



## Article

# A Game-Theoretic Analysis of Canada's Entry for LNG Exports in the Asia-Pacific Market

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**Abstract:** The import demand for energy resources, including liquefied natural gas (LNG), has been steadily increasing in the Asia-Pacific region. Australia, the Middle East (Qatar), the Russian Federation, and the U.S. are the major players who compete strategically to capture this ever-growing market for LNG. The objective of this paper is to examine the potential for Canada's entry into this market as another LNG exporter and what impact that can have on the existing suppliers. Using a game-theoretic LNG export competition model, we explore the conditions under which Canada can make a profitable entry. We also investigate the effect of Canada's entry on the profitability of the four incumbent exporters. Employing a multi-leader Stackelberg model, we found that Canada's entry could be a Pareto superior outcome under certain conditions because it benefits all competing firms and consumers. Further, Canada's entry into the LNG export market always helps the low-cost incumbent firms by increasing their output and profit. However, the high-cost incumbent firms' output falls, while their profit may increase or decrease depending on the unit cost and market size parameters. With differential export costs between Canada and the U.S., the latter has an incentive to act strategically to affect the entrance of the former.

**Keywords:** Asia-Pacific; Canada; game theory; LNG export; oligopoly



**Citation:** Ghosh, S.; Islam, S. A Game-Theoretic Analysis of Canada's Entry for LNG Exports in the Asia-Pacific Market. *Commodities* **2023**, *2*, 169–187. <https://doi.org/10.3390/commodities2020011>

Academic Editor: Jung-ho Baik

Received: 18 April 2023

Revised: 25 May 2023

Accepted: 7 June 2023

Published: 12 June 2023



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## 1. Introduction

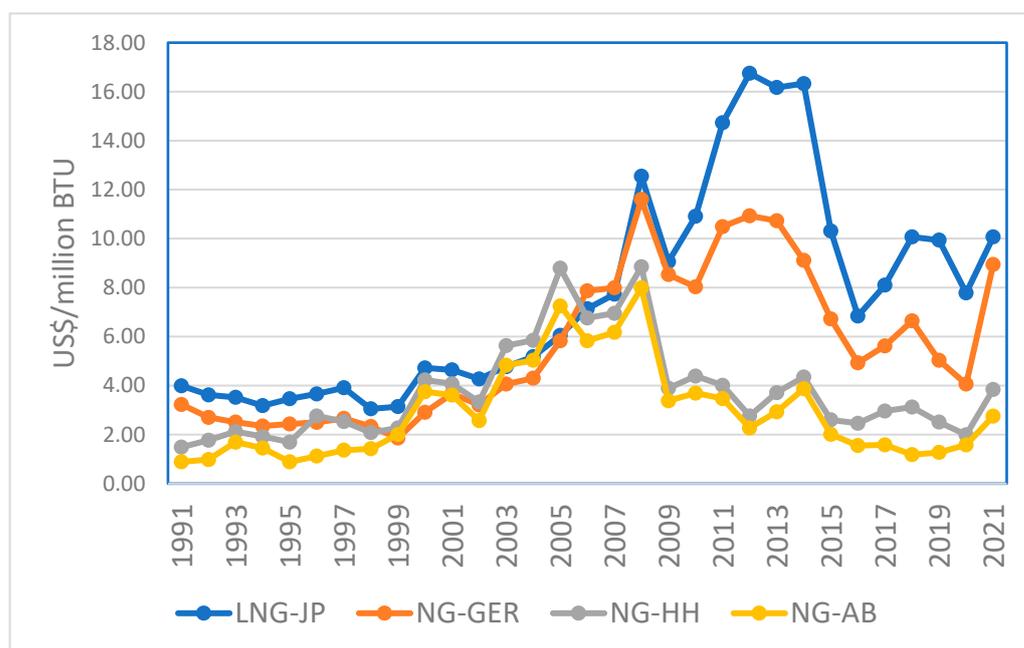
Canada is the sixth largest natural gas producer after the United States (U.S.), the Russian Federation, Iran, China, and Qatar [1]. However, it only exports to the U.S. via pipelines, as it has neither liquefaction capacity nor land borders with other countries. As a result, its natural gas production has experienced only a modest increase during the past 15 years [2]. Canada has been planning to liquefy natural gas and export liquefied natural gas (LNG) to Asian countries for the last several years with little success, primarily due to its internal issues and the impact of international energy prices. Recently, however, with the construction of an LNG plant underway on its west coast (Kitimat, British Columbia), Canada is expected to be in the LNG export market soon. Now, how much potential does Canada have to capture a share of this lucrative Asia-Pacific LNG market? This paper examines Canada's prospect for LNG export to the Asia-Pacific markets and its impact on the incumbent exporters using a game-theoretic export competition framework.

The Asia-Pacific region is highly energy-hungry due to its rapid economic progress and population growth. However, the major economies in this region are experiencing an energy deficit due to their sharp increase in energy demand. As a result, the area is becoming increasingly energy deficient and increasingly reliant on imports.

The popularity of LNG as a commodity for world trade has increased for a few reasons. Natural gas is a cleaner non-renewable energy source, as it produces less greenhouse gas and is a lower contributor to global warming than oil and coal. This results in its ever-increasing demand worldwide. In addition, LNG facilitates the creation of a global natural gas market with little restriction. Traditionally, natural gas gets transported through a

pipeline, restricting trade between two endpoints or economies connected through the land. The conversion of LNG from natural gas has created an opportunity to circumvent such a problem, allowing LNG to be transported to anywhere vessels can travel. However, it has its own problems—technology, and cost required for liquefaction and regasification. Over time, international LNG trade has become increasingly competitive with the addition of newer and newer players on both sides of the market. Still, only some players remain dominant on either side. Given the dynamic nature of the market situation, any new entrant must understand the entire market process, including how the existing market will respond to the new entrant [3].

Canada, in general, experiences the lowest natural gas price in the world, which provides a natural advantage for Canadian natural gas to compete in the export markets. Figure 1 shows comparative LNG and natural gas prices in major markets. Historically, Canada exports natural gas only to the U.S. through pipelines, and as such, the natural gas market in Canada and the U.S. are integrated. Canada exports natural gas to the U.S. on the west coast but imports a fraction of that on the east coast [2]. Canada's net natural gas exports to the U.S. have fallen over 35% since 2007 and are now at their lowest since 1993. The net import by the U.S. is predicted to decrease to near zero as the U.S. import from Canada's west coast continues to decline and export on the east coast continues to rise [4]. In addition, the U.S. continues to increase its domestic natural gas production to rely less on imports. With the U.S.'s active liquefaction and export facility in the Gulf of Mexico and declining import from its northern neighbor, Canada's LNG export to the Asia Pacific has become increasingly important. It will need new markets for its natural gas. It is seeking other markets. Since Canada does not have land borders with other countries, its only option is to liquefy natural gas and ship LNG to other countries.



**Figure 1.** LNG and Natural Gas prices [USD per million BTU] in different regions (Data Source: B.P. 2022 [1]) [LNG-JP = Japan LNG import CIF price; NG-GER = Average German natural gas import price; NG-HH = U.S. Henry Hub natural gas price; NG-AB = Natural gas price in Alberta, Canada].

Most LNG projects proposed in Canada are on the west coast of British Columbia. Since the Asia-Pacific market is closer to Canada's west coast, the west coast LNG development naturally targets the Asia-Pacific market. Several factors contribute to the production cost of LNG on Canada's west coast, thus affecting its international competitiveness. In addition to its proximity to the Asian markets, its closeness to natural gas reserves, a competitive cost of natural gas feedstock, a lower temperature regime, and lesser operating

costs provide an advantage over other exporters. Relatively high capital costs due to the remoteness of production areas, the requirement of pipelines in mountain terrain, the necessary support from indigenous people, and the taxation regime contribute, to some extent, toward increased cost [5]. Nonetheless, Canada's natural gas price remains the lowest globally (Figure 1).

Aside from competing with the U.S., Canada must also compete with the other incumbent suppliers to capture a share of the Asia-Pacific LNG market. However, many countries export LNG to the Asia Pacific. Among them, Australia, the Middle East, the Russian Federation, and North America (U.S.) are the major players. The Asia-Pacific market is oligopolistic, with Australia, the Middle East, the Russian Federation, and the U.S. being the primary exporters [2]. Upon reviewing the LNG trade over the past two decades, Wood [6] observed a rapid growth, diversification, and increased flexibility of LNG trade movement and expects a growth of spot markets. Barnes and Bosworth [7], employing a gravity modeling approach on the U.N.'s Comtrade and World Bank data for 92 countries, observed that the LNG trade grew as a global commodity. Such an increase expands the overall global natural gas market. They found that income had little effect on the natural gas trade. Zhang et al. [8] used a gravity modeling approach to LNG trade between 26 exporting and 29 importing countries from 2004 to 2015. They found that LNG trade demonstrated both general and regional characteristics, with the Asia Pacific [mainly Japan, South Korea, and China] being the largest importing region (60–70% by volume). They also found that income and economic scale are the primary driving forces of LNG imports. Competition among exporters, however, is becoming more intense, dynamic, and complex over time [9]. Meza et al. [10] studied the impact of the LNG trade between Qatar (Middle East) and East Asia using the Porter's Five-Forces Analysis (PFFA) framework. However, they did not explicitly consider the strategic nature of the LNG export market due to the presence of other big exporters such as Australia, the Russian Federation, and the U.S. As mentioned, the LNG export market in the Asia Pacific can be characterized as oligopolistic. Hence, we first develop a Cournot oligopoly model using four LNG exporters: Australia, the Middle East, the Russian Federation, and the U.S. Since our objective is to examine Canada's potential, we next expand the model by including Canada. We analyze the world LNG trade using a novel five-player multi-leader Stackelberg model, with Australia, the Middle East, the Russian Federation, and the U.S. as leaders and Canada as the follower.

Applying oligopoly models to study the LNG market is not new. Growitsch et al. [11] examined a spatial oligopoly model to analyze the global natural gas market using LNG and natural gas movement through pipelines. They studied the impact on prices due to supply shock. Although their findings favor a Cournot setting over a perfect competition setting, a mixed model is less appropriate and needs more accuracy, as evidenced by sensitivity analysis. Focusing on Cournot competition, Dorigoni et al. [12] analyzed the entry of LNG to the natural gas market. While this model is appropriate for new entrants, it is less suitable for examining the existing LNG market. Nevertheless, this provides a good starting point for analyzing the current LNG market. Indeed, the setup described by them substantially influences the development of our model. The difference between our model and that of Dorigoni et al. [12] is that our model addresses exporters' perspectives and expands further, using a more-realistic multi-leader scenario. We used the downstream market as competitive, but Dorigoni et al. [12] used the downstream market as an oligopoly.

Cann [3] notes that the market for LNG exhibits monopsony power in the Asia-Pacific region (Japan, Korea, and Taiwan as a bundle of buyers). With China and India's increasing participation in the LNG trade, the region should include China and India, but the monopsony buying power of the region remains. Chang et al. [13] considered a game-theoretic model between Qatar and the Russian Federation, competing exporters of LNG to the Asia Pacific and the European market, considering both Cournot and Stackelberg duopoly models. This study is somewhat limited in its application to the Asia-Pacific market since Australia is the major exporter in the Asia-Pacific market, followed by Qatar, the U.S., and the Russian Federation [2]. In 2020, the Asia-Pacific region received

30.75 percent of LNG from Australia alone. Further, while they consider a regular duopoly model, we have considered a novel five-country multi-leader Stackelberg model to examine the effect of Canada's entry into the Asia-Pacific market.

Gkonis and Psaraftis [14] applied a game-theoretical approach to examine LNG shipping competition, using both Cournot and Stackelberg duopoly models. However, a simple duopoly is unrealistic to represent the complexities of the current LNG trade, as more than two regions are exporting LNG. In addition, Gkonis and Psaraftis [14] focused only on shipping, which is one component of the entire process of the LNG trade. The entire process of the LNG trade involves extraction, transportation by pipeline to the liquefaction facility, followed by liquefaction (preparation of LNG), shipping LNG to the regasification plant in the importing country for regasification, and then distribution to consumers [15].

Ikonnikova and Zwart [16] applied a bilateral oligopoly model using three major exporters and three major importers and imposed quotas as trade restrictions. Jansen et al. [17] used a modified Cournot model in the European gas market, citing the Russian Federation as a player with objectives beyond profit maximization. In an earlier paper, Boots et al. [18] used a successive oligopoly model to explain the natural gas market in Europe. Although these examples of oligopoly models help illustrate the natural gas market in Europe, more is needed to represent the situation of the world LNG trade. European countries, especially those used as exporters and importers, are in proximity and physically connected, and as such, natural gas transport through the pipeline is more economical. LNG in such a situation is different than in the case of the Asia Pacific, where it is the only economically infeasible option.

The multi-leader Stackelberg model used in this paper is closest to that used by Mukherjee and Zhao [19]. They showed that entry by a Stackelberg follower firm increases the output and profit of the low-cost Stackelberg leader. However, it reduces the profit (and may or may not increase the output) of the high-cost leader firm. In contrast, in our model, a similar entry always increases the output and profit of the low-cost leaders but reduces the output of the high-cost leader, while the profit of the high-cost leader may or may not increase. Further, in their model, the new entrant had higher costs than all the incumbent firms, while in this paper, the cost of the new entrant is higher than the low-cost incumbents but lower than the high-cost ones. Finally, in our model, we have four leader firms (as opposed to two in Mukherjee and Zhao [19]), and there is a prior relationship between the new entrant and the high-cost leader firm.

The effect of Canada's entry to the Asia-Pacific LNG Market has been previously studied by Ghosh and Islam (2020), using an oligopoly framework [20]. However, they used a much simpler Cournot quantity competition, where all players were acting simultaneously. In contrast, we used a multi-leader Stackelberg model, with four leaders and one follower, the Canadian firm. We believe this model is more appropriate since Australia, Qatar, the Russian Federation, and the U.S. are already established exporters in the Asia-Pacific market and, hence, will enjoy a first-mover advantage against the Canadian firm. In addition, this paper examines the possibility of the U.S. firm acting strategically in the upstream market to deter (encourage) entry of the Canadian firm when the latter's entry reduces (increases) the former's profit.

The rest of the paper is organized as follows. Section 2 offers a model overview. Section 3 analyzes Canada's entry's effect on Canada's profitability and the four incumbent exporters. Section 4 examines the potential strategic responses of the U.S. firm on Canada's entrance, while Section 5 concludes and presents some policy implications.

## 2. The Model

The four LNG-exporting regions are Australia (*A*), the Middle East (*M*), the United States (*U*), and the Russian Federation (*R*). For simplicity, we assume that there is one exporting firm from each of the four countries (or regions) competing in the LNG market in the Asia Pacific. Our results will go through if we allow multiple firms from the same

country so long as the number of firms from each country remains the same. We start by defining the following notations:

- $q_i$ : Quantity of LNG export to the Asia Pacific by country  $i$ , where  $i \in \{A, M, R, U\}$ ;
- $Q$ : Total quantity sold in the Asia-Pacific market,  $Q = q_A + q_M + q_U + q_R$ ;
- $P$ : Unit price of LNG in the Asia-Pacific market
- $c_i$ : Total unit cost of exporting LNG in the Asia-Pacific market for player  $i$ , including unit extraction, liquefaction, regasification, environmental, and shipping cost
- $F_i$ : Fixed export cost for firm  $i$ , where  $i \in \{A, M, R, U\}$ . This includes the firm's portion of the fixed shipping cost (as per shipping terms and conditions), as well as any fixed production costs involved including setting up liquefaction and regasification plants.

We assume that the nature of competition between these four firms (players) is a Cournot quantity competition. Suppose that LNG is a homogenous product and all four firms are assumed to sell it at the same price. As mentioned before,  $P$  denotes the unit price paid to the LNG sellers in the Asia-Pacific market. Let the inverse demand function for LNG in the Asia-Pacific market be:  $P = a - Q$ , where  $Q = q_A + q_M + q_R + q_U$ ; and  $a (>0)$  is the demand parameter representing market size.

How does the Canadian firm enter the above model? For now, we assume that the U.S. is the only exporter of LNG from North America to the Asia Pacific. However, the U.S. firm may export part of Canadian natural gas as LNG, as there is a natural gas flow through pipelines from Canada to the U.S. For simplicity, we assume that the U.S. firm  $U$  makes a transfer payment of  $TR_E$  to the Canadian Firm for the natural gas that the latter supplies the former. Moreover, after subtracting its production costs as well as the costs of transferring natural gas to the U.S. through the pipeline, the Canadian firm makes a profit of  $\pi_E^N$ .

The costs of sending natural gas to the U.S. for the Canadian firm will include the extraction costs and cost of transport through pipelines to the U.S. The U.S. and Canada are each other's largest energy trading partners, and the energy market in both countries is highly integrated for oil, natural gas, and electricity [21]. As a result, natural gas pricing between the U.S. and Canada is determined competitively, along with oil prices. Historically, natural gas prices in Canada are lower than in the U.S., so a transfer payment for the U.S. firm is viable. We also assume some supply constraints exist on the natural gas imported by the U.S. firm through the pipeline from Canada. Therefore, the U.S. firm produces some natural gas and imports the rest from Canada.

The value of the transfer payments made by the U.S. firm to the Canadian firm  $TR_E$  depends on the quantity of exports and the bargaining power between the U.S. and the Canadian firms. These transfer payments will, in turn, determine the payoff obtained by the Canadian firm through exporting natural gas to the U.S. via pipelines when it is not directly exporting to the Asia-Pacific market, which we have denoted  $\pi_E^N$ . Obviously, the transfer payments  $TR_E$  must be more than the production costs plus the export costs of transferring natural gas to the U.S. for the Canadian firm. Otherwise, such natural gas exports to the U.S. would be unprofitable for the Canadian firm. Similarly,  $TR_E$  must be lower than the U.S. firm's revenue from natural gas exports to the Asia Pacific.

Later in Section 3, we will bring the Canadian firm, as a separate player, into the Asia-Pacific LNG export market as a Stackelberg follower. We will then compare the output and profits of each player before and after entry by the Canadian Firm under different parametric configurations. As will be evident, it will offer some interesting insights.

### 2.1. Analysis of LNG Export Competition between Australia, the Middle East, the Russian Federation, and the U.S.

Given the assumptions and notations defined earlier, the profit function of firms  $A$ ,  $M$ , and  $R$  are as follows:  $\pi_i = P \cdot q_i - c_i q_i - F_i$ ; where  $i \in \{A, M, R\}$ .

The objective of firms  $A$ ,  $M$ , and  $R$  will be to choose their output  $q_A$ ,  $q_M$ , and  $q_A$ , respectively, to maximize:

$$\pi_i = P \cdot q_i - (c_i)q_i - F_i = (a - q_i + q_j + q_k + q_U)q_i - (c_i)q_i - F_i; \text{ where } i, j, k \in \{A, M, R\}, i \neq j \neq k$$

Next, the objective of the U.S. firm  $U$  is to select its optimal output,  $q_U$  to maximize its profits  $\pi_U$  denoted by:  $\pi_U = (a - q_A + q_M + q_R + q_U)q_U - c_U q_U - F_U - TR_E$ .

Note that, as stated earlier, an additional term needs to be subtracted from its total revenue for the U.S. firm  $U$  to obtain its net profit. This term is  $TR_E$ , the transfer payments paid to the Canadian firm for the import of Canadian natural gas through the pipeline. The U.S. firm then converts this natural gas into LNG in its liquefaction plant to export to the Asia Pacific.

We use the Cournot–Nash equilibrium concept. Maximizing the objective functions, we obtain the best response function for each of the four firms. Solving the best functions simultaneously, we obtain the following Cournot–Nash equilibrium outputs for each firm:

$$q_i^N = \frac{a - 4c_i + c_j + c_k + c_l}{5}; \text{ where } i, j, k, l \in \{A, M, R, U\}, i \neq j \neq k \neq l \quad (1)$$

The total quantity sold by the four firms is given by:

$$Q^N = q_A^N + q_M^N + q_R^N + q_U^N = \frac{4a - c_A - c_M - c_R - c_U}{5}$$

The equilibrium market price is:

$$P^N = a - Q^N = \frac{a + c_A + c_M + c_R + c_U}{5} \quad (2)$$

Plugging in the equilibrium values of the price and quantity variables from Equations (1) and (2), we obtain the following equilibrium profit expressions for the four exporting firms.

$$\pi_i^N = \left( \frac{a - 4c_i + c_j + c_k + c_U}{5} \right)^2 - F_i; \text{ } i, j, k \in \{A, M, R\}, i \neq j \neq k \quad (3)$$

$$\pi_U^N = \left( \frac{a - 4c_U + c_A + c_M + c_R}{5} \right)^2 - F_U - TR_E \quad (4)$$

These are then the equilibrium profits of the four firms before entry by the Canadian Firm as a direct exporter of LNG in the Asia-Pacific market.

## 2.2. Comparative Statics

Now consider the effects of a change in some of the parameters such as the unit cost of exporting for the U.S. firm  $c_U$ , which, among other things, captures a change in environmental standards in the U.S., and  $c_M$ , which captures the production and supply risk from the Middle East. For illustration purposes, we use only these two cases.

### 2.2.1. A Reduction in Environmental Standards in the U.S.

In the U.S., engaging in importing and exporting natural gas, including LNG, from and to a foreign country requires permission from the Department of Energy. Over the past 15 years, natural gas production in the U.S. has continued to rise, with a corresponding decrease in price, mainly because of increases in U.S. natural gas production. With a substantial increase in domestic natural production through shale gas and horizontal drilling, coupled with a decline in imports by pipeline and LNG and an increase in LNG export terminal capacity, the U.S. has become a net exporter of LNG since 2017 [22]. U.S. LNG exports have surged recently, but the production, transportation, distribution, and storage require strict safety and environmental regulations and standards. Particularly, the Trump Administration's pro-energy development (oil, gas, and coal) policies and reduction of environmental regulations are well-known [23,24]. A reduction of environmental standards

and regulatory hurdles in the U.S. commonly means a reduction in the extraction cost (including meeting environmental standards), thus reducing  $c_U$ . As evident from Equation (1), this would mean an increase in the output of firm  $U$ , and a reduction in the output of firms  $A$ ,  $M$ , and  $R$ . In turn, this leads to an increase in overall market supply and a reduction in market price (from Equation (2)). From Equations (3) and (4), the equilibrium profit of firm  $U$ ,  $\pi_U^*$ , goes up, while that of firms  $A$ ,  $M$ , and  $R$  goes down. However, the magnitude of negative pressure on the profit of firms  $A$ ,  $M$ , and  $R$  depends on the oligopoly behavior among them, assuming all other parameters remain the same.

### 2.2.2. An Increase in the Perceived Political Risk in the Middle East

The natural gas market has not been as politically influenced as the oil market. However, the scenario may change with the increase in production, trade, and use of natural gas, especially with the rise in the worldwide movement of LNG. The erosion of indexing natural gas prices with oil, the reduction of long-term contracts, and the increase in spot prices make the LNG market more independent and susceptible to politicization. Unver [25], using Iran as an example, presents a clear picture of how natural gas export to the Middle East can be affected by global politics. Cirdei [26] points out the contradictory interests of different states in the Middle East and how those interests play a significant role in energy security in the region. In our study, this is captured by an increase in  $c_M$ , which, from Equations (1), (3) and (4), shows that it will lead to a reduction in the equilibrium output and profit of firm  $M$  and an increase in the equilibrium output and profits of firms  $A$ ,  $U$ , and  $R$ , with a reduction in overall output. The market price goes up, as can be observed from Equation (2). The magnitude of the positive effect on firms in  $A$ ,  $U$ , and  $R$  depends on the unit costs of each of the three firms. The low-cost firms will benefit more than the high-cost ones.

## 3. Effect of Entry of the Canadian Firm

In this section, we relax the assumption that North America has a single firm from the U.S., namely firm  $U$ . Instead, two firms in North America, one from the U.S. and one from Canada, compete non-cooperatively with other exporting firms in the Asia-Pacific market. Thus, there are now five competitors. However, while including Canada in this LNG export game, it must be noted that the other four players, namely Australia, the Middle East, the Russian Federation, and the U.S., are already in the Asia-Pacific market and enjoy a head start over Canadian LNG producers. To capture this situation, we consider a novel five-firm Stackelberg leader-follower model. We assume that in this model, the four incumbent firms, namely  $A$ ,  $M$ ,  $R$ , and  $U$ , are the Stackelberg leaders and enjoy a first-mover advantage. They simultaneously choose their level of LNG exports in the Asia-Pacific market. The Canadian firm (firm  $E$ ) is the new entrant, who moves later as a Stackelberg follower after observing the actions of the four leaders.

Assume that the inverse demand function is the same as before:  $P = a - Q$ ; with  $Q = q_A + q_M + q_R + q_U + q_E$ ; where  $q_E$  is the quantity the Canadian exporter sells, while other notations have their usual meanings.

To focus on the difference in shipping costs between the U.S. and Canadian firms, we assume that each firm's unit cost of exporting LNG to the Asia-Pacific market, aside from the shipping cost, is the same for each firm, and is denoted by:

" $c$ ": This includes unit extraction, liquefaction, regasification, and environmental costs.

We further denote:

$t_i$ : Unit transport cost of shipping LNG to the Asia Pacific for firm  $i$ , where  $i \in \{A, M, R, U, E\}$ .

We continue to denote:

$c_i$ : Total unit cost of exporting LNG in the Asia-Pacific market for player  $i$ , including shipping cost,  $t_i$ . Therefore,  $c_i = c + t_i$ ,  $i \in \{A, M, R, U, E\}$  Specifically, as with the incumbent firms, we assume that the new entrant Canadian firm has fixed export costs, denoted by  $F_E$ , which includes the costs of building a liquefaction plant and regasification plant, and unit export cost  $c_E = c + t_E$ .

### 3.1. Timing and Solution of the 5 Player Game

We consider the following two-stage game.

Stage 1: Firms  $A$ ,  $R$ ,  $M$ , and  $U$  play a Cournot game and set their leadership outputs simultaneously, knowing the reaction function of the follower Canadian firm  $E$ .

Stage 2: Given the output choices of firms  $A$ ,  $R$ ,  $U$ , and  $M$  in stage 1, firm  $E$  sets its own output  $q_E$  to maximize profit.

Following the logic of backward induction, we start with the stage 2 game, where the follower firm  $E$  chooses its output, given the outputs of the leaders.

In Stage 2, the objective function of firm  $E$  is to maximize profits by choosing its output  $q_E$ , given the incumbent firms' production and export to the Asia Pacific. The profit expression is:

$$\pi_E(q_E; q_A, q_M, q_R, q_U) = q_E(a - q_A - q_M - q_R - q_U - q_E) - c_E q_E - F_E \quad (5)$$

Maximizing this profit function with respect to  $q_E$ , we obtain the best response function of firm  $E$ , denoted by  $q_E^B$ :

$$q_E^B = \frac{a - q_A - q_M - q_R - q_U - c_E}{2} \quad (6)$$

Now, we examine Stage 1, where the firms  $A$ ,  $M$ ,  $R$ , and  $U$ , the four leaders simultaneously choose their outputs in Cournot–Nash fashion, anticipating the best response function of the follower Canadian firm  $E$ . The objective functions of the four leader firms are the following:

$$\pi_i = q_i \left( a - q_i - q_j - q_k - q_l - q_E^B \right) - c_i q_i - F_i; \quad (7)$$

where  $i, j, k, l \in \{A, M, R, U\}, i \neq j \neq k \neq l$ ;

Plugging in the value from the best response function of the firm  $E$  from (6) in the Equation (7) above and simplifying, we obtain the reduced form profit function of any leader firm  $i$ :

$$\pi_i = \frac{(a - q_i - q_j - q_k - q_l + c_E - 2c_i)q_i - 2F_i}{2}; \text{ where } i, j, k, l \in \{A, M, R, U\}, i \neq j \neq k \neq l; \quad (8)$$

Maximizing this profit function for any leader firm  $i$  above with respect to its output  $q_i$ , and then simplifying, we obtain the best response function of any leader firm  $i$ :

$$q_i = \frac{1}{2}(a - q_j - q_k - q_l + c_E - 2c_i); \text{ where } i, j, k, l \in \{A, M, R, U\}, i \neq j \neq k \neq l; \quad (9)$$

Solving the four best response functions, we get the equilibrium outputs for the four leader firms:

$$q_i^S = \frac{a + c_E - 8c_i + 2(c_j + c_k + c_l)}{5}; \text{ where } i, j, k, l \in \{A, M, R, U\}, i \neq j \neq k \neq l; \quad (10)$$

Plugging these values in the best response function of the follower firm  $E$  in Equation (6), we reach:

$$q_E^S = \frac{a - 9c_E + 2(c_A + c_M + c_R + c_U)}{10} \quad (11)$$

We assume that

$$q_E^S > 0, \text{ i.e., } c_E < \frac{a + 2(c_A + c_M + c_R + c_U)}{9} \quad (12)$$

Condition (12) ensures that Canadian firm  $E$  produces a positive output in equilibrium.

### 3.2. Condition for Profitable Entry by the Canadian Firm and Its Effect on the Profitability of Incumbent Firms

Under what conditions can the Canadian firm make a profitable entry? Given that their costs are different, how does the Canadian firm's entry affect the incumbent firms' output and profits? Does the Canadian firm's entry reduce the profits of each incumbent firm, or only the high-cost firms? Is there any set of parametric arrangements such that an entry by the Canadian firm will increase the profit of all the firms? If the latter situation occurs, the entry by the Canadian firm  $E$  will be Pareto improving. This is because, in this case, not only will each firm gain, but the consumers will also be better off due to higher output and lower costs. We intend to examine these issues in this subsection.

One interesting empirical observation is that even if Canada is a new entrant in the Asia-Pacific market, it has a cost advantage over the U.S. firm when shipping LNG to the Asia-Pacific market. The transport cost of U.S. LNG from its Gulf Coast to the Asia-Pacific market is estimated to be nearly double compared to Canada's because of shipping distance and the Panama Canal fee. The marine transport distances between Sabine (the U.S.) and Osaka (Japan) are 9481 nautical miles through the Panama Canal, 14,312 nautical miles through the Suez Canal, 15,552 nautical miles via Cape of Good Hope, 16,825 nautical miles via Strait of Magellan, and 16,895 nautical miles via Cape Horn [27]. In comparison, the distance between Kitimat (BC, Canada) to Osaka (Japan) is only 4222 nautical miles.

To focus exclusively on the issue of the shipping cost of LNG to the Asia-Pacific market, we normalize the unit export cost (other than shipping cost) of each exporting firm to the Asia Pacific to zero, i.e.,  $c = 0$ . We thus have  $c_i = t_i$ , where  $t_i$ , as before, is the unit shipping cost of firm  $i$ , where  $i \in \{A, M, R, U, E\}$ . Since our primary focus is the effect of Canada's entry on the U.S. firm, we further assume that the unit shipping cost of the other firms, namely  $A$ ,  $M$ , and  $R$ , is equal. That is, we assume  $t_A = t_M = t_R = t$ . We further assume realistically that the unit shipping cost of the Canadian firm ( $t_E$ ) is lower than that of the U.S. firm ( $t_U$ ), but not lower than the other three incumbent firms, that is,  $t \leq t_E \leq t_U$ . To economize on notations, we further assume that  $t = 0$ . Therefore, we can summarize our assumptions on the unit costs as follows:

$$c_U = t_U > c_E = t_E \geq c_A = c_M = c_R = 0 \quad (13)$$

First, we examine the conditions under which the Canadian firm can profitably enter the Asia-Pacific LNG market as a Stackelberg follower. Later, we will examine the effect of its entry on the profitability of the other firms.

We further assume that after the Canadian firm starts directly exporting LNG to the Asia Pacific, it significantly reduces its natural gas exports through pipelines to the U.S. firm. This is a plausible scenario as the U.S. continues increasing its domestic production, and the price differential between Canada and the U.S. has decreased. Suppose the transfer payments that it obtains from the U.S. firm after it becomes a direct exporter are denoted by  $TR_E^S$ . Following our assumption, since the Canadian firm now exports less, it will receive less transfer payments as well, that is,  $TR_E > TR_E^S$ . Further, for the sake of simplicity, we assume that  $TR_E^S = 0$ , that is, the Canadian firm does not export to the U.S. at all once it starts exporting directly to the Asia-Pacific market. However, all of our results will remain valid if we assume instead that the Canadian natural gas exports of LNG to the U.S. through pipelines are reduced but not set to zero.

From the above assumption, we can conclude that for the exports to the Asia Pacific to be profitable for the Canadian firm, the following condition must hold:

$$\pi_E^S = \left(q_E^S\right)^2 - F_E \geq \pi_E^N$$

Recall that  $\pi_E^N$  denotes the payoff of firm  $E$  when it does not directly export to the Asia Pacific. Using the value of the equilibrium Stackelberg follower output of the Canadian firm  $E$  from Equation (11), the above expression can be expressed as:

$$\pi_E^S = \left[ \frac{a - 9t_E + 2t_u}{10} \right]^2 - F_E \geq \pi_E^N$$

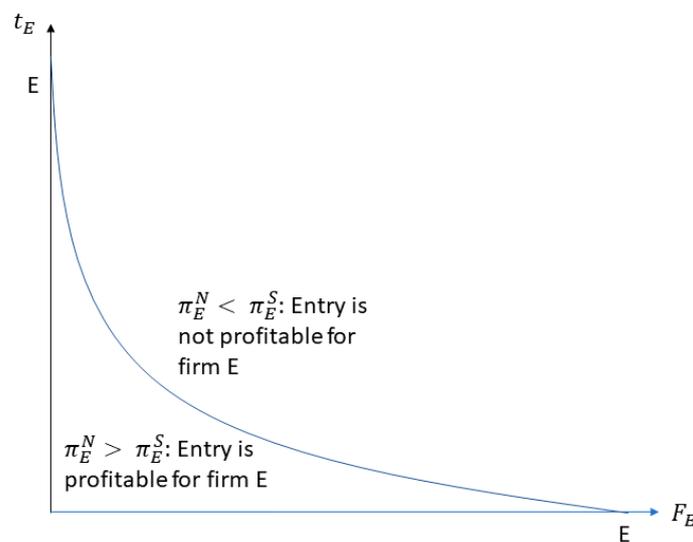
If the above condition holds, Canadian firm  $E$  will have the incentive to export to the Asia-Pacific market directly. If we simplify it, we obtain:  $\left[ \frac{a - 9t_E + 2t_u}{10} \right]^2 \geq F_E + \pi_E^N$ .

This can be further simplified into:

$$t_E \leq \frac{a + 2t_u - 10\sqrt{F_E + \pi_E^N}}{9} = \bar{t}_E \tag{14}$$

Thus, direct entry to the Asia-Pacific export market is profitable for the Canadian firm only if its unit transport cost (of exporting to the Asia Pacific) is sufficiently low, i.e.,  $t_E \leq \bar{t}_E$ . An increase in the transport cost of the U.S. firm ( $t_U$ ) relaxes the constraint and the relationship between  $\bar{t}_E$  and  $t_U$  is linear.

On the other hand, an increase in the fixed entry cost for Firm  $E$ , namely  $F_E$ , lowers  $\bar{t}_E$ , making the inequality constraint more stringent. The relationship between  $\bar{t}_E$  and  $F_E$  is, however, non-linear. In particular, differentiating  $\bar{t}_E$  with respect to  $F_E$ , it can be easily seen that:  $\frac{\partial \bar{t}_E}{\partial F_E} < 0$ , and  $\frac{\partial^2 \bar{t}_E}{\partial F_E^2} > 0$ . We plot this relationship depicted in (13) in Figure 2 below in the  $(t_E - F_E)$  space.



**Figure 2.** Profitable entry condition of Canadian Firm  $E$  as a follower.

The area where the entry constraint of the Canadian firm  $E$  is satisfied ( $t_E < \bar{t}_E$  in (14) above) is below the  $EE$  curve. Entry is not profitable for Canadian firm in the area above the  $EE$  curve. Note from (14) that as  $\pi_E^N$  goes up, the  $EE$  curve shifts to the left; that is, entry is only profitable under a lower set of the parametric range.

Note also that if the U.S. firm imports more natural gas from Canada, it will increase the transfer payment received by Canadian firm  $E$ , namely  $TR_E$ . Consequently, the profit of the Canadian firm in the case of no entry ( $\pi_E^N$ ) will also increase, shifting the  $EE$  curve to the left. Higher Canadian natural gas imports by the U.S. firm imply that profitable entry by the Canadian firm is possible only under a lower range of parameter values.

### 3.3. Effect of Entry by Canadian Firm on the Other Firms

To examine the effect of entry by the Canadian firm on the incumbent firms, we need to compare the output of the incumbent firms before and after entry by the Canadian firm. Using the assumptions on unit costs in (13), the output of the four incumbent firms before entry by the Canadian firm can be obtained by plugging  $c_A = c_M = c_R = 0$ , and  $c_U = t_U$  in Equation (1). Similarly, we can obtain their profits by applying the same assumptions in Equations (3) and (4). Under these simplifying assumptions, the Cournot–Nash equilibrium outputs of each firm are given by:

$$q_A^N = q_M^N = q_R^N = \frac{a + t_U}{5}; q_U^N = \frac{a - 4t_U}{5} \quad (15)$$

On the other hand, the equilibrium output of each incumbent firm after entry by the Canadian Firm as a Stackelberg follower under these simplifying assumptions, namely  $c_A = c_M = c_R = c = 0$ ,  $c_U = t_u$  and  $c_E = t_E$ , is obtained by plugging these values into Equation (10):

$$q_A^S = q_M^S = q_R^S = \frac{a + t_E + 2t_u}{5} \quad (16)$$

Comparing this with the output of these firms in case of no entry, denoted  $q_A^N$ ,  $q_M^N$ , and  $q_R^N$  as before, we find that:

$$q_A^S > q_A^N; q_M^S > q_M^N, \text{ and } q_R^S > q_R^N \quad (17)$$

Similarly, we obtain that the profits of these low-cost incumbent firms also increase after entry by the Canadian Firm. Hence, we have:

$$\pi_A^S > \pi_A^N, \pi_M^S > \pi_M^N, \text{ and } \pi_R^S > \pi_R^N \quad (18)$$

This leads us to our first proposition:

**Proposition 1.** *The low-cost incumbent firms are better off after entry by the Canadian firm as a Stackelberg follower in the sense that their output and profits increase after the latter's entry.*

The output of the high-cost incumbent U.S. firm following entry by the Canadian Firm is obtained by plugging the simplified values of  $c_E$  and  $c_U$  from (12) in Equation (10):

$$q_U^S = \frac{a + t_E - 8t_u}{5}$$

Comparing this with its equilibrium output ( $q_U^N$ ) before entry by the Canadian firm, as obtained in (14), we find that:

$$q_U^N > q_U^S \quad (19)$$

That is, total exports to the Asia-Pacific market by the U.S. firm are lower after entry by the Canadian firm as a Stackelberg follower. In other words, while the exports of the efficient incumbent firms go up after entry by the Canadian firm, that of the less efficient U.S. firm goes down.

This result is similar in spirit to Mukherjee and Zhao [19], though in their case, the unit cost of the new follower firm was lower than all the incumbent Stackelberg leaders. The intuition is as follows. As a follower enters on the one hand, each incumbent Firm has an incentive to increase output, as Stackelberg leaders. However, the incumbent firms also compete as Cournot competitors among themselves. Since they are strategic substitutes, as one incumbent firm increases output, the other's best response is to decrease output. This is the second effect. This second effect dominates the first for higher-cost incumbent firms, so the net effect is that the equilibrium output decreases. Whereas, for the low-cost firms, the first effect dominates the second effect, increasing their output and profit post-entry.

We found that the total exports by the U.S. firm fall after the Canadian firm enters the Asia-Pacific market, but what happens to its profit? To compare the profits of the U.S. firm before and after entry by the Canadian firm, we need to consider an additional effect. Recall that the U.S. firm does not need to make any more transfer payments to the Canadian firm after entry. For the U.S. firm  $U$ , from (4) and (14), pre-entry profit under the above cost assumptions is given by:

$$\pi_u^N = (q_u^N)^2 - F_u - TR_E = \frac{(a - 4t_U)^2}{5^2} - F_u - TR_E \quad (20)$$

Under our assumptions, the post-entry profit of the U.S. firm from Equation (10) is given by:

$$\pi_U^S = (q_U^S)^2 - F_U = \frac{(a + t_E - 8t_U)^2}{5^2} - F_U \quad (21)$$

The profit of the U.S. firm will be lower after entry by the Canadian firm if  $\pi_U^N > \pi_U^S$ . Plugging in their values from (19) and (20) above, we obtain:

$$\frac{(a - 4t_U)^2}{5^2} - F_u - TR_E > \frac{(a + t_E - 8t_U)^2}{5^2} - F_U$$

It can be shown that this above expression can be expressed as the following condition:

$$t < t_E^* = -(a - 8t_U) + \sqrt{(a - 4t_U)^2 - 25TR_E} \quad (22)$$

For the sake of brevity, the proof is relegated to Appendix A. In condition (22), to ensure that  $t_E^*$  is a real number, we require that the term inside the square root is non-negative. It can be easily seen that this requires the following condition to be satisfied:  $TR_E \leq \frac{(a - 4t_U)^2}{25}$ . That is, the transfer payments must be less than the square of the output of the U.S. firm  $U$  before entry by firm  $E$ . This result (in 22) is presented in the following Proposition.

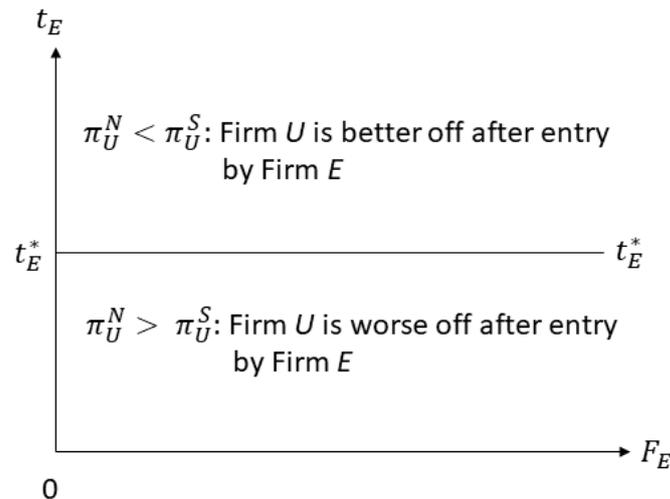
**Proposition 2.** *After entry by the Canadian firm  $E$  as a Stackelberg follower, the profit of the higher cost U.S. firm is lower if the transport cost of firm  $E$  is sufficiently small:  $\pi_u^N > \pi_U^S$  if  $t_E < t_E^*$ .*

This is described in Figure 3 in the same  $(t_E - F_E)$  space that was used in Figure 2. Since  $t_E^*$  does not contain the term  $F_E$ , the constraint in (22), Equation (22) is a straight line parallel to the horizontal axis at  $t_E = t_E^*$  in Figure 3. The area below the horizontal line represents the area where entry by firm  $E$  reduces the profit of firm  $U$ , namely  $\pi_u^N > \pi_U^S$ . Conversely, in the area above the horizontal line at  $t_E^*$  in Figure 3, we have  $\pi_u^N < \pi_U^S$ .

Intuitively, as the Canadian firm enters, it has both positive and negative effects on the profits of the U.S. firm. On one hand, its profit goes up as it no longer pays the transfer payment to the Canadian firm. On the other hand, its output and profit go down for the reasons stated in Proposition 1. In addition, the Canadian firm competes for market share as a Stackelberg follower. Since the U.S. firm has a higher unit cost than the other incumbent firms, it loses out more than other incumbent firms. When the unit (transport) of the Canadian firm is sufficiently low, this latter effect is stronger. Hence, the negative effect on the U.S. firm's profit due to entry by the Canadian firm outweighs the positive effect. Consequently, the profit of the U.S. firm decreases.

Suppose the U.S. firm decides to import more natural gas (through the pipeline) from Canada before the Canadian firm enters the Asia-Pacific market as a direct exporter. Formally, there is an increase in the transfer payments  $TR_E$ . From condition (22), it shifts the horizontal line at  $t_E^*$  below, thus making entry by firm  $E$  profitable for firm  $U$  over a higher range of parameters. Intuitively, when  $TR_E$  is higher, entry by the Canadian firm is profitable for the U.S. firm over a higher range of parameters since the pre-entry profits of the U.S. firm are lower.

Propositions 1 and 2 imply that since the low-cost Stackelberg leader firms will be better off after entry by the Canadian firm as a Stackelberg follower, they may encourage such entry. On the other hand, the higher transport cost U.S. firm will be worse off after entry if the transport cost of the Canadian firm is sufficiently small ( $t_E < t_E^*$ ). In that case, the U.S. firm may discourage entry of the Canadian firm. However, even in that situation, since the entry by the Canadian firm affects the incumbent firms asymmetrically (some are better off while some are worse off), it rules out the possibility of the incumbent firms together coordinating in some entry-detering strategy to prevent entry by the Canadian firm in the LNG market.



**Figure 3.** Profitability of U.S. Firm U following entry by Canadian firm E.

#### 4. Strategic Response of the U.S. Firm after Entry by the Canadian Firm

The strategic response of the incumbent firms depends on the relative cost structure among them. Given the production and transportation costs among the incumbent firms, Australia, Russia, and the Middle East have lower costs than the U.S. Under such a situation, the U.S. has a strategic incentive to prevent the entry of Canadian firms into the LNG export market to the Asia Pacific. One option for the U.S. is to increase natural gas import from Canada, as that would reduce the latter's incentive to directly export LNG to the Asia-Pacific market. Let us examine these issues next.

We combine the profitability conditions of the Canadian and U.S. firms after entry by the former, as depicted in Figures 2 and 3, respectively, in a single figure. Two possible situations can arise here. The first is depicted in Figure 4. It illustrates a situation where the  $EE$  curve from Figure 2 intersects with the  $t_E^*$  line in Figure 3 at a point where both  $t_E$  and  $F_E$  are positive, denoted by  $(t_E^*, F_E^*)$  in Figure 4. Equating the value of  $t_E$  from condition (14) to that of  $t_E^*$  from (22), we can solve for the value of  $F_E^*$  as follows:

$$F_E^* = \left( (10a - 70t_u) - 9\sqrt{(a - 4t_u)^2 - 25TR_E} \right)^2 - \pi_E^N \quad (23)$$

The other situation occurs when the  $EE$  curve touches the vertical axis (the axis mapping  $t_E$ ) below the  $t_E^*$  line. That is, the  $EE$  curve always stays below the  $t_E^*$  line in the positive quadrant. In this case, the  $EE$  curve and the  $t_E^*$  line do not intersect at a point where  $t_E$  and  $F_E$  are both positive.

Let us now identify the condition under which Figure 4 is the appropriate description of our model. Comparing conditions (14) and (22), this occurs when the value of  $t_E$  in

Equation (14) obtained by setting  $F_E = 0$  is higher than the value of  $t_E^*$  in Equation (22), that is, the  $EE$  curve touches the vertical axis below the  $t_E = t_E^*$  line. In other words,

$$\frac{a + 2t_U - 10\sqrt{\pi_E^N}}{9} > -(a - 8t_U) + \sqrt{(a - 4t_U)^2 - 25TR_E} \tag{24}$$

It can be easily shown that this result always holds, that is, Figure 4 is the appropriate description of our model under our assumptions. The proof that condition (24) always holds is available in Appendix B.

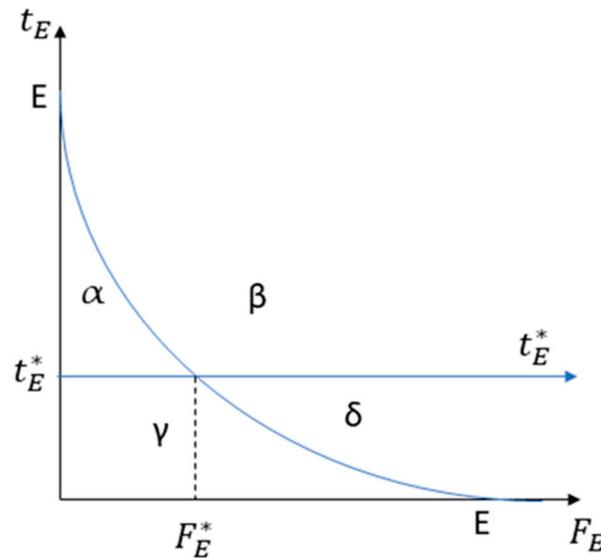


Figure 4. Profitability of the Canadian and the U.S. firm.

We now examine Figure 4 carefully to describe the different areas (parametric configurations in the  $(t_E - F_E)$  space) that it depicts, denoted by  $(\alpha)$ ,  $(\beta)$ ,  $(\gamma)$ , and  $(\delta)$ . Recall that entry is profitable for firm  $E$  in the area below the curve  $EE$ , while entry by firm  $E$  increases the profits of firm  $U$  if  $t_E > t_E^*$ , i.e., above the horizontal line at  $t_E^*$ . Note that the area  $(\alpha)$  in Figure 4 is below the  $EE$  line but above the horizontal line at  $t_E^*$ . In this parametric configuration, Canadian firm  $E$  will prefer to enter the Asia-Pacific market. Its entry will also be profitable for the U.S. firm  $U$ . Thus, entry by the Canadian firm is a win-win situation for the two North American firms in area  $\alpha$ .

In the area  $(\beta)$  which is above the  $EE$  line, as well as the horizontal line at  $t_E^*$ , the Canadian firm  $E$  cannot enter profitably. However, firm  $E$ 's entry will increase firm  $U$ 's profits in this area  $(\beta)$ . In contrast, in the area  $(\gamma)$  below the  $EE$  line and the horizontal line at  $t_E^*$ , the Canadian firm can enter profitably as a direct exporter. This entry will, however, reduce the profits of the U.S. firm. Finally, in the area  $(\delta)$  above the  $EE$  line but below the horizontal line at  $t_E^*$ , the Canadian firm will find it unprofitable to enter and such entry will reduce the profits of the U.S. firm.

It can be observed that in Figure 4, entry by the Canadian firm is profitable for both the U.S. and the Canadian firm only in area  $(\alpha)$ . In this case, entry will occur since the incentives for both firms are aligned. This result is summarized below in Proposition 3.

**Proposition 3.** *The entry by the Canadian firm in the Asia-Pacific LNG market will increase the profits of both the North American firms if the fixed cost of entry for the Canadian firm is sufficiently low, that is  $F_E \leq F_E^*$ , and its unit shipping cost is in the intermediate range, namely  $t_E^* \leq t_E \leq \bar{t}_E$ .*

This implies that when the fixed cost of entry and the unit shipping cost for firm  $E$  is sufficiently low, that is  $F_E \leq F_E^*$  and  $t_E \leq \bar{t}_E$ , then it is possible for the Canadian firm  $E$  to enter profitably. On the other hand, for profits of firm  $U$  to go up, the unit shipping

cost of firm  $E$  must not be too low, that is  $t_E \geq t_E^*$ . Further, in the region ( $\alpha$ ) where both conditions (13) and (22) are satisfied, the entry by the Canadian firm is a Pareto superior outcome. Not only does entry increase the profits of both the North American firms in this region ( $\alpha$ ), but as noted in Proposition 1, it also increases the profits of the other incumbent firms. Moreover, the consumers of the Asia-Pacific market are also better off, as the overall output is higher (and hence the price is lower) after entry by the Canadian firm.

Entry will not occur when it is unprofitable for each firm. This situation is captured in the area ( $\delta$ ) in Figure 4. More interestingly, consider area ( $\gamma$ ) in Figure 4, where the Canadian firm can enter profitably, but it reduces the profits of the U.S. firm. Hence there is a scope for the U.S. firm to act strategically to affect the incentives of the Canadian firm and increase its payoff. The U.S. firm can increase the quantity of purchase of natural gas through pipeline from the Canadian firm. This will increase  $TR_E$ , consequently increasing the Canadian Firm's profit  $\pi_E^N$  from exporting natural gas to the U.S. through pipelines. From condition (13), this will shift the  $EE$  curve to the left, and the horizontal line at  $t_E^*$  down from condition (22). As evident from Figure 4, this will reduce the area ( $\gamma$ ), making profitable entry by the Canadian firm possible only over a smaller set of parametric configurations. Thus, under this situation, the U.S. firm may be able to deter the entry of the Canadian firm if its increase in profits through entry deterrence is more than the higher transfer payment it needs to pay to the latter.

Similarly, consider the area ( $\beta$ ) in Figure 4. The Canadian firm will find it unprofitable to enter the Asia-Pacific market in these parametric configurations. However, the profit of the U.S. firm will increase if the Canadian firm makes an entry. This also creates an opportunity for the U.S. firm to increase its own profits by acting strategically to affect the choice of entry of the Canadian firm. In this case, the U.S. firm can reduce its imports from the Canadian firm (reduce  $TR_E$ , and consequently  $\pi_E^N$ ), shifting the  $EE$  curve to the right, making entry profitable to the Canadian firm over a higher set of parameters.

**Proposition 4.** *In the set of parametric configurations, when the Canadian firm can make a profitable entry in the Asia-Pacific LNG market, but the profit of the U.S. firm goes down, the latter can indirectly deter entry by offering to import more natural gas from Canada by pipeline. Similarly, under conditions when the Canadian firm cannot profitably enter, but such entry will increase the profit of the U.S. firm, the latter can indirectly assist the Canadian firm to make a profitable entry by importing less natural gas from Canada by pipelines.*

Intuitively, when the U.S. firm increases natural gas imports through pipeline from Canada, the reservation payoff of directly entering the Asia-Pacific LNG market goes up for the Canadian firm. With a tighter reservation constraint, the Canadian firm will only find it profitable to enter under a smaller set of parametric configurations. The opposite happens when the U.S. firm decreases its natural gas imports from Canada. In the latter case, the Canadian firm finds it profitable to enter as a direct exporter under a larger set of parametric configurations.

## 5. Discussion and Policy Implications

We have examined the potential and effect of Canada's entry into the LNG export market in the Asia-Pacific region on various stakeholders using an oligopoly framework. In terms of competitiveness, the development of pipeline and liquefaction terminals in the west coast will give Canada a cost-advantage for the export of LNG to the Asia-Pacific market. This means a decline in unit costs for the Canadian firm, an increase in its equilibrium output (market share) and profit, and a decrease in those of the other firms. A similar effect happens in case of a decrease in environmental standards in Canada.

Canada has several advantages regarding the export of LNG to the Asia Pacific. It has a large natural gas reserve which can be converted to LNG in a competitive low-temperature regime [5]. The operating costs of LNG projects in western Canada are \$0.52/mmBtu lower than those in Sabine Pass, Texas [5]. However, there are hurdles to overcome before reaping

benefits. Building pipelines through rugged mountains and liquefaction facilities in remote areas is challenging. Additionally, building and maintaining pipelines require indigenous peoples as partners, as those pipelines often cross their territories. The Canadian taxation regime and environmental regulations are generally more stringent than those of some of the other LNG exporters, creating additional challenges. Despite these challenges, Canada's prospect for LNG export to the Asia Pacific is significant.

Our model is based on the current world's LNG trade. The four regions considered in our model are responsible for over 60 percent of the world's LNG exports. In addition, they all are major exporters to the Asia Pacific. There may be concerns about the inclusion of the Russian Federation in the model. Previous studies suggest that the energy sector in the Russian Federation is controlled by the government, which uses energy trade to pursue geo-political motives, rather than allowing private firms to pursue profit motives [17,28]. Nonetheless, the Russian Federation has been a signatory of the World Trade Organization (WTO) since 2012 and is subject to the usual principles of international trade. In that sense, the inclusion of the Russian Federation when modeling international LNG trade seems justified. In addition, our model stands and generates similar outcomes even if the Russian Federation is excluded.

In a competitive market, LNG prices are to be closely tied with the domestic natural gas market, as the liquefaction, shipping, and regasification costs are standards. However, in the Asia-Pacific markets, LNG prices are commonly determined based on an oil-indexed formula to mitigate long-term price fluctuations. This also keeps the LNG prices in the Asia-Pacific market higher than those in the rest of the world. In North America, LNG prices are not tied to oil prices. With the increasing number of short-term contracts and with the expiration of previously instituted long-term contracts, the LNG trade is becoming progressively more competitive among the players [29,30]. In addition, more importers and exporters are joining the trading market, although the number of major players remains few. Despite increasing competitiveness across several fronts, oligopoly behavior among major firms remains prevalent. The increasing competitiveness among exporting firms is expected to lower returns on investment, putting downward pressure on the LNG sector, making it less attractive for future investment. However, the increasing environmental concerns favor the LNG industry, as it is the least polluting fossil energy.

LNG has advantages over other fossil fuels on several fronts. First, it is cleaner and more energy-intensive than other fossil fuels. Second, the development of low-cost liquefaction, transportation, and regasification processes is reducing its costs. Third, LNG is becoming more and more versatile for use by road freight [31], heavy trucks [32], cruise ships [33], etc. Pfooser et al. [34] concluded that LNG is a viable alternative for other non-renewable resources, both economically and environmentally, if the appropriate policies are followed to stimulate demand, increase supply, and improve technology for ecological friendliness.

Canada has already set foot in the LNG market and the first liquefaction facility on its west coast is nearly complete. Our model predicts that under certain condition, Canada's entrance could result in a Pareto superior outcome benefitting the Canadian firm and the incumbent firms as well as consumers in the Asia-Pacific natural gas market. However, if the Canadian firm's fixed cost of entry is sufficiently low, it can benefit at the expense of the U.S. firm, as part of the U.S. firm's LNG export (production and transport) cost is higher than its Canadian counterpart. Moreover, the U.S. exports part of Canadian natural gas before the entrance of the Canadian firm. Due to this, the U.S. is likely to experience more adverse effects from Canada's entry, as its transportation cost is higher than the others. The LNG production facilities in the U.S. are in the Gulf of Mexico, from where, the distance to the Asia-Pacific is nearly twice that of Canada's. In addition to travelling a longer distance, the U.S. firm must pay fees to the Panama Canal authority, which further adds to its transportation cost. One might argue that Australia becoming the largest LNG exporter, surpassing Qatar [2,34] and being relatively closer to the Asia-Pacific market than Canada, may cause Canada to lose competitiveness to Australia. However, the distance

from Australia [Rockhampton, for example] to Osaka is 3,953 nautical miles (only about 270 miles less); furthermore, the production cost of natural gas in Australia is high [35], which does not guarantee competitive advantage over Canada.

Since the U.S. is at the greatest disadvantage regarding Canada's entry to the LNG market, it has an incentive to impose some barriers to the latter's entry. There are two tools that the U.S. can apply. One, as natural gas pipelines exist between the U.S. and Canada and the U.S. already imports Canadian natural gas, it can increase its import to disincentivize Canada's effort to directly export natural gas to the Asia-Pacific market. A second option would be to build LNG plants on its Pacific coast—the coast of the states of Washington, Oregon, or California—and directly compete with Canada. Thus, from a strategic point of view, Canada should continue its effort to build its own LNG terminals to capture the Asia-Pacific market.

**Author Contributions:** Conceptualization, S.G. and S.I.; methodology, S.G.; software, S.I.; validation, S.G. and S.I.; formal analysis, S.G.; resources, S.G. and S.I.; data curation, S.I.; writing—original draft preparation, S.G. and S.I.; writing—review and editing, S.G. and S.I. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** All the data are available publicly.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

**Proof of Condition (22).** The profit of the U.S. firm will be lower after entry by the Canadian firm if the following condition holds:  $\frac{(a-4t_U)^2}{5^2} - F_U - TR_E > \frac{(a+t_E-8t_U)^2}{5^2} - F_U$

Simplifying, we get,  $t_E^2 + 2t_E(a - 8t_U) - [25TR_E - 8t_U(a - 6t_U)] < 0$ ;

Since this is a quadratic condition in  $t_E$ , we solve for  $t_E$  to get a critical value, say  $t_E^*$  such that  $\pi_U^N > \pi_U^S$  if  $t_E < t_E^*$ . Solving the above expression, we obtain:

$$t_E^* = \frac{-2(a - 8t_U) \pm \sqrt{2^2(a - 8t_U)^2 - 4[25TR_E - 8t_U(a - 6t_U)]}}{2}$$

Further simplifying, the following expression is obtained:

$$t_E^* = -(a - 8t_U) \pm \sqrt{(a - 4t_U)^2 - 25TR_E}$$

Since  $-(a - 8t_U) < 0$ , we consider the positive square root of the above expression, since  $t_E$  cannot be negative. In other words, the condition becomes:

$$t < t_E^* = -(a - 8t_U) + \sqrt{(a - 4t_U)^2 - 25TR_E}$$

□

## Appendix B

**Proof of Condition (24).** Here we illustrate the derivation of the proof that condition (24) always holds, that is:

$$\frac{a + 2t_U - 10\sqrt{\pi_E^N}}{9} > -(a - 8t_U) + \sqrt{(a - 4t_U)^2 - 25TR_E}$$

This can be simplified into the following condition:

$$10(a - 7t_U - \sqrt{\pi_n}) > 9 \left[ \sqrt{(a - 4t_U)^2 - 25TR_E} \right]$$

Squaring both sides, and simplifying, we obtain:

$$19a^2 + 2048at_U - 200a\sqrt{\pi_N} + 3604t_U^2 + 1400t_U\sqrt{\pi_N} + 100\sqrt{\pi_N} + 25TR_E > 0$$

Using our assumptions of non-negative outputs of each firm, and condition (12) in the original text, we find that the inequality (24) always holds.  $\square$

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