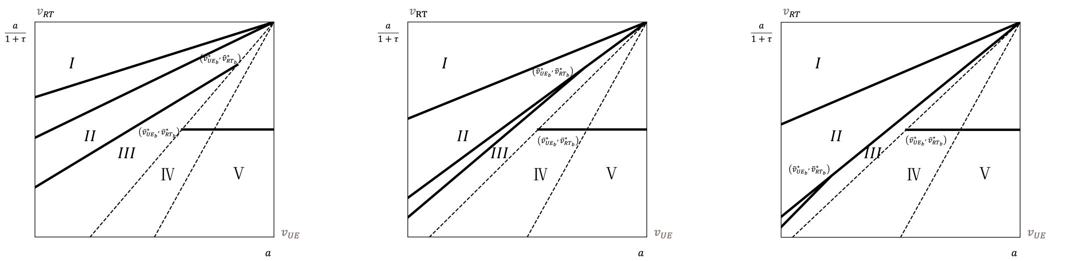
Then, we can show that there exists an intersection $(\bar{v}^*_{UE_a}, \bar{v}^*_{RT_a})$ between $v^*_{UEB} = \frac{a}{2}$ and $v_{RT} = \frac{2a\psi+(1-\psi)v_{UE}}{(1+\tau)(1+\psi)}$, where $\bar{v}^*_{UE_a} = \frac{a}{2}$ and $\bar{v}^*_{RT_a} = \frac{3a\psi+a}{2(1+\tau)(1+\psi)}$. Besides, there also exists an intersection $(\hat{v}^*_{UE_a}, \hat{v}^*_{RT_a})$ between $v^*_{UEC} = \frac{a\psi+(\tau+2)v_{RT}}{2(1+\psi)}$ and $v_{RT} = \frac{2a\psi+(1-\psi)v_{UE}}{(1+\tau)(1+\psi)}$, where $\hat{v}^*_{UE_a} = \frac{a\psi(\tau(\psi+3)+\psi+5)}{\tau\psi(2\psi+5)+\tau+2\psi(\psi+3)}$ and $\hat{v}^*_{RT_a} = \frac{a\psi(3\psi+5)}{\tau\psi(2\psi+5)+\tau+2\psi(\psi+3)}$. Note that when $\tau < \frac{4\psi}{1-\psi}$, $\bar{v}^*_{RT_a} - \hat{v}^*_{RT_a} = \frac{a[\tau(1-\psi)-4\psi]}{2[\tau\psi(2\psi+5)+\tau+2\psi(\psi+3)]} < 0$. Otherwise, $\bar{v}^*_{RT_a} \geq \hat{v}^*_{RT_a}$. These relationships are illustrated in Figures B.6(a) and B.6(b).

(a) $\tau < min\{\frac{4\psi}{1-\psi}, 1\}$ (b) $\psi < \frac{1}{5}$ and $\frac{4\psi}{1-\psi} \leq \tau < 1$

Figure B.6: LSP's Best Response Curve Regarding UE Supplier's Freight Charge Under DAP

Similarly, we get the LSP's best response function regarding the RT supplier's freight charge when the UE supplier's is given. In region V, the LSP's best response freight charge towards the RT supplier is $v^*_{RTA} = \frac{a}{2(1+\tau)}$ by maximizing $\frac{v_{RT}[a-(1+\tau)v_{RT}]}{4b}$. In region IV, the LSP's best response freight charge towards the RT supplier is $v^*_{RTB} = \frac{a}{2(1+\tau)}$ by maximizing $\frac{v_{RT}(a-v_{UE})}{2b}$, where $v_{UE} = \frac{a\psi+(1+\tau)v_{RT}}{1+\psi}$. In region III, the LSP's best response freight charge towards the RT supplier is $v^*_{RTC} = \frac{2a\psi+(\tau+2)(1-\psi)v_{UE}}{2(1+\tau)(1+\psi)}$ by maximizing $\frac{v_{RT}[2a\psi+(\tau+2)(1-\psi)v_{UE}]+(\psi-1)v_{UE}[(1+\psi)v_{UE}-a\psi]-(1+\tau)(1+\psi)v^2_{RT}}{2b\psi(\psi+3)}$. In region II, the RT supplier receives no order, and the optimal freight charge is equal to the minimum value in this region, i.e., $v^*_{RTD} = \frac{2a\psi+(1-\psi)v_{UE}}{(1+\tau)(1+\psi)}$. In region I, the RT supplier receives no order, and the optimal freight charge is equal to the minimum value in this region, i.e., $v^*_{RTE} = \frac{a(1+\psi)+(1-\psi)v_{UE}}{2(1+\tau)}$.

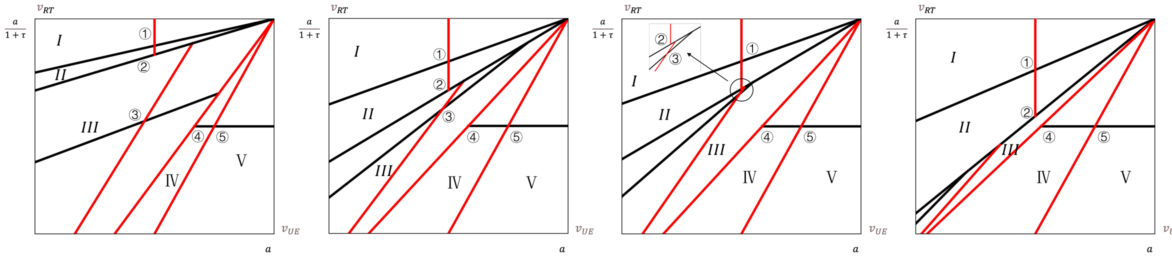
Then, we can show that there exists an intersection $(\bar{v}^*_{UE_b}, \bar{v}^*_{RT_b})$ between $v^*_{RTB} = \frac{a}{2(1+\tau)}$ and $v_{RT} = \frac{(1+\psi)v_{UE}-a\psi}{1+\tau}$, where $\bar{v}^*_{UE_b} = \frac{a(2\psi+1)}{2(1+\psi)}$ and $\bar{v}^*_{RT_b} = \frac{a}{2(1+\tau)}$. Besides, there also exists an intersection $(\hat{v}^*_{UE_b}, \hat{v}^*_{RT_b})$ between $v^*_{RTC} = \frac{2a\psi+(\tau+2)(1-\psi)v_{UE}}{2(1+\tau)(1+\psi)}$ and $v_{RT} = \frac{(1+\psi)v_{UE}-a\psi}{1+\tau}$, where $\hat{v}^*_{UE_b} = \frac{2a\psi(\psi+2)}{2\psi(\psi+3)-\tau(1-\psi)}$ and $\hat{v}^*_{RT_b} = \frac{a\psi(\tau+4-\tau\psi)}{(1+\tau)[2\psi(\psi+3)-\tau(1-\psi)]}$. Furthermore, there also exists an intersection $(\widetilde{v}^*_{UE_b}, \widetilde{v}^*_{RT_b})$ between $v^*_{RTC} = \frac{2a\psi+(\tau+2)(1-\psi)v_{UE}}{2(1+\tau)(1+\psi)}$ and $v_{RT} = \frac{2a\psi+(1-\psi)v_{UE}}{(1+\tau)(1+\psi)}$, where $\widetilde{v}^*_{UE_b} = \frac{2a\psi}{\tau(1-\psi)}$ and $\widetilde{v}^*_{RT_b} = \frac{2a\psi}{\tau(1+\psi)}$. Based on the comparative analysis of $\bar{v}^*_{UE_b}$ and $\hat{v}^*_{UE_b}$, and $\hat{v}^*_{UE_b}$ and a, we identify three distinct cases, each corresponding to a specific configuration of equilibrium outcomes, as shown in Figures B.7(a), B.7(b), and B.7(c), respectively.



(a) $\tau < min\{\frac{2\psi}{1-\psi}, 1\}$ (b) $\psi < \frac{1}{3}$ and $\frac{2\psi}{1-\psi} \leq \tau < min\{\frac{4\psi^2+4\psi}{1+\psi-2\psi^2}, 1\}$ (c) $\psi < \frac{1}{12}(\sqrt{33} - 3)$ and $\frac{4\psi^2+4\psi}{1+\psi-2\psi^2} \leq \tau < 1$

Figure B.7: LSP's Best Response Curve Regarding RT Supplier's Freight Charge Under DAP

Then, we can get the equilibrium by intersecting the reaction curves, and derive four conditions by noting that $\frac{4\psi^2+4\psi}{1+\psi-2\psi^2} < \frac{4\psi}{1-\psi}$, as shown in Figures B.8(a), B.8(b), B.8(c), and B.8(d), respectively.



(a) $\tau < min\{\frac{2\psi}{1-\psi}, 1\}$ (b) $\psi < \frac{1}{3}$ and $\frac{2\psi}{1-\psi} \leq \tau < min\{\frac{4\psi^2+4\psi}{1+\psi-2\psi^2}, 1\}$ (c) $\psi < \frac{1}{12}(\sqrt{33} - 3)$ and $\frac{4\psi^2+4\psi}{1+\psi-2\psi^2} \leq \tau < min\{\frac{4\psi}{1-\psi}, 1\}$ (d) $\psi < \frac{1}{5}$ and $\frac{4\psi}{1-\psi} \leq \tau < 1$

Figure B.8: LSP's Optimal Freight Charges Under DAP

We show that under DAP, there are five equilibrium freight charges:

(1) $v^*_{RT} = \frac{a(\psi+3)}{4(1+\tau)}, v^*_{UE} = \frac{a}{2}, \Pi^*_{L1} = \frac{a^2(1-\psi)}{16b}$.

(2) $v^*_{RT} = \frac{3a\psi+a}{2(1+\tau)(1+\psi)}, v^*_{UE} = \frac{a}{2}, \Pi^*_{L2} = \frac{a^2(1-\psi)}{8b(1+\psi)}$.

(3) $v^*_{RT} = \frac{a\psi[\tau(1-\psi)+2(\psi+3)]}{\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)}, v^*_{UE} = \frac{2a\psi[\tau(\psi+2)+\psi+3]}{\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)}, \Pi^*_{L3} = \frac{a^2\psi[\tau(1-\psi)-\psi+3]}{2bM}$.

(4) $v^*_{RT} = \frac{a}{2(1+\tau)}, v^*_{UE} = \frac{2a\psi+a}{2(1+\psi)}, \Pi^*_{L4} = \frac{a^2}{8b(1+\tau)(1+\psi)}$.

(5) $v^*_{RT} = \frac{a}{2(1+\tau)}, v^*_{UE} = \frac{3a}{4}, \Pi^*_{L5} = \frac{a^2}{16b(1+\tau)}$.

A close look at Figures B.8(a), B.8(b), and B.8(c) shows that there exist five equilibria when $\tau < min\{\frac{4\psi}{1-\psi}, 1\}$. Specifically, $\Pi^*_{L3} - \Pi^*_{L1} = \frac{a^2[\tau^2(1-\psi)^2+4\tau\psi^3(1+\tau)+\psi(12-4\tau)]}{16bM}$, where $M = \tau^2(\psi - 1) + 4\tau\psi(\psi + 3) + 4\psi(\psi + 3)$. The derivative of M with respect to τ is $\frac{\partial M}{\partial \tau} = 2\tau(\psi - 1) + 4\psi(\psi + 3)$, which is positive if $\tau < \frac{2\psi(\psi+3)}{1-\psi}$. It is straightforward that M is increasing in τ because $\frac{4\psi}{1-\psi} < \frac{2\psi(\psi+3)}{1-\psi}$, and thus $M > M|_{\tau=0} = 4\psi(\psi+3) > 0$. Similarly, define $N = \tau^2(\psi-1)-4\tau\psi(\psi+3)+4\psi(\psi+3)$, and we have $N > N|_{\tau=\frac{4\psi}{3\psi+1}} = \frac{12(1-\psi)\psi(1+\psi)^2}{(3\psi+1)^2} > 0$ for $\tau < \frac{4\psi}{3\psi+1}$ (both facts applied in the upcoming proof). Therefore, $\Pi^*_{L3} > \Pi^*_{L1}$ if $\tau < \frac{4\psi}{1-\psi}$. Other results for $\tau < \frac{4\psi}{1-\psi}$ can be easily verified, since $\Pi^*_{L3} - \Pi^*_{L2} = \frac{a^2[\tau-(\tau+4)\psi]^2}{8b(1+\psi)M} > 0$, $\Pi^*_{L3} - \Pi^*_{L4} = \frac{a^2(1-\psi)[2(1+\tau)\psi+\tau]^2}{8b(1+\tau)(1+\psi)M} > 0$, and $\Pi^*_{L3} - \Pi^*_{L5} = \frac{a^2(1-\psi)[\tau^2+4(1+\tau)(2\tau+3)\psi]}{16b(1+\tau)M} > 0$. Then, as depicted in Figure B.8(d), there are four equilibriums if $\psi < \frac{1}{5}$ and $\tau \geq \frac{4\psi}{1-\psi}$. Under these conditions, the profits can be compared sequentially. Let $\bar{\tau}^f_2[\psi] = \frac{4\psi}{1-\psi}$, we obtain that if $\tau < min\{\bar{\tau}^f_2[\psi], 1\}$, the buyer sources from both suppliers and the equilibrium outcomes are $v^{A*}_{RT} = \frac{a\psi[\tau(1-\psi)+2(\psi+3)]}{M}$, $v^{A*}_{UE} = \frac{2a\psi[\tau(\psi+2)+\psi+3]}{M}$. All the equilibrium outcomes under FOB based tariff are summarized in Table B.3. □

B.1.2 Proof of Proposition 3.2

When switching from EXW to DAP, we begin by examining the dual sourcing region where $\tau < min\{\frac{4\psi}{1-\psi}, 1\}$. (1) $v_{RT}^A - v_{RT}^E = \frac{a\tau[\tau(1-\psi)-2\psi(3\psi+5)]}{2M} < 0$. (2) $w_{RT}^A - v_{RT}^A - w_{RT}^E = \frac{-a\tau(1-\psi)\psi[\tau(\psi+2)+\psi+3]}{(1+\tau)(\psi+3)M} < 0$. (3) $(1+\tau)w_{RT}^A - [v_{RT}^E + (1+\tau)w_{RT}^E] = \frac{3a\tau^2(1-\psi^2)}{2(\psi+3)M} > 0$. (4) $q_{RT}^A - q_{RT}^E = \frac{-a\tau(1-\psi)[\tau(\psi+2)+\psi+3]}{2b(\psi+3)M} < 0$. After that, we turn to the single sourcing region under DAP, characterized by $\psi < \frac{1}{5}$ and $\tau \geq \frac{4\psi}{1-\psi}$. Adopting a similar derivation method in the dual sourcing region, we can show that the results continue to hold in the single sourcing region.

Next, when switching from DAP to DDP, we focus on the dual sourcing region where $\tau < \frac{4\psi}{3\psi+1}$. (1) $v_{RT}^D - v_{RT}^A = \frac{a\tau^2\psi h_1(\tau)}{MN}$, where $h_1(\tau) = \tau^2(3\psi^2 + 2\psi - 5) + 4\tau(3\psi^3 + 13\psi^2 + 13\psi + 3) - 4\psi(3\psi^2 + 14\psi + 15)$. Moreover, $\frac{\partial h_1(\tau)}{\partial \tau} = 6\tau\psi^2 + 4\tau\psi + 12 - 10\tau + 12\psi^3 + 52\psi^2 + 52\psi > 0$, implying $h_1(\tau)$ is strictly increasing in τ. Since $h_1(\tau) < h_1(\tau)|_{\tau=\frac{4\psi}{3\psi+1}} = \frac{-12(1-\psi)\psi(1+\psi)[3\psi(\psi+4)+1]}{(3\psi+1)^2} < 0$, we conclude that $v_{RT}^D < v_{RT}^A$. (2) $(1-\tau)w_{RT}^D - v_{RT}^D - (w_{RT}^A - v_{RT}^A) = \frac{a\tau^2\psi h_2(\tau)}{MN}$, where $h_2(\tau) = \tau^2(3\psi^2 - 2\psi - 1) + 4\tau\psi(3\psi^2 + 8\psi + 5) - 4\psi(3\psi^2 + 10\psi + 3)$. It is easy to verify that $h_2(\tau) < 0$. (3) $w_{RT}^D - (1+\tau)w_{RT}^A = \frac{12a\tau^3\psi(1-\psi^2)}{MN} > 0$. (4) $q_{RT}^D - q_{RT}^A = \frac{-a\tau^2(1-\psi)[\tau^2(1-\psi)+4\tau\psi(1+\psi)+4\psi(\psi+3)]}{2bMN} < 0$. After that, we turn to the single sourcing region under DDP, characterized by $\frac{4\psi}{3\psi+1} \leq \tau < min\{\frac{4\psi}{1-\psi}, 1\}$. Adopting a similar derivation method in the dual sourcing region, we can show that the results continue to hold in the single sourcing region. Finally, we discuss the single sourcing region under both trade contracts, characterized by $\psi < \frac{1}{5}$ and $\tau \geq \frac{4\psi}{1-\psi}$, a condition that can be easily verified. □

B.1.3 Proof of Proposition 3.3

When switching from EXW to DAP, we begin by examining the dual sourcing region where $\tau < min\{\frac{4\psi}{1-\psi}, 1\}$. (1) $w_{UE}^A - v_{UE}^A - w_{UE}^E = \frac{a\tau\psi[\tau(1-\psi)+2\psi+6]}{2(\psi+3)M} > 0$. (2) $v_{UE}^A - v_{UE}^E = \frac{a\tau[\tau(1-\psi)-4\psi]}{2M} < 0$. (3) $w_{UE}^A - (v_{UE}^E + w_{RT}^E) = -\frac{a\tau[\tau(2\psi^2+\psi-3)+2\psi(\psi+3)]}{2(\psi+3)M} > 0$ if $\tau > \frac{2\psi^2+6\psi}{3-2\psi^2-\psi}$. Combined with $\frac{2\psi^2+6\psi}{3-2\psi^2-\psi} < min\{\frac{4\psi}{1-\psi}, 1\}$, we get $4\psi^2 + 7\psi - 3 < 0$. It is clear to verify that there exists a unique root $\psi = \frac{1}{8}(\sqrt{97} - 7)$ satisfying $4\psi^2 + 7\psi - 3 = 0$. Let $\psi_1^f[\psi] = \frac{1}{8}(\sqrt{97} - 7)$ and $\tau_2^f[\psi] = \frac{2\psi^2+6\psi}{3-2\psi^2-\psi}$, and then

$w^A_{UE} > v^E_{UE} + w^E_{RT}$ if $\psi < \psi^f_1[\psi]$ and $\tau > \tau^f_2[\psi]$. (4) $q^A_{UE} - q^E_{UE} = \frac{a\tau[\tau(1-\psi)+2\psi+6]}{4b(\psi+3)M} > 0$. After that, we turn to the single sourcing region under DAP, characterized by $\psi < \frac{1}{5}$ and $\tau \geq \frac{4\psi}{1-\psi}$. Adopting a similar derivation method in the dual-sourcing region, we can show that the results continue to hold in the single-sourcing region. Next, the proof from DAP to DDP is similar to that from EXW to DAP; here, we omit details. □

B.1.4 Proof of Proposition 3.4

When switching from EXW to DAP, we begin by examining the dual sourcing region where $\tau < min\{\frac{4\psi}{1-\psi}, 1\}$. $\Pi^A_B - \Pi^E_B = \frac{a^2\tau(1-\psi)f_1(\tau)}{16b(\psi+3)^2M^2}$, where $f_1(\tau) = 16\psi^2(\psi+3)^2 + 4\psi\tau(8\psi^3+27\psi^2-6\psi-45)+8\psi\tau^2(2\psi^3+\psi^2-24\psi-27)+\tau^3(-4\psi^3-25\psi^2+2\psi+27)$. Let $f^{(i)}_1(\tau)$ denote the ith-order derivative of $f_1(\tau), i = 1, 2, ...n$. We first observe that $f^{(3)}_1(\tau) = 6(1-\psi)(4\psi^2+29\psi+27) > 0$, which implies that $f^{(2)}_1(\tau)$ is strictly increasing in τ. Evaluating its endpoints, we have $f^{(2)}_1(0) = 16\psi(\psi+3)(2\psi^2-5\psi-9) < 0$ and $f^{(2)}_1(\frac{4\psi}{1-\psi}) = 8\psi(4\psi^3+14\psi^2+39\psi+27) > 0$. This implies that $f^{(1)}_1(\tau)$ first decreases and then increases with τ. Furthermore, $f^{(1)}_1(0) = 4\psi(\psi+3)(8\psi^2+3\psi-15) < 0$ and $f^{(1)}_1(\frac{4\psi}{1-\psi}) = \frac{12\psi(\psi+1)(8\psi^3+7\psi^2-8\psi-15)}{1-\psi} < 0$, indicating that $f_1(\tau)$ is strictly decreasing in τ. Since $f_1(0) = 16\psi^2(\psi+3)^2 > 0$ and $f_1(\frac{4\psi}{1-\psi}) = \frac{144\psi^2(\psi+1)^2(\psi^2-\psi-4)}{(\psi-1)^2} < 0$, there exists a unique threshold $\tau^f_4[\psi] < \frac{4\psi}{1-\psi}$ such that $f_1(\tau^f_4) = 0$. After that, we turn to the single sourcing region under DAP, characterized by $\psi < \frac{1}{5}$ and $\tau \geq \frac{4\psi}{1-\psi}$, and the result can be easily verified. Next, for the transition from DAP to DDP, the analysis in this case parallels the arguments used in the transition from EXW to DAP. Therefore, we omit the detailed proof here for brevity. □

B.1.5 Proof of Corollary 3.1

We aim to prove that $\tau^f_5[\psi] < \tau^f_4[\psi]$. Previously, we showed that there exists a unique threshold $\tau^f_4[\psi] < \frac{4\psi}{1-\psi}$ such that $f_1(\tau^f_4[\psi]) = 0$, with $f_1(0) > 0$ and $f_1(\frac{4\psi}{1-\psi}) < 0$. Evaluating at $\tau = \frac{7}{10}\psi$, we obtain $f_1(\frac{7}{10}\psi) = \frac{3\psi^2[2156\psi^4+5317\psi^3+(1-\psi)(5793-598\psi^2)+207]}{1000} > 0$, which implies $\tau^f_4[\psi] > \frac{7}{10}\psi$ for all ψ. Likewise, it can be shown that $\tau^f_5[\psi] < \frac{2}{5}\psi$ always holds. Combining these results yields the strict inequality: $\tau^f_4[\psi] > \frac{7}{10}\psi >$

$\frac{2}{5}\psi > \tau_5^f[\psi]$, which completes the proof. □

B.1.6 Proof of Proposition 3.5

The proof of comparisons from EXW to DAP is easy to derive. From DAP to DDP, we first focus on the dual sourcing region where $\tau < \frac{4\psi}{3\psi+1}$. (1) $\Pi_L^D - \Pi_L^A = \frac{a^2\tau^2\psi g_1(\tau)}{bMN}$, where $g_1(\tau) = \tau^2(\psi-1) + \tau(5\psi^2+8\psi+3) - 4\psi(\psi+3)$. Then, $\frac{\partial g_1(\tau)}{\partial\tau} = 3 + 2\tau(\psi-1) + 5\psi^2 + 8\psi > 0$. Thus, $g_1(\tau)$ increases in τ, and we find that $g_1(\tau) < g_1(\tau)|_{\tau=\frac{4\psi}{3\psi+1}} = \frac{24\psi^2(\psi^2-1)}{(3\psi+1)^2} < 0$. Therefore, $\Pi_L^D < \Pi_L^A$. (2) $\Pi_{RT}^D - \Pi_{RT}^A = \frac{a^2\psi g_2(\tau)}{2bM^2N^2}$, where $g_2(\tau) = (1-\tau)[4\psi-\tau(3\psi+1)]^2M^2 - (1+\tau)[4\psi-\tau(1-\psi)]^2N^2$. To establish that $\Pi_{RT}^D < \Pi_{RT}^A$, we need to show $g_2(\tau) < 0$, or equivalently, $\frac{1-\tau}{1+\tau} < \frac{[4\psi-\tau(1-\psi)]^2N^2}{[4\psi-\tau(3\psi+1)]^2M^2}$. We proceed in two steps. First, $\frac{1-\tau}{1+\tau} - \frac{(1-\frac{\tau}{2})^2}{(1+\frac{\tau}{2})^2} = -\frac{2\tau^3}{(1+\tau)(\tau+2)^2} < 0$. Second, $(1-\frac{\tau}{2})[4\psi-\tau(3\psi+1)]M - (1+\frac{\tau}{2})[4\psi-\tau(1-\psi)]N = \tau^2(1+\psi)[\tau^2(\psi-1)+8\tau\psi(1+\psi) - 4\psi(\psi+3)] < 0$ which holds under the condition $\tau < \frac{4\psi}{3\psi+1}$. Hence, we can derive that $\frac{1-\tau}{1+\tau} < \frac{(1-\frac{\tau}{2})^2}{(1+\frac{\tau}{2})^2} < \frac{[4\psi-\tau(1-\psi)]^2N^2}{[4\psi-\tau(3\psi+1)]^2M^2}$, and thus we obtain $\Pi_{RT}^D < \Pi_{RT}^A$ if $\tau < \frac{4\psi}{3\psi+1}$. (3) $\Pi_{UE}^D - \Pi_{UE}^A = \frac{a^2(1-\psi)\psi g_3(\tau)}{2bN^2M^2}$, where $g_3(\tau) = (1-\tau)^2(\tau+2\psi)^2M^2 - [2(1+\tau)\psi+\tau]^2N^2$. Thus, to establish that $\Pi_{UE}^D > \Pi_{UE}^A$, we need to show that $g_2(\tau) > 0$, or equivalently, $\frac{(1-\tau)^2(\tau+2\psi)^2}{[2(1+\tau)\psi+\tau]^2} > \frac{N^2}{M^2}$. As shown in (2), we obatin $(1-\tau)(\tau+2\psi)M - [2(1+\tau)\psi + \tau]N = \tau^2[\tau^2(1-\psi) - 8\tau\psi(1+\psi) + 4\psi(\psi+3)] > 0$. Therefore, it follows that $\frac{(1-\tau)^2(\tau+2\psi)^2}{[2(1+\tau)\psi+\tau]^2} > \frac{N^2}{M^2}$, and thus $\Pi_{UE}^D > \Pi_{UE}^A$ if $\tau < \frac{4\psi}{3\psi+1}$. After that, we turn to the single sourcing region under DDP, characterized by $\frac{4\psi}{3\psi+1} \le \tau < min\{\frac{4\psi}{1-\psi}, 1\}$. Adopting a similar derivation method in the dual-sourcing region, we can show that the results continue to hold in the single-sourcing region. Finally, we discuss the single sourcing region under both trade contracts where $\psi < \frac{1}{5}$ and $\tau \ge \frac{4\psi}{1-\psi}$. (1) $\Pi_L^D - \Pi_L^A = 0$. (2) $\Pi_{RT}^D - \Pi_{RT}^A = 0$. (3) $\Pi_{UE}^D - \Pi_{UE}^A = 0$. □

B.1.7 Proof of Corollary 3.2

This can be derived directly from Propositions 3.4 and 3.5. □

B.1.8 Proof of Proposition 3.6

This is directly inferred from Corollary 3.1. □

B.1.9 Proof of Proposition 3.7

It is straightforward to verify that w_{UE}^E is independent of τ, while $w_{RT}^E = \frac{a\psi}{(1+\tau)(\psi+3)}$ is decreasing in τ. Taking the FOC of of $w_{RT}^i, i \in \{A, D\}$ to τ, we obtain $\frac{\partial w_{RT}^A}{\partial \tau} = -\frac{6a\psi(\psi+1)(4\psi(\psi+3)-2\tau(1-\psi))}{M^2} < 0$ for $\tau < \frac{4\psi}{1-\psi}$ and $\frac{\partial w_{RT}^D}{\partial \tau} = \frac{6a(2-\tau)\tau(1-\psi)\psi(\psi+1)}{N^2} > 0$ for $\tau < \frac{4\psi}{3\psi+1}$. Similarly, we obtain $\frac{\partial w_{UE}^A}{\partial \tau} = -\frac{a\psi(\tau^2(4\psi^2+\psi-5)+4\tau(2\psi^2+\psi-3)+4\psi(\psi+3))}{M^2} < 0$ for $\tau < \frac{4\psi}{5}$, and $\frac{\partial w_{UE}^D}{\partial \tau} = -\frac{a\psi(\tau^2(9\psi+7)-4\tau(5\psi+3)+4\psi(\psi+3))}{N^2} < 0$ for $\tau < \frac{3\psi}{5}$. Since $\tau_4^f[\psi] < \frac{4\psi}{5}$ and $\tau_5^f[\psi] < \frac{3\psi}{5}$, these inequalities hold under $\tau_5^f[\psi] < \tau \leq \tau_4^f[\psi]$ and $\tau \leq \tau_5^f[\psi]$, respectively. □

B.1.10 Proof of Corollary 3.3

We show that $q_{RT}^E = \frac{a}{2b\psi+6b}$, which is independent of τ. Taking the FOC of $q_{RT}^i, i \in \{A, D\}$ with respect to τ, we obtain $\frac{\partial q_{RT}^A}{\partial \tau} = -\frac{a(1-\psi)[\tau^2[\psi(4\psi+7)+1]+8\tau\psi(\psi+2)+4\psi(\psi+3)]}{2bM^2} < 0$ and $\frac{\partial q_{RT}^D}{\partial \tau} = -\frac{a(1-\psi)[\tau^2(3\psi+1)-8\tau\psi+4\psi(\psi+3)]}{2bN^2} < 0$. Therefore, both $q_{RT}^A(\tau)$ and $q_{RT}^D(\tau)$ are decreasing in τ, and reach their minimum values at $\tau = \tau_4^f[\psi]$ and $\tau = \tau_5^f[\psi]$, respectively. We further compute: $q_{RT}^A(\frac{7}{10}\psi) - q_{RT}^D(\frac{2}{5}\psi) = \frac{a(1-\psi)(15-14\psi)(21\psi^2+69\psi+100)}{4b(3\psi^2+2\psi-25)(329\psi^2+1191\psi+1200)} < 0$ and $q_{RT}^A(\frac{7}{10}\psi) - q_{RT}^E = \frac{-7a(1-\psi)[\psi(7\psi+24)+30]}{2b(\psi+3)[\psi(329\psi+1191)+1200]} < 0$. Since we have already established that $\tau_4^f[\psi] > \frac{7}{10}\psi$ and $\tau_5^f[\psi] < \frac{2}{5}\psi$, it follows that $q_{RT}^A(\tau_4^f[\psi]) < q_{RT}^A(\frac{7}{10}\psi)$ and $q_{RT}^D(\frac{2}{5}\psi) < q_{RT}^D(\tau_5^f[\psi])$. Therefore, we obtain $q_{RT}^A(\tau_4^f[\psi]) < q_{RT}^A(\frac{7}{10}\psi) < q_{RT}^D(\frac{2}{5}\psi) < q_{RT}^D(\tau_5^f[\psi])$ and $q_{RT}^A(\tau_4^f[\psi]) < q_{RT}^A(\frac{7}{10}\psi) < q_{RT}^E$. Also, the proof regarding the impact of tariffs on the order quantity from the UE supplier follows the same structure as that for the RT supplier. Hence, we omit the details here. □

B.1.11 Proof of Proposition 3.8

First, consider EXW. It is straightforward to verify that the profits of the buyer, the UE supplier, and the LSP are independent of τ, while the profit of the RT supplier, $\Pi_{RT}^E = \frac{a^2\psi}{2b(\tau+1)(\psi+3)^2}$ is decreasing in τ. Then, consider DAP. Taking the FOC of Π_B^A with respect to τ, we obtain $\frac{\partial \Pi_B^A}{\partial \tau} = \frac{a^2(1-\psi)\psi s_1(\tau)}{2bM^3}$, where $s_1(\tau) = 6\tau^4(1-\psi^2) + \tau^3(8\psi^3 - 36\psi^2 - 33\psi + 13) + 6\tau^2\psi(4\psi^2 - 11\psi - 17) + 12\tau\psi(2\psi^2 - \psi - 5) + 8\psi^2(\psi + 3)$. Let $\tau_{s1}^f[\psi]$ denote the root of $s_1(\tau)$, i.e., $s_1(\tau_{s1}^f[\psi]) = 0$. It follows that

Π_B^A is increasing in τ for $\tau < \tau_{s1}^f[\psi]$ and decreasing in τ otherwise. Recall from the proof of Proposition 3.7 that $\tau_4^f[\psi] > \frac{2\psi}{5}$. Evaluating $s_1(\tau)$ at $\tau = \frac{2\psi}{5}$ yields $s_1(\frac{2\psi}{5}) = \frac{32}{625}\psi^3(7\psi^3 + 30\psi^2 - 57\psi - 240) < 0$, which implies that $\tau_{s1}^f[\psi] < \frac{2\psi}{5}[\psi]$. Consequently, we have $\tau_{s1}^f[\psi] < \frac{2\psi}{5} < \tau_4^f[\psi]$. Similarly, we compare τ_{s1}^f with τ_5^f. Recall that $f_1(\tau_5^f[\psi]) = 0$ and $f_1(\tau)$ is decreasing in τ (as established in the proof of Proposition 3.4). Tedious algebraic calculation can verify that $f_1(\tau_{s1}^f[\psi]) < 0$, which implies that $\tau_5^f[\psi] < \tau_{s1}^f[\psi]$. Thus, there exists a threshold $\tau_{s1}^f[\psi]$ such that $\tau_{s1}^f[\psi] \in (\tau_5^f[\psi], \tau_4^f[\psi])$. As a result, under DAP, the buyer's profit is unimodal in τ. Similarly, for the RT supplier, we have $\frac{\partial \Pi_{RT}^A}{\partial \tau} = \frac{a^2\psi(4\psi - \tau(1-\psi))s_2(\tau)}{2bM^3}$, where $s_2(\tau) = -\tau^3(1-\psi)^2 - 2\tau^2(1-\psi)(1-\psi(1-2\psi)) - 4\tau\psi(\psi(\psi+10)+5) - 8\psi(\psi+1)(\psi+3) < 0$. Thus, $\frac{\partial \Pi_{RT}^A}{\partial \tau} < 0$ since $\tau < \frac{4\psi}{1-\psi}$, and thus Π_{RT}^A is decreasing in τ. The results for the UE supplier and the LSP can be derived using a similar method, and we omit the detailed derivations. Likewise, a similar method applies under DDP, where the buyer's profit is also unimodal in τ. The proof can be established in an analogous manner, and we omit the details here. □

B.1.12 Proof of Proposition 3.9∼3.10

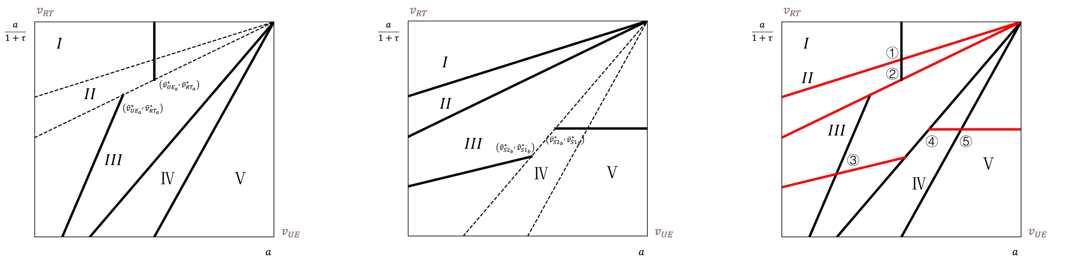
The proof regarding the impact of ψ on the equilibrium wholesale price follows the same logic as that for τ. Since the derivation is routine and tedious, we omit the details here. The thresholds of $\psi_2^f[\tau]$ and $\psi_3^f[\tau]$ are defined in Table B.2 in Appendix B.2. □

B.1.13 Proof of Proposition 3.11

Taking the DAP as an example. The proof of dedicated LSPs is different from that of the common LSP as two LSPs compete for the buyer's orders in stage 1. The profit functions of the LSPs are $\hat{\Pi}_{L1}^A = \hat{q}_{RT}^A \hat{v}_{RT}^A$ and $\hat{\Pi}_{L2}^A = (1-\psi)\hat{q}_{UE}^A \hat{v}_{UE}^A$.

In stage 1, we can see that the plane contains five regions in Figure B.5. We get the LSP 2's reaction curve when the RT supplier's freight charge is given. In region I, the LSP 2's best response freight charge towards the UE supplier is $\hat{v}_{UEA}^* = \frac{a}{2}$ by maximizing $\frac{(1-\psi)\hat{v}_{\mathrm{UE}}(a-\hat{v}_{\mathrm{UE}})}{4b}$. In region II, the LSP 2's best response freight charge towards the UE supplier is $\hat{v}^*_{UEB} = \frac{a}{2}$ by maximizing $\frac{\hat{v}_{\text{UE}}[a-(1+\tau)\hat{v}_{\text{RT}}]}{2b}$, where $\hat{v}_{RT} = \frac{2a\psi+(1-\psi)\hat{v}_{\text{UE}}}{(1+\tau)(1+\psi)}$. In region III, the LSP 2's best response freight charge towards the UE supplier is $\hat{v}^*_{UEC} = \frac{a\psi+\hat{v}_{\text{RT}}(1+\tau)}{2(1+\psi)}$ by maximizing $\frac{(1-\psi)\hat{v}_{\text{UE}}[a\psi+(1+\tau)\hat{v}_{\text{RT}}-(1+\psi)\hat{v}_{\text{UE}}]}{2b\psi(\psi+3)}$. In region IV, the UE supplier receives no order, and the optimal freight charge is equal to the minimum value in this region, i.e., $\hat{v}^*_{UED} = \frac{a\psi+(1+\tau)\hat{v}_{\text{RT}}}{1+\psi}$. In region V, the UE supplier receives no order, and the optimal freight charge is equal to the minimum value in this region, i.e., $\hat{v}^*_{UEE} = \frac{1}{2}[a+(1+\tau)\hat{v}_{\text{RT}}]$.

Then, there exists an intersection $(\bar{v}^*_{UE_a}, \bar{v}^*_{RT_a})$ between $\hat{v}^*_{UEB} = \frac{a}{2}$ and $\hat{v}_{\text{RT}} = \frac{2a\psi+(1-\psi)\hat{v}_{\text{UE}}}{(1+\tau)(1+\psi)}$, where $\bar{v}^*_{UE_a} = \frac{a}{2}$ and $\bar{v}^*_{RT_a} = \frac{3a\psi+a}{2(1+\tau)(1+\psi)}$. There also exists an intersection $(\hat{v}^*_{UE_a}, \hat{v}^*_{RT_a})$ between $\hat{v}^*_{UEC} = \frac{a\psi+(1+\tau)\hat{v}_{\text{RT}}}{2(1+\psi)}$ and $\hat{v}_{\text{RT}} = \frac{2a\psi+(1-\psi)\hat{v}_{\text{UE}}}{(1+\tau)(1+\psi)}$, where $\hat{v}^*_{UE_a} = \frac{a\psi(\psi+3)}{2\psi^2+5\psi+1}$ and $\hat{v}^*_{RT_a} = \frac{a\psi(3\psi+5)}{(1+\tau)(2\psi^2+5\psi+1)}$. We find that $\bar{v}^*_{RT_a} - \hat{v}^*_{RT_a} > 0$, see Figure B.9(a).



(a) LSP 2's Best Response Curve (b) LSP 1's Best Response Curve (c) LSP's Optimal Freight Charges

Figure B.9: Optimal Freight Charges Under LSP Competition

Similarly, we get the LSP 1's best response function regarding the RT supplier's freight charge when the UE supplier's is given. There exists an intersection $(\bar{v}^*_{UE_b}, \bar{v}^*_{RT_b})$ between $\hat{v}^*_{RTB} = \frac{a}{2\tau+2}$ and $\hat{v}_{\text{RT}} = \frac{(1+\psi)\hat{v}_{\text{UE}}-a\psi}{1+\tau}$, where $\bar{v}^*_{UE_b} = \frac{a(2\psi+1)}{2(1+\psi)}$ and $\bar{v}^*_{RT_b} = \frac{a}{2(1+\tau)}$. Note that there also exists an intersection $(\hat{v}^*_{UE_b}, \hat{v}^*_{RT_b})$ between $\hat{v}^*_{RTC} = \frac{2a\psi+(1-\psi)\hat{v}_{\text{UE}}}{2(1+\tau)(1+\psi)}$ and $\hat{v}_{\text{RT}} = \frac{(1+\psi)\hat{v}_{\text{UE}}-a\psi}{1+\tau}$, where $\hat{v}^*_{UE_b} = \frac{2a\psi(\psi+2)}{2\psi^2+5\psi+1}$ and $\hat{v}^*_{RT_b} = \frac{a\psi(\psi+3)}{(1+\tau)(2\psi^2+5\psi+1)}$. We find that, $\bar{v}^*_{RT_b} - \hat{v}^*_{RT_b} > 0$, see Figure B.9(b). We can derive five equilibrium freight charges intersecting the reaction curves in Figure B.9(c):

(1) $\hat{v}^*_{RT} = \frac{a(\psi+3)}{4(\tau+1)}, \hat{v}^*_{UE} = \frac{a}{2}$, $\hat{\Pi}^*_{L11} = 0, \hat{\Pi}^*_{L21} = \frac{a^2(1-\psi)}{16b}$.

(2) $\hat{v}^*_{RT} = \frac{3a\psi+a}{2(1+\tau)(1+\psi)}, \hat{v}^*_{UE} = \frac{a}{2}$, $\hat{\Pi}^*_{L12} = 0, \hat{\Pi}^*_{L22} = \frac{a^2(1-\psi)}{8b(\psi+1)}$.

(3) $\hat{v}^*_{RT} = \frac{a\psi(3\psi+5)}{(\tau+1)(4\psi^2+9\psi+3)}, \hat{v}^*_{UE} = \frac{2a\psi(\psi+2)}{4\psi^2+9\psi+3}$, $\hat{\Pi}^*_{L13} = \frac{a^2\psi(\psi+1)(3\psi+5)^2}{2b(\tau+1)(\psi+3)[\psi(4\psi+9)+3]^2}, \hat{\Pi}^*_{L23} = \frac{2a^2\psi(\psi+2)^2(1-\psi^2)}{b(\psi+3)[\psi(4\psi+9)+3]^2}$.

(4) $\hat{v}^*_{RT} = \frac{a}{2(1+\tau)}, \hat{v}^*_{UE} = \frac{2a\psi+a}{2(1+\psi)}, \hat{\Pi}^*_{L14} = \frac{a^2}{8b(\tau+1)(\psi+1)}, \hat{\Pi}^*_{L24} = 0.$

(5) $\hat{v}^*_{RT} = \frac{a}{2\tau+2}, \hat{v}^*_{UE} = \frac{3a}{4}, \hat{\Pi}^*_{L15} = \frac{a^2}{16b\tau+16b}, \hat{\Pi}^*_{L25} = 0.$

By comparing the profits, we derive that $\hat{\Pi}_{L14}$ and $\hat{\Pi}_{L22}$ yield the maximum profits for LSP 1 and LSP 2, given $c < \frac{a}{1+\tau}$. Therefore, both LSPs aim to shift to their respective single-sourcing regions. It follows that the LSPs undercut their freight charges to their marginal cost. Consequently, dual sourcing becomes the equilibrium outcome, as can be seen from Figure B.9(c). Then, we can show that the equilibrium profits of supply chain parties are identical under each trade contract with $\hat{\Pi}^i_{RT} = \frac{2a^2\psi}{b(1+\tau)(\psi+3)^2}$, $\hat{\Pi}^i_{UE} = \frac{a^2(1-\psi)\psi}{2b(\psi+3)^2}$, $\hat{\Pi}^i_{L1} = 0$, $\hat{\Pi}^i_{L2} = 0$, and $\hat{\Pi}^i_B = \frac{a^2(9-5\psi)}{4b(\psi+3)^2}$, where $i = E, A, D$. □

B.1.14 Proof of Proposition 3.12

Under FOB based tariff, the proof of comparisons under competition is similar to that without competition. Here, we omit details. The thresholds of $\hat{\tau}^f_1[\psi]$ and $\hat{\tau}^f_2[\psi]$ are defined in Table B.2 in Appendix B.2. □

B.1.15 Proof of Corollary 3.4∼3.6

The proof under CIF based tariff, as well as the comparison between CIF- and FOB-based tariff, is similar to the proof under FOB based tariff. Since the derivation is routine and tedious, we omit the details here. The equilibrium outcomes are summaried in Table B.4. Moreover, the thresholds of $\bar{\tau}^c_1[\psi]$, $\bar{\tau}^c_2[\psi]$, $\bar{\tau}^c_3[\psi]$, $\tau^c_5[\psi]$, $\tau^c_6[\psi]$, and $\tau_1[\psi]$ are defined in Table B.2 . □

B.1.16 Proof of Proposition 3.13∼3.14

The logic of the comparison proof is similar to that under FOB based tariff. Since the derivation is routine and tedious, we omit the details here. □

B.1.17 Proof of Corollary 3.7∼3.8

The proofs of contract H are similar to those under EXW, DAP, and DDP. Since the derivation is routine and tedious, here we omit details. Under FOB based tariff, the buyer always sources from both suppliers and the equilibrium outcomes are the same as EXW under FOB based tariff except that $w_{RT}^{H*} = \frac{a\psi}{(1+\tau)(\psi+3)}$, and $\Pi_{RT}^{H*} = \frac{a^2\psi}{2b(1+\tau)(\psi+3)^2}$.

Under CIF based tariff, let $\bar{\tau}_H^c[\psi] = \frac{4\psi}{3\psi+1}$, we obtain that if $\tau < \bar{\tau}_H^c[\psi]$, the buyer sources from both suppliers and equilibrium outcomes are $\widetilde{v}_{RT}^{H*} = \frac{a(1-\tau)\psi[2(\psi+3)-\tau(3\psi+5)]}{N}$, $\widetilde{v}_{UE}^{H*} = \frac{2a(1-\tau)\psi(3+\psi-\tau)}{N}$, $\widetilde{w}_{RT}^{H*} = \frac{a(1-\tau)\psi[\tau(3\psi+5)+4\psi]}{N}$, $\widetilde{w}_{UE}^{H*} = \frac{a(1-\tau)\psi(\tau+2\psi)}{N}$, $\widetilde{q}_{RT}^{H*} = \frac{a(4\psi-3\tau\psi-\tau)}{2bN}$, $\widetilde{q}_{UE}^{H*} = \frac{a(1-\tau)(\tau+2\psi)}{2bN}$, $\widetilde{\Pi}_{RT}^{H*} = \frac{a^2(1-\tau)\psi(3\tau\psi+\tau-4\psi)^2}{2bN^2}$, $\widetilde{\Pi}_{UE}^{H*} = \frac{a^2(1-\tau)^2(1-\psi)\psi(\tau+2\psi)^2}{2bN^2}$, $\widetilde{\Pi}_{L}^{H*} = \frac{a^2(1-\tau)\psi(3-2\tau-\psi)}{2bN}$, and $\widetilde{\Pi}_{B}^{H*} = \frac{a^2\left[\tau^4-[(\tau-10)\tau+11]\tau^2\psi-4(\tau-1)(4\tau-5)\psi^3+[\tau[(43-10\tau]\tau-68)+36]\psi^2\right]}{4bN^2}$. Otherwise, the buyer only sources from the UE supplier and the equilibrium outcomes are $\widetilde{v}_{RT}^{H*} = \frac{(1-\tau)(3a\psi+a)}{2(1+\psi)}$, $\widetilde{v}_{UE}^{H*} = \frac{a}{2}$, $\widetilde{w}_{RT}^{H*} = \frac{a\tau(3\psi+1)}{2(1+\psi)}$, $\widetilde{w}_{UE}^{H*} = \frac{a\psi}{2(1+\psi)}$, $\widetilde{q}_{RT}^{H*} = 0$, $\widetilde{q}_{UE}^{H*} = \frac{a}{4b(1+\psi)}$, $\widetilde{\Pi}_{RT}^{H*} = 0$, $\widetilde{\Pi}_{UE}^{H*} = \frac{a^2(1-\psi)\psi}{8b(1+\psi)^2}$, $\widetilde{\Pi}_{L}^{H*} = \frac{a^2(1-\psi)}{8b(1+\psi)}$, and $\widetilde{\Pi}_{B}^{H*} = \frac{a^2(1-\psi)}{16b(1+\psi)^2}$. The thresholds of $\tau_{H1}^c[\psi]$ and $\tau_{H2}^c[\psi]$ are defined in Table B.2 in Appendix B.2. □

B.2 Summery of Notations

Table B.1: List of Notations

Notation	Definition
p_k	Market-clearing price under $k, k \in \{d, n\}$
a	Maximum willingness to pay
$b > 0$	Quantity sensitivity
q_i	Supplier i's order quantity, $i \in \{RT, UE\}$
$\tau \in (0, 1)$	High tariff rate
$\psi \in (0, 1)$	Probability of supply disruption
v_i	Unit freight charge of channel i
w_i	Unit wholesale price of supplier i
C_i	Expected total purchasing cost of channel i
R	Expected total revenue of the buyer
Π_i	Supplier i's expected profit
Π_B	Buyer's expected profit
Π_L	LSP's expected profit

Table B.2: List of Thresholds

Threshold	Expression
$\bar{\tau}_2^f[\psi]$	$\frac{4\psi}{1-\psi}$
$\bar{\tau}_3^f[\psi]$	$\frac{4\psi}{3\psi+1}$
$\tau_1^f[\psi]$	$\frac{\psi^2+4\psi+3-\sqrt{\psi^4+12\psi^3+30\psi^2+12\psi+9}}{1-\psi}$
$\tau_2^f[\psi]$	$\frac{2\psi^2+6\psi}{3-2\psi^2-\psi}$
$\tau_3^f[\psi]$	$\frac{2(-\psi^2+2\psi+3)-2\sqrt{\psi^4-3\psi^3+9\psi+9}}{1-\psi}$
$\tau_4^f[\psi]$	${\tau_4^f}^3(4\psi^3+25\psi^2-2\psi-27)-{\tau_4^f}^2(16\psi^4+8\psi^3-192\psi^2-216\psi)-\tau_4^f(32\psi^4+108\psi^3-24\psi^2-180\psi)-16\psi^4-96\psi^3-144\psi^2=0$
$\tau_5^f[\psi]$	${\tau_5^f}^6(\psi^2-2\psi+1)-{\tau_2^f}^5(12\psi^3-30\psi^2-8\psi+26)+{\tau_5^f}^4(48\psi^4+140\psi^3+56\psi^2+12\psi)-{\tau_5^f}^3(64\psi^5-256\psi^4-1712\psi^3-1760\psi^2-432\psi)-{\tau_5^f}^2(64\psi^5+464\psi^4+928\psi^3+336\psi^2)+\tau_5^f(64\psi^5-288\psi^4-1920\psi^3-1440\psi^2)+64\psi^5+384\psi^4+576\psi^3=0$
ψ_1^f	$\frac{1}{8}(\sqrt{97}-7)$
$\psi_2^f[\tau]$	${\psi_2^f}^4(16\tau^2+32\tau+16)+{\psi_2^f}^3(-4\tau^3+8\tau^2+108\tau+96)+{\psi_2^f}^2(-25\tau^3-192\tau^2-24\tau+144)+\psi_2^f(2\tau^3-216\tau^2-180\tau)+27\tau^3=0$
$\psi_3^f[\tau]$	${\psi_3^f}^5(64\tau^3+64\tau^2-64\tau-64)+{\psi_3^f}^4(-48\tau^4-256\tau^3+464\tau^2+288\tau-384)+{\psi_3^f}^3(12\tau^5-140\tau^4-1712\tau^3+928\tau^2+1920\tau-576)+{\psi_3^f}^2(-\tau^6-30\tau^5-56\tau^4-1760\tau^3+336\tau^2+1440\tau)+\psi_3^f(2\tau^6-8\tau^5-12\tau^4-432\tau^3)-\tau^6+26\tau^5=0$
$\bar{\tau}_1^c[\psi]$	$\frac{4\psi}{1-\psi}$
$\bar{\tau}_2^c[\psi]$	$\frac{2\psi}{1-\psi}$
$\bar{\tau}_3^c[\psi]$	$\frac{2\psi}{1+\psi}$
$\tau_5^c[\psi]$	$\tau_5^{c6}(24\psi^3-24\psi^2-24\psi+24)+\tau_5^{c5}(48\psi^4+348\psi^3-81\psi^2-354\psi+39)-\tau_5^{c4}(64\psi^5-112\psi^4-1554\psi^3-700\psi^2+766\psi)-\tau_5^{c3}(192\psi^5-12\psi^4-2775\psi^3-2418\psi^2+405\psi)-\tau_5^{c2}(208\psi^5+280\psi^4-1760\psi^3-2184\psi^2)-\tau_5^c(96\psi^5+324\psi^4-72\psi^3-540\psi^2)-16\psi^5-96\psi^4-144\psi^3=0.$
$\tau_6^c[\psi]$	$\tau_6^{c6}(4\psi^4+15\psi^3+7\psi^2-15\psi-11)-\tau_6^{c5}(8\psi^5-4\psi^4-90\psi^3-118\psi^2-14\psi+26)-\tau_6^{c4}(16\psi^5+3\psi^4-142\psi^3-301\psi^2-168\psi)-\tau_6^{c3}(2\psi^5+40\psi^4+158\psi^3+4\psi^2-108\psi)+\tau_6^{c2}(14\psi^5-31\psi^4-308\psi^3-267\psi^2)+\tau_6^c(10\psi^5+18\psi^4-66\psi^3-90\psi^2)+2\psi^5+12\psi^4+18\psi^3=0$
$\tau_1[\psi]$	$\tau_1^6(2\psi^2-4\psi+2)+\tau_1^5(-20\psi^3+33\psi^2+26\psi-39)+\tau_1^4(64\psi^4+240\psi^3-24\psi^2-152\psi)+\tau_1^3(-64\psi^5+64\psi^4+1009\psi^3+1338\psi^2+405\psi)+\tau_1^2(-296\psi^4-1136\psi^3-744\psi^2)+\tau_1(48\psi^5+36\psi^4-504\psi^3-540\psi^2)+16\psi^5+96\psi^4+144\psi^3=0.$
$\hat{\tau}_1^f[\psi]$	$\frac{2\psi^2+5\psi-3+\sqrt{4\psi^4+12\psi^3-3\psi^2-6\psi+9}}{2(1-\psi)}$
$\hat{\tau}_2^f[\psi]$	$\frac{2\psi^2+7\psi+3-\sqrt{4\psi^4+12\psi^3-3\psi^2-6\psi+9}}{4(1+\psi)}$
$\bar{\tau}_H^c[\psi]$	$\frac{4\psi}{3\psi+1}$
$\tau_{H1}^c[\psi]$	${\tau_{H1}^c}^6(2\psi^2-4\psi+2)+{\tau_{H1}^c}^5(-20\psi^3+33\psi^2+26\psi-39)+{\tau_{H1}^c}^4(64\psi^4+240\psi^3-24\psi^2-152\psi)+{\tau_{H1}^c}^3(-64\psi^5+64\psi^4+1009\psi^3+1338\psi^2+405\psi)+{\tau_{H1}^c}^2(-296\psi^4-1136\psi^3-744\psi^2)+\tau_{H1}^c(48\psi^5+36\psi^4-504\psi^3-540\psi^2)+16\psi^5+96\psi^4+144\psi^3=0$
$\tau_{H2}^c[\psi]$	${\tau_{H2}^c}^6(\psi^2-2\psi+1)+{\tau_{H2}^c}^5(-12\psi^3+30\psi^2+8\psi-26)+{\tau_{H2}^c}^4(48\psi^4+140\psi^3+56\psi^2+12\psi)+{\tau_{H2}^c}^3(-64\psi^5+256\psi^4+1712\psi^3+1760\psi^2+432\psi)+{\tau_{H2}^c}^2(-64\psi^5-464\psi^4-928\psi^3-336\psi^2)+\tau_{H2}^c(64\psi^5-288\psi^4-1920\psi^3-1440\psi^2)+64\psi^5+384\psi^4+576\psi^3=0$

Table B.3: Equilibrium Outcomes of FOB

Trade Contract	Decision Variables and Profits	Sourcing Strategy
EXW	$v_{RT}^{E*} = \frac{a}{2}$ $w_{RT}^{E*} = \frac{a\psi}{(1+\tau)(\psi+3)}$ $q_{RT}^{E*} = \frac{a}{2b(\psi+3)}$ $\Pi_{RT}^{E*} = \frac{a^2\psi}{2b(1+\tau)(\psi+3)^2}$ $\Pi_{L}^{E*} = \frac{a^2(3-\psi)}{8b(\psi+3)}$ $v_{UE}^{E*} = \frac{a}{2}$ $w_{UE}^{E*} = \frac{a\psi}{2(\psi+3)}$ $q_{UE}^{E*} = \frac{a}{4b(\psi+3)}$ $\Pi_{UE}^{E*} = \frac{a^2(1-\psi)\psi}{8b(\psi+3)^2}$ $\Pi_{B}^{E*} = \frac{a^2(5\psi-9)}{16b(\psi+3)^2}$	Dual sourcing
DAP	$v_{RT}^{A*} = \frac{a\psi[\tau(1-\psi)+2(\psi+3)]}{\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)}$ $w_{RT}^{A*} = \frac{6a\psi(1+\psi)}{\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)}$ $q_{RT}^{A*} = \frac{a(1+\tau)[\tau(\psi-1)+4\psi]}{2b[\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)]}$ $\Pi_{RT}^{A*} = \frac{a^2(1+\tau)\psi[\tau(\psi-1)+4\psi]^2}{2b[\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)]^2}$ $\Pi_{L}^{A*} = \frac{a^2\psi[\tau(1-\psi)-\psi+3]}{2b[\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)]}$ $v_{UE}^{A*} = \frac{2a\psi[\tau(\psi+2)+\psi+3]}{\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)}$ $w_{UE}^{A*} = \frac{a\psi[\tau(4\psi+5)+4\psi+6]}{\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)}$ $q_{UE}^{A*} = \frac{a[2(1+\tau)\psi+\tau]}{2b[\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)]}$ $\Pi_{UE}^{A*} = \frac{a^2(1-\psi)\psi(2\tau\psi+\tau+2\psi)^2}{2b[\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)]^2}$ $\Pi_{B}^{A*} = \frac{a^2[\tau^4-[2\tau(\tau+6)+11]\tau^2\psi-4(1+\tau)^2(\tau+5)\psi^3+(1+\tau)[\tau[\tau(\tau+15)+40]+36]\psi^2]}{4b[\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)]^2}$	Dual sourcing $\tau < min\{\bar{\tau}_2^f[\psi], 1\}$
	$v_{RT}^{A*} = \frac{3a\psi+a}{2(1+\tau)(1+\psi)}$ $w_{RT}^{A*} = \frac{3a\psi+a}{2(1+\tau)(1+\psi)}$ $q_{RT}^{A*} = 0$ $\Pi_{RT}^{A*} = 0$ $\Pi_{L}^{A*} = \frac{a^2(1-\psi)}{8b(1+\psi)}$ $v_{UE}^{A*} = \frac{a}{2}$ $w_{UE}^{A*} = \frac{2a\psi+a}{2(1+\psi)}$ $q_{UE}^{A*} = \frac{a}{4b(1+\psi)}$ $\Pi_{UE}^{A*} = \frac{a^2(1-\psi)\psi}{8b(1+\psi)^2}$ $\Pi_{B}^{A*} = \frac{a^2(1-\psi)}{16b(1+\psi)^2}$	Single sourcing from UE $\psi < \frac{1}{5}$ and $\tau > \bar{\tau}_2^f[\psi]$
DDP	$v_{RT}^{D*} = \frac{a(1-\tau)\psi[2(\psi+3)-\tau(3\psi+5)]}{\tau^2(\psi-1)-4\tau\psi(\psi+3)+4\psi(\psi+3)}$ $w_{RT}^{D*} = \frac{6a(1-\tau)\psi(1+\psi)}{\tau^2(\psi-1)-4\tau\psi(\psi+3)+4\psi(\psi+3)}$ $q_{RT}^{D*} = \frac{a(4\psi-3\tau\psi-\tau)}{2b[\tau^2(\psi-1)-4\tau\psi(\psi+3)+4\psi(\psi+3)]}$ $\Pi_{RT}^{D*} = \frac{a^2(1-\tau)\psi(3\tau\psi+\tau-4\psi)^2}{2b[\tau^2(\psi-1)-4\tau\psi(\psi+3)+4\psi(\psi+3)]^2}$ $\Pi_{L}^{D*} = \frac{a^2(1-\tau)\psi(3-2\tau-\psi)}{2b[\tau^2(\psi-1)-4\tau\psi(\psi+3)+4\psi(\psi+3)]}$ $v_{UE}^{D*} = \frac{2a(1-\tau)\psi(3+\psi-\tau)}{\tau^2(\psi-1)-4\tau\psi(\psi+3)+4\psi(\psi+3)}$ $w_{UE}^{D*} = \frac{a(1-\tau)\psi(4\psi+6-\tau)}{\tau^2(\psi-1)-4\tau\psi(\psi+3)+4\psi(\psi+3)}$ $q_{UE}^{D*} = \frac{a(1-\tau)(\tau+2\psi)}{2b[\tau^2(\psi-1)-4\tau\psi(\psi+3)+4\psi(\psi+3)]}$ $\Pi_{UE}^{D*} = \frac{a^2(1-\tau)^2(1-\psi)\psi(\tau+2\psi)^2}{2b[\tau^2(\psi-1)-4\tau\psi(\psi+3)+4\psi(\psi+3)]^2}$ $\Pi_{B}^{D*} = \frac{a^2[\tau^4-[(\tau-10)\tau+11]\tau^2\psi-4(\tau-1)(4\tau-5)\psi^3+[\tau[(43-10\tau]\tau-68)+36]\psi^2]}{4b[\tau^2(\psi-1)-4\tau\psi(\psi+3)+4\psi(\psi+3)]^2}$	Dual sourcing $\tau < \bar{\tau}_3^f[\psi]$
	$v_{RT}^{D*} = \frac{(1-\tau)(3a\psi+a)}{2(1+\psi)}$ $w_{RT}^{D*} = \frac{3a\psi+a}{2(1+\psi)}$ $q_{RT}^{D*} = 0$ $\Pi_{RT}^{D*} = 0$ $\Pi_{L}^{D*} = \frac{a^2(1-\psi)}{8b(1+\psi)}$ $v_{UE}^{D*} = \frac{a}{2}$ $w_{UE}^{D*} = \frac{2a\psi+a}{2(1+\psi)}$ $q_{UE}^{D*} = \frac{a}{4b(1+\psi)}$ $\Pi_{UE}^{D*} = \frac{a^2(1-\psi)\psi}{8b(1+\psi)^2}$ $\Pi_{B}^{D*} = \frac{a^2(1-\psi)}{16b(1+\psi)^2}$	Single sourcing from UE $\tau \geq \bar{\tau}_3^f[\psi]$

Table B.4: Equilibrium Outcomes of CIF

Trade Contract	Decision Variables and Profits	Sourcing Strategy
EXW	$\widetilde{v}_{RT}^{E*} = \frac{a\psi(\tau-\tau\psi+2\psi+6)}{\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)}$ $\widetilde{w}_{RT}^{E*} = \frac{a\psi[\tau(\psi-1)+4\psi]}{\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)}$ $\widetilde{q}_{RT}^{E*} = \frac{a(1+\tau)[\tau(\psi-1)+4\psi]}{2b[\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)]}$ $\widetilde{\Pi}_{RT}^{E*} = \frac{a^2(1+\tau)\psi[\tau-(\tau+4)\psi]^2}{2b[\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)]^2}$ $\widetilde{\Pi}_{L}^{E*} = \frac{a^2\psi[3-\psi-\tau(\psi-1)]}{2b[\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)]}$ $\widetilde{\Pi}_{B}^{E*} = \frac{a^2[\tau^4-[2\tau(\tau+6)+11]\tau^2\psi-4(1+\tau)^2(\tau+5)\psi^3+(1+\tau)[\tau[\tau(\tau+15)+40]+36]\psi^2]}{4b[\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)]^2}$ $\widetilde{v}_{UE}^{E*} = \frac{2a\psi[\tau(\psi+2)+\psi+3]}{\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)}$ $\widetilde{w}_{UE}^{E*} = \frac{a\psi[2(1+\tau)\psi+\tau]}{\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)}$ $\widetilde{q}_{UE}^{E*} = \frac{a[2(1+\tau)\psi+\tau]}{2b[\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)]}$ $\widetilde{\Pi}_{UE}^{E*} = \frac{a^2(1-\psi)\psi[2(1+\tau)\psi+\tau]^2}{2b[\tau^2(\psi-1)+4\tau\psi(\psi+3)+4\psi(\psi+3)]^2}$	Dual Sourcing $\tau < min\{\bar{\tau}_1^c[\psi], 1\}$
	$\widetilde{v}_{RT}^{E*} = \frac{3a\psi+a}{2(1+\tau)(1+\psi)}$ $\widetilde{w}_{RT}^{E*} = 0$ $\widetilde{q}_{RT}^{E*} = 0$ $\widetilde{\Pi}_{RT}^{E*} = 0$ $\widetilde{\Pi}_{L}^{E*} = \frac{a^2(1-\psi)}{8b(1+\psi)}$ $\widetilde{v}_{UE}^{E*} = \frac{a}{2}$ $\widetilde{w}_{UE}^{E*} = \frac{a\psi}{2(1+\psi)}$ $\widetilde{q}_{UE}^{E*} = \frac{a}{4b(1+\psi)}$ $\widetilde{\Pi}_{UE}^{E*} = \frac{a^2(1-\psi)\psi}{8b(1+\psi)^2}$ $\widetilde{\Pi}_{B}^{E*} = \frac{a^2(1-\psi)}{16b(1+\psi)^2}$	Single sourcing from UE If $\psi < \frac{1}{5}$ and $\tau > \bar{\tau}_1^c[\psi]$
DAP	$\widetilde{v}_{RT}^{A*} = \frac{a\psi[2\tau(\psi+2)+\psi+3]}{2\tau^2(\psi-1)+4\tau\psi(\psi+3)+2\psi(\psi+3)}$ $\widetilde{w}_{RT}^{A*} = \frac{a\psi[\tau[\tau(\psi-1)+5\psi+3]+3(1+\psi)]}{2(1+\tau)[\tau^2(\psi-1)+2\tau\psi(\psi+3)+\psi(\psi+3)]}$ $\widetilde{q}_{RT}^{A*} = \frac{a(1+2\tau)[\tau(\psi-1)+2\psi]}{4b[\tau^2(\psi-1)+2\tau\psi(\psi+3)+\psi(\psi+3)]}$ $\widetilde{\Pi}_{RT}^{A*} = \frac{a^2(1+2\tau)^2\psi(\tau(\psi-1)+2\psi)^2}{8b(1+\tau)[\tau^2(\psi-1)+2\tau\psi(\psi+3)+\psi(\psi+3)]^2}$ $\widetilde{\Pi}_{L}^{A*} = \frac{a^2\psi[3+2\tau(1-\psi)-\psi]}{8b[\tau^2(\psi-1)+2\tau\psi(\psi+3)+\psi(\psi+3)]}$ $\widetilde{\Pi}_{B}^{A*} = \frac{a^2[4\tau^4-[8\tau(\tau+3)+11]\tau^2\psi-(1+2\tau)^2(2\tau+5)\psi^3+(1+2\tau)[\tau[\tau(2\tau+15)+20]+9]\psi^2]}{16b[\tau^2(\psi-1)+2\tau\psi(\psi+3)+\psi(\psi+3)]^2}$ $\widetilde{v}_{S_2}^{A*} = \frac{a\psi[2\tau(\psi+2)+\psi+3]}{2\tau^2(\psi-1)+4\tau\psi(\psi+3)+2\psi(\psi+3)}$ $\widetilde{w}_{S_2}^{A*} = \frac{a\psi[\tau(4\psi+5)+2\psi+3]}{2\tau^2(\psi-1)+4\tau\psi(\psi+3)+2\psi(\psi+3)}$ $\widetilde{q}_{S_2}^{A*} = \frac{a(2\tau\psi+\tau+\psi)}{4b[\tau^2(\psi-1)+2\tau\psi(\psi+3)+\psi(\psi+3)]}$ $\widetilde{\Pi}_{UE}^{A*} = \frac{a^2(1-\psi)\psi(2\tau\psi+\tau+\psi)^2}{8b[\tau^2(\psi-1)+2\tau\psi(\psi+3)+\psi(\psi+3)]^2}$	Dual Sourcing $\tau < min\{\bar{\tau}_2^c[\psi], 1\}$
	$\widetilde{v}_{RT}^{A*} = \frac{3a\psi+a}{2(1+2\tau)(1+\psi)}$ $\widetilde{w}_{RT}^{A*} = \frac{3a\psi+a}{2(1+2\tau)(1+\psi)}$ $\widetilde{q}_{RT}^{A*} = 0$ $\widetilde{\Pi}_{RT}^{A*} = 0$ $\widetilde{\Pi}_{L}^{A*} = \frac{a^2(1-\psi)}{8b(1+\psi)}$ $\widetilde{v}_{S_2}^{A*} = \frac{a}{2}$ $\widetilde{w}_{S_2}^{A*} = \frac{2a\psi+a}{2(1+\psi)}$ $\widetilde{q}_{S_2}^{A*} = \frac{a}{4b(1+\psi)}$ $\widetilde{\Pi}_{UE}^{A*} = \frac{a^2(1-\psi)\psi}{8b(1+\psi)^2}$ $\widetilde{\Pi}_{B}^{A*} = \frac{a^2(1-\psi)}{16b(1+\psi)^2}$	Single sourcing from UE $\psi < \frac{1}{3}$ and $\tau > \bar{\tau}_2^c[\psi]$
DDP	$\widetilde{v}_{RT}^{D*} = \frac{a(1-\tau)\psi[2\tau(1+\psi)-\psi-3]}{2\tau^2(1+\psi)^2-2\psi(\psi+3)}$ $\widetilde{w}_{RT}^{D*} = \frac{3a(\tau^2-1)\psi(1+\psi)}{2\tau^2(1+\psi)^2-2\psi(\psi+3)}$ $\widetilde{q}_{RT}^{D*} = \frac{a(1+\tau)[(\tau-2)\psi+\tau]}{4b[\tau^2(1+\psi)^2-\psi(\psi+3)]}$ $\widetilde{\Pi}_{RT}^{D*} = \frac{a^2(1-\tau)(1+\tau)^2\psi[(\tau-2)\psi+\tau]^2}{8b[\tau^2(1+\psi)^2-\psi(\psi+3)]^2}$ $\widetilde{\Pi}_{L}^{D*} = \frac{a^2(1-\tau)\psi(\tau\psi+\tau+\psi-3)}{8b[\tau^2(1+\psi)^2-\psi(\psi+3)]}$ $\widetilde{\Pi}_{B}^{D*} = \frac{a^2[4\tau^4+[\tau(-2\tau^3-5\tau+2)+9]\psi^2+[\tau(5\tau-2)-11]\tau^2\psi-(\tau-1)(1+\tau)^2(3\tau-5)\psi^3]}{16b[\tau^2(1+\psi)^2-\psi(\psi+3)]^2}$ $\widetilde{v}_{UE}^{D*} = \frac{a(\tau-1)\psi(\tau\psi+\tau+\psi+3)}{2\tau^2(1+\psi)^2-2\psi(\psi+3)}$ $\widetilde{w}_{UE}^{D*} = \frac{a(\tau-1)\psi[2\tau(1+\psi)+2\psi+3]}{2\tau^2(1+\psi)^2-2\psi(\psi+3)}$ $\widetilde{q}_{UE}^{D*} = \frac{a(\tau-1)(\tau\psi+\tau+\psi)}{4b[\tau^2(1+\psi)^2-\psi(\psi+3)]}$ $\widetilde{\Pi}_{UE}^{D*} = \frac{a^2(\tau-1)^2(1-\psi)\psi(\tau\psi+\tau+\psi)^2}{8b[\tau^2(1+\psi)^2-\psi(\psi+3)]^2}$	Dual Sourcing $\tau < \bar{\tau}_3^c[\psi]$
	$\widetilde{v}_{RT}^{D*} = \frac{a(1-\tau)(3\psi+1)}{2(1+\tau)(1+\psi)}$ $\widetilde{w}_{RT}^{D*} = \frac{3a\psi+a}{2(1+\psi)}$ $\widetilde{q}_{RT}^{D*} = 0$ $\widetilde{\Pi}_{RT}^{D*} = 0$ $\widetilde{\Pi}_{L}^{D*} = \frac{a^2(1-\psi)}{8b(1+\psi)}$ $\widetilde{v}_{UE}^{D*} = \frac{a}{2}$ $\widetilde{w}_{UE}^{D*} = \frac{2a\psi+a}{2(1+\psi)}$ $\widetilde{q}_{UE}^{D*} = \frac{a}{4b(1+\psi)}$ $\widetilde{\Pi}_{UE}^{D*} = \frac{a^2(1-\psi)\psi}{8b(1+\psi)^2}$ $\widetilde{\Pi}_{B}^{D*} = \frac{a^2(1-\psi)}{16b(1+\psi)^2}$	Single sourcing from UE $\tau \geq \bar{\tau}_3^c[\psi]$

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