6-25-2018

# International Trade and Environmental Regulation

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**DOI:** 10.25148/etd.FIDC006909

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# INTERNATIONAL TRADE AND ENVIRONMENTAL REGULATION

A dissertation submitted in partial fulfillment of the

requirements for the degree of

DOCTOR OF PHILOSOPHY

in

ECONOMICS

by

Qingru Tu

2018

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Steven J. Green School of International and Public Affairs

This dissertation, written by Qingru Tu, and entitled International Trade and Environmental Regulation, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this dissertation and recommend that it be approved.

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Florida International University, 2018

DEDICATION

To my parents.

ACKNOWLEDGMENTS

I express my sincere gratitude to my major advisor, Dr. Kaz Miyagiwa, who trained me to do academic research, advised me on theoretical study in microeconomics, enlightened me on various research topics, and encouraged me in my future career. I am grateful to my dissertation committee members for their help and guidance.

I thank all the faculty and staff in the Department of Economics for their great help.

I acknowledge the financial support from the Florida International University, including a Teaching Assistantship and Tuition Waivers during my doctoral study.

I am eternally grateful to my dearest parents and family for their love and unwavering support for pursuing my dreams.

ABSTRACT OF THE DISSERTATION

# INTERNATIONAL TRADE AND ENVIRONMENTAL REGULATION

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This dissertation is composed of three chapters regarding international trade and environmental regulation. The first chapter focuses on the relationship between port ownership and the port R&D investment. I investigate whether a larger degree of private involvement in the port sector makes for a higher level of welfare, as well as an improvement in port performance. I establish the stage games to analyze the reciprocal international trade. The theoretical findings indicate that the endowment of population plays an essential role in choosing the optimal port ownership.

In the second chapter, I investigate the effect of port pollution regulation on port ownership. I incorporate the regulation tax on emissions from port cargo handling into the international duopoly trade model. The results of the stage games suggest the same ownership of the ports in both countries. I also extend the categories of port structures to include the transfer of port ownership to the other country. The policy implication is to have the small country own both ports, which is opposite to the port governance in reality.

In the third chapter, I explore the equilibrium port ownership structures without other policy issues or regulation on the port sector being considered. The influence of country size per se suggests that a small country should privatize its port in the context of a privatized port in the large country. For a large country, it is better to

choose a type of ownership different from the small country's. In addition, it is the country whose population is greater than a third of the scale in the other country that should own both ports.

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CHAPTER 1

# PORT OWNERSHIP AND PORT R&D

## 1.1 Introduction

According to the International Maritime Organization (IMO), more than 90% of the global trade is transported by sea. In a maritime logistical chain, ports play an indispensable role in providing international transport services, such as cargo handling, intermodal transshipment, and administrative documents, for both imports and exports[1]. Port performance thus influences the global trade flows. For example, ports with the highest efficiency (e.g., the speed of processing cargo) always charge the lowest for their services and furthermore augment the trade volume (Blonigen and Wilson, 2008; Clark et al., 2004).

To enhance the port efficiency, some scholars advocate more private participation in the port sector (Tongzon and Heng, 2005; Gonzalez and Trujillo, 2008; Cheon et al., 2010). Since the late 1980s, there have been institutional reforms in port governance and management. Private operation of the port facilities takes place in countries like UK, Spain, Cyprus, etc. However, in practice, private port ownership does not always serve as the essence of high port efficiency. For instance, both Singapore and Hong Kong are highly efficient ports, though the former is devoid of private involvement in port activities and the latter is a private seaport (Trujillo and Nombela, 1999). Moreover, the recent trend in port governance infers increased engagement of state and federal governments, like in the U.S. (Zhang et al., 2018).

[1] Trujillo and Nombela (1999) delineate the multiple functions carried by different agents in a port. In this paper, we do not distinguish the various port agents or the pertinent multi-product nature of a port. We consider the port as a whole. The port ownership in question throughout the paper focuses on the ownership of port facilities.

Whether to privatize ports has been controversially discussed in the literature. Matsushima and Takauchi (2014) explore the strategic port ownership structure within the framework of reciprocal trade between international duopoly. They find that the government's incentive to privatize a port is dependent on the level of unit transport cost. Choi and Lim (2016) investigate the performance of port privatization on the basis of an import-competing trade model. With two countries and two ports as in Matsushima and Takauchi (2014), they assume only one country acts as the consumer market of the world productions. The import tariff impacts the decision of port ownership. Czerny et al. (2014) evaluate the welfare effects of port privatization in the context of duopolistic port competition for providing transshipment services in a third region.

In this paper, following Matsushima and Takauchi (2014), we leave out the effects of extrinsic factors on optimal port ownership but concentrate on the market endownments——population sizes, to explore the conditions where privatization is suggested. Under the duopoly setup, for a country with less(more) people than the other's, should the government allow private participation in its port sector? Does the difference in population sizes influence the optimal degree of private involvement?

To find out the optimal port ownership, the authors as mentioned above only consider fully nationalized and completely privatized ports. These types of port ownership indicate either the government or the private entity owns the port. The port owner is responsible for all port services, port investment, and planning. The difference between nationalization and privatization lies in the port owner's optimality objective. The government aims to maximize the national welfare, while the private entity tries to maximize the port profit.

In this paper, we enlarge the scope of potential ownership structures by taking partial(or mixed) privatization into account. If a port is partially privatized, we assume the government owns it legally; however, its operation is carried out by the private sector.

To include partial privatization is following the empirical findings by Tongzon and Heng (2005). They believe that "full port privation is not an effective way to increase port operation efficiency". It is better to limit the private participation to being the port landowner and operator[2]. Referring to the World Bank Port Reform Toolkit (Second Edition), the administration models of the port structure fall into four categories: public service, tool, landlord, and private service port, ranked in order by the extent of private sector participation. The public and private service ports are respectively equivalent to the complete nationalization and privatization[3] in our setup.

The other two cases generally equate to the mixed allocation of port responsibilities. To be specific, the private activities under the tool port model mostly proceed in the form of concession contracts. Tool port model is not strictly the same as privatization[4]. Our assumption of partial privatization is much closer to the case of landlord port. The landlord model suggests that the government owns the port infrastructures, while the private participant functions the other port services. This administrative structure is commonly applied in reality.

Therefore, to contextualize all the three types of port ownership in each country and figure out the optimal port governance strategy can generate an overall picture of the port ownership reforms. The policy suggestions extrapolated from all the po-

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[2]The extent of private involvement in port functions is based on Baird (2000).

[3]Brooks (2004) explains the four cases from the regulatory and operational viewpoints. The author also represents an alternative classification of port governance and management models.

[4]In Brooks (2004), "true privatization is the full transfer of ownership". The concession agreements are "just a transfer of temporal rights". For a more detailed explanation of concession, see Wang et al. (2018).

tential ownership combinations are more persuasive than the conclusions in previous literature. For example, Xiao et al. (2012) also cover the three types of ownership. However, they assume the ports in a country have the same governance structure. They do not contemplate which is the strategic port ownership. This paper fills in the gap of a comprehensive analysis of strategic port ownership.

Moreover, our study is also related to the literature regarding the effect of private participation on port investment. Contemporary ports are becoming capital-intensive industries (Trujillo and Nombela, 1999). The investments in modern port facilities, especially in container ports with specialized requirements, may cause huge debts and even declined credit rating of a port. The government may be unable to fully finance the ports at the risks of running into fiscal issues. Therefore, port privatization becomes an alternative to private investment (Talley, 2000). The degree of private sector's investment incentive is contentious. Xiao et al. (2012) find out that when the ports have the same ownership, the port capacity investment decreases with the private sector participation. On the contrary, Matsushima and Takauchi (2014) consider the port investment when the small country privatizes its port, and the large country nationalizes. The authors show that the privatized port has stronger incentive to engage in port cost-reducing activities.

To add evidence of how privatization impacts port investment, we incorporate port R&D, the cost-reducing investment, into each type of ownership. We assume the port owner in each country invests in port facilities to achieve the optimality objective. For a nationalized port, the government as the port owner lays out R&D to maximize the national welfare. The private sector as the owner of a completely privatized port invests with the intent of maximizing the port profit.

A partially privatized port, in particular, is assumed to have the government make the investment. This assumption not only complies with the characteristics of a landlord port as defined by the World Bank, but also reflects the degrees of involvement of different agents in reality. Baird (2002) weighs up the performance of standard ports around the world. The evidence suggests a central role of public sector in port investment, planning, regulation, and development, even if the private sector has prominent involvement in port services and operations. Therefore, to assume the government makes the port R&D reflects the significance of the public sector.

With an increase in port investment, port with good infrastructure faces a decreased operation cost. Therefore, the port charges a lower price of using the port services (Clark et al., 2004; Xiao et al., 2012). The cheaper port services indicate high port efficiency (Blongien and Wilson, 2008)[5]. We compare the port investments under different port ownership structures and the corresponding port charges to evaluate the effect of private involvement on port efficiency.

In this paper, we introduce a four-stage game. We assume there are two countries in the world. Each country has a port. International trade requires the usage of both ports. In the first stage of the game, each government simultaneously chooses its port ownership. In the second stage, the port owners make decisions on port R&D investments. In the third stage, the port operators set the prices of port services. In the last stage, the manufacturing firms determine their outputs.

The remainder of this paper is organized as follows: Section 1.2 establishes the basic model of the international duopoly trade. Section 1.3 explains the subgames in context of different simultaneous ownership structures. Section 1.4 evaluates the

[5]As for port efficiency, multiple factors have an impact on it, such as hinterland transportation, port delay time, port reliability. See Tongzon and Heng (2005) for details. There is no uniform measure of efficiency. In the empirical study, the commonly applied methods include firm-level survey data, Data Development Analysis based on input and output, and econometric estimation of port production/cost functions. See Blongien and Wilson (2008) for details. Taking the definition of import charges by US Census as the reference point, Blongien and Wilson (2008) use the costs of unloading the products upon arrival at the port to measure the port's efficiency.

numerical results between the subgames. Section 1.5 concludes the paper and suggests further research extension.

## 1.2 Model

### 1.2.1 Basic Model

We assume there are only two countries in the world, Home and Foreign. Each country has a manufacturing firm. Both firms produce the same homogeneous goods[6]. Each firm serves both markets. The price of goods in each country is an inverse-demand function.

$$p = a - \frac{1}{b}(x + Y), \tag{1.1}$$

$$P = A - \frac{1}{1-b}(X + y), \tag{1.2}$$

where $p$ is the price of goods in Home country and $P$ the price of goods in Foreign[7]; $a$ and $A$ are positive constants. $x$ denotes Home domestic consumption of its production, and $y$ is the Home exports to Foreign. $X$ and $Y$ are the counterparts in Foreign. To differentiate the country sizes, we use the ratio of population. Suppose the total population worldwide is equal to one. $b$ $(0 < b < 1)$ is the rate of the Home population to the world total amount. $1 - b$ is the Foreign population ratio. In doing

[6]The assumption of homogeneous goods ensures the port infrastructures and port services needed in both ports are the same. It justifies the comparison between the two ports.

[7]We use lower case letters to represent the variables in Home, and upper cases for the corresponding variables in Foreign throughout the paper.

so, when we consider the change of population in either country, we do not have to change the world total population accordingly[8].

Each firm needs the shipper's service to export its goods. We assume there is a third-party shipping carrier. This shipper charges $\tau$ per unit of goods as its transport fee. $\tau$ is a non-negative constant. Meanwhile, each manufacturing firm needs to use both domestic and foreign ports to do cargo handling. The ports in the countries provide the cargo services and charge the port usage fees[9]. We assume there is only one port in each country. The port in Home charges $f$ per unit of goods. Foreign port charges $F$. Given these transport costs occurred during international shipping, each manufacturing firm's profit, $\pi$ and $\Pi$, can be written as

$$\pi = px + (P - \tau - f - F)y, \tag{1.3}$$

$$\Pi = PX + (p - \tau - f - F)Y. \tag{1.4}$$

To find the strategic port ownership structures, we build a simultaneous four-stage game model. In the first stage, each government decides the ownership of its port: privatization, nationalization, or partial privatization. In the second stage, given the port ownership, either the private port owner or the government makes the port's cost-reducing investment, R&D. To be specific, the private entity invests for a fully privatized port. The government makes the R&D investment for both nationalized and partially privatized ports.

In the third stage of the game, having the port investment determined, each port operator decides its port usage fees. A privately possessed port has its usage fee

[8]For example, Matsushima and Takauchi (2014) assume Home has a unit country size, and Foreign has $b$. To compare the country sizes, $b$ changes while the other country's population is fixed. It implies a burgeoning population in one country. The population distribution used in this paper can avoid an unexpected boom or slump in global population.

[9]We do not distinguish the concepts of port charge, port fee, and price as in Hidalgo-Gallego et al. (2017).

determined by its private owner. If a port is nationalized, the government sets up the port charge. As for a partially privatized port, it is the private port operator that determines how much to charge for using the port. In the last stage, both manufacturing firms decide their productions, given the port charges.

### 1.2.2 Backward Induction

To find the Nash-equilibrium port ownership structure, we employ the backward induction. First of all, we look for the manufacturers' productions, taking the port charges as given. For the Home producer, we plug the prices of goods in equations (1.1) and (1.2) back into the Home producer's profit function (1.3). We maximize the Home producer's profit $\pi$ with respect to Home domestic consumption $x$ and Home export $y$ respectively. The first-order conditions generate that

$$x = \frac{1}{2}(ab - Y), \ y = \frac{1}{2}\left[(1-b)(A - f - F - \tau) - X\right]. \tag{1.5}$$

Meanwhile, to find the Foreign productions, we maximize the Foreign producer's profit in equation (1.4) with respect to Foreign domestic consumption $X$ and Foreign export $Y$. It gives

$$X = \frac{1}{2}\left[A(1-b) - y\right], \ Y = \frac{1}{2}\left[b(a - f - F - \tau) - x\right]. \tag{1.6}$$

Taking all the productions in equations (1.5) to (1.6), we can derive the best response of productions which are

$$x_{BR} = \frac{b}{3}(a + f + F + \tau), \ y_{BR} = \frac{1-b}{3}(A - 2f - 2F - 2\tau), \tag{1.7}$$

$$X_{BR} = \frac{1-b}{3}(A + f + F + \tau), \ Y_{BR} = \frac{b}{3}(a - 2f - 2F - 2\tau). \tag{1.8}$$

Secondly, with the productions, we can find the port usage fees. The best response of port charges depends on the ownership of both ports. If a port is privatized or partially privatized, the port charge is the one that maximizes the private port profit. In the Home country, the private owner's profit $r$ is equal to

$$r = f * (y + Y) - (c - m)(y + Y) - m^2, \tag{1.9}$$

where $c$ is the Home port's unit operating cost and $m$ is the port cost-reducing investment made by its private operator. Similarly, a privatized Foreign port has the profit $R$ written as

$$R = F * (y + Y) - (C - M)(y + Y) - M^2, \tag{1.10}$$

where $C$ is the Foreign port's unit operating cost and $M$ is the Foreign private port operator's investment in improving the port infrastructures.

Otherwise, if a port is nationalized, the port charge is determined by the government which aims at maximizing the national welfare. We consider the national welfare consists of consumer surplus, domestic producer's profit, and the profit gained from the port. To be specific, the national welfare $w$ in the Home country is equal to

$$\begin{aligned} w &= \left[ \int_0^{x+Y} (a - \frac{q}{b})\, dq - p * (x + Y) \right] + \pi + r \\ &= \frac{1}{2b}(x + Y)^2 + \pi + r. \end{aligned} \tag{1.11}$$

Likewise, the Foreign welfare $W$ equals to

$$\begin{aligned} W &= \left[ \int_0^{X+y} (A - \frac{q}{1-b})\, dq - P * (X + y) \right] + \Pi + R \\ &= \frac{1}{2(1-b)}(X + y)^2 + \Pi + R. \end{aligned} \tag{1.12}$$

Which of the private port profit and the national welfare is the objective function of deriving the port charges depends on the port ownership that the government chooses.

Thirdly, taking the port charges derived in the previous step, we calculate the strategic port investments. If a port is privatized, its private owner chooses the level of R&D that can maximize the port profit. If a port is nationalized or partially privatized, it is the government that invests to maximize the national welfare.

The derivation of port usage fees and cost-reducing investments is in light of the simultaneous port ownership in both countries. In the following section, we elucidate choosing strategic port ownership from the perspective of the Home country, when given the Foreign port ownership.

## 1.3 Ownership Structures

Since there are three ownership structures available for each port, totally we have nine different combinations of the simultaneous port ownership in both countries. We continue the backward induction in each case and look for the optimal strategy from the viewpoint of Home country. In deference to certain ownership of the Foreign port, how much private involvement in the Home port sector is welfare optimal?

To start with, let the Foreign port be fully privatized. It means that the Foreign private port owner determines its port charge $F$ and the port investment $M$. When the Foreign port is privatized, there are three combinations of port ownership per Home port policy. We use $PP$, $NP$, and $BP$ to denote the three cases. The first letter stands for the ownership of the Home port and the second represents the Foreign port ownership. Specifically, $PP$ is the case where both ports are completely privatized; $NP$ indicates that Home government owns the port without private participation; $BP$ suggests a partially privatized Home port.

### 1.3.1 PP

Suppose the Home government also privatizes its port. Therefore, in the second step of induction, the private port owner in each country chooses the port charge to maximize its profit. To this end, we take the first-order condition of the Home port profit in equation (1.9) with respect to the Home port charge $f$. Also, we maximize the Foreign port profit in equation (1.10) with respect to the Foreign port fee $F$. It gives the best response of port usage fees , $f(m,M)^{PP}$ and $F(m,M)^{PP}$, as

$$f(m,M)^{PP} = \frac{1}{6}(2M - 4m + A + ab - Ab + 4c - 2C - 2\tau), \tag{1.13}$$

$$F(m,M)^{PP} = \frac{1}{6}(2m - 4M + A + ab - Ab + 4C - 2c - 2\tau). \tag{1.14}$$

With the port charges, we plug them back into the port profit functions (1.9) and (1.10). Then, we maximize each port profit with respect to its R&D. The best response of port investments, $m(M)^{PP}$ and $M(m)^{PP}$, are derived to be

$$m(M)^{PP} = \frac{1}{25}\left[A + ab - Ab - 2(c + C + \tau - M)\right], \tag{1.15}$$

$$M(m)^{PP} = \frac{1}{25}\left[A + ab - Ab - 2(c + C + \tau - m)\right]. \tag{1.16}$$

Using the best response of port investments, we can get their equilibrium values $m^{PP}$ and $M^{PP}$, which are

$$m^{PP} = M^{PP} = \frac{1}{23}\left[A + ab - Ab - 2(c + C + \tau)\right]. \tag{1.17}$$

Back to the best response functions (1.13) (1.14) of the port charges, we replace the port investments with their equilibrium values. As a result, it gives the equilibrium port usage fees, $f^{PP}$ and $F^{PP}$.

$$f^{PP} = \frac{1}{46}\left[7A(1-b) + 7ab + 32c - 14C - 14\tau\right], \tag{1.18}$$

$$F^{PP} = \frac{1}{46}\left[7A(1-b) + 7ab + 32C - 14c - 14\tau\right]. \tag{1.19}$$

In the end, we derive the equilibrium productions under $PP$ by substituting the port fees in equations (1.7) to (1.8) with their equilibrium values. Therefore, the productions at equilibrium are as follows:

$$x^{PP} = \frac{b}{69}\left[7A(1-b) + a(23+7b) + 9(c+C+\tau)\right], \tag{1.20}$$

$$y^{PP} = \frac{1-b}{69}\{A(9+14b) - 2\left[7ab + 9(c+C+\tau)\right]\}, \tag{1.21}$$

$$X^{PP} = \frac{1-b}{69}\left[A(30-7b) + 7ab + 9(c+C+\tau)\right], \tag{1.22}$$

$$Y^{PP} = -\frac{b}{69}\left[14A(1-b) + a(14a-23) + 18(c+C+\tau)\right]. \tag{1.23}$$

Up to this point, the equilibrium values of all unknown endogenous variables are figured out. That is, the model in the case of $PP$ is closed. Hence, we can plug all the equilibrium variables into the national welfare functions (1.11) and (1.12) to calculate the Home and Foreign welfare levels, $w^{PP}$ and $W^{PP}$. We can furthermore compare the equilibrium welfare under $PP$ with the results generated from other ownership combinations.

$$\begin{aligned} w^{PP} = \frac{1}{9522}\{&a^2b(3174+617b-245b^2) + A^2(387+39b-181b^2-245b^3) - 18ab(35b \\ &-6)(c+C+\tau) - 9(45b-172)(c+C+\tau)^2 + 2A(b-1)[ab(245b+27) \\ &+9(35b+86)(c+C+\tau)]\}, \end{aligned} \tag{1.24}$$

$$\begin{aligned} W^{PP} = \frac{1}{9522}\{&a^2b(1058-916b+245b^2) + A^2(3546-3673b-118b^2+245b^3) \\ &+18ab(35b-121)(c+C+\tau) + 9(45b+127)(c+C+\tau)^2 \\ &-2A(b-1)[ab(245b-272) + 9(35b-29)(c+C+\tau)]\}. \end{aligned} \tag{1.25}$$

In addition, we need to find out the range of coefficients to ensure the variables being non-negative. Since the role of transport cost in influencing the strategic port ownership is not the main focus in this paper, we assume the unit transport cost $\tau$ is zero. We also assume both ports have the same unit operating cost, $c = C$. Meanwhile, the initial national incomes are equal to each other, $a = A$. To have positive equilibrium productions, port charges, port investments, and the decreased port operation cost, $c - m$, being positive, we obtain the intersection of the ranges of $a$ and $c$. That is, the coefficients must meet the requirement that $4c < a < 27c$, given the population ratio $b$ can be of any value within $(0, 1)$.

### 1.3.2 NP

Now we presuppose the Home government nationalizes its port when the Foreign port is privatized. To determine the Home port charge, the Home government maximizes its national welfare. We first replace the productions in Home welfare function (1.11) with the best response of productions in equations (1.7) to (1.8). To obtain the best response of port charges, the Home government maximizes the welfare with respect to the Home port charge $f$. Simultaneously, the Foreign private port owner chooses the port charge $F$ that maximizes the port profit in equation (1.10). As a consequence, we have the best response of port charges in terms of port investments, $f(m, M)^{NP}$ and $F(m, M)^{NP}$:

$$\begin{aligned} f(m, M)^{NP} = \frac{1}{10(2+b)}[&ab(14 - 5b) + A(5b^2 - 3b - 2) + 2(12c + 2C - 5bC - 12m \\ &- 2M + 5bM + 2\tau - 5b\tau)], \end{aligned} \tag{1.26}$$

$$\begin{aligned} F(m, M)^{NP} = \frac{1}{10(2+b)}[&ab(5b - 2) - A(5b^2 + b - 6) + 2(-6c + 4C + 5bC + 6m \\ &- 4M - 5bM - 6\tau)]. \end{aligned} \tag{1.27}$$

In the next step of backward induction, substituting the best response of port charges into the Home welfare function (1.11), we take the first-order condition of

$w$ with respect to the government investment $m$. It generates the best response of Home port R&D in terms of the Foreign R&D, $m(M)^{NP}$ as

$$m(M)^{NP} = -\frac{(4+5b)\left[ab(2-5b) + A(5b^2+b-6) + 12(c+C-M+\tau)\right]}{6(25b^2+90b+92)}. \quad (1.28)$$

In the Foreign country, we replace the port fees in Foreign port profit function (1.10) with their best response $f(m, M)^{NP}$ and $F(m, M)^{NP}$ in equations (1.26) and (1.27). Maximizing the Foreign port profit $R$ with respect to its port investment $M$, we have the best response of Foreign port R&D, $M(m)^{NP}$, which is equal to

$$M(m)^{NP} = \frac{2ab(5b-2) - 2A(5b^2+b-6) - 24(c+C-m+\tau)}{25b^2+100b+75}. \quad (1.29)$$

With the best response functions (1.28) and (1.29) of the port investments, their equilibrium values, $m^{NP}$ and $M^{NP}$, are derived to be

$$m^{NP} = -\frac{(4+5b)\left[ab(2-5b) + A(5b^2+b-6) + 12(c+C+\tau)\right]}{6(25b^2+90b+68)}, \quad (1.30)$$

$$M^{NP} = \frac{2ab(5b-2) - 2A(5b^2+b-6) - 24(c+C+\tau)}{25b^2+90b+68}. \quad (1.31)$$

Therefore, we can use the equilibrium port investments to figure out the equilibrium port charges, $f^{NP}$ and $F^{NP}$. By substituting the port R&D in the best response of port charges in equation (1.26) and (1.27) with their equilibrium values, the port charges at equilibrium are equal to

$$f^{NP} = \frac{1}{2(25b^2+90b+68)}[5ab(20+6b-5b^2) + A(25b^3+25b^2-22b-28) + 24c(8 + 5b) - 2(C+\tau)(25b^2+30b-28)], \quad (1.32)$$

$$F^{NP} = \frac{1}{2(25b^2+90b+68)}(A(1-b)(6+5b)^2 + ab(25b^2+20b-12) - 12c(6+5b) + 8C(8+15C) + 50b^2C - 12\tau(6+5b)). \quad (1.33)$$

Then, we calculate the productions at equilibrium by replacing the port fees in production functions (1.7) to (1.8) with the equilibrium charges. The equilibrium productions under the circumstance of $NP$ are calculated to be

$$x^{NP} = \frac{b\left[A(4+b-5b^2)+2a(25b^2+67b+34)+30(2+b)(c+C+\tau)\right]}{3(25b^2+90b+68)}, \tag{1.34}$$

$$y^{NP} = \frac{(b-1)\left[2ab(25b+44)-A(35b^2+88b+60)+60(2+b)(c+C+\tau)\right]}{3(25b^2+90b+68)}, \tag{1.35}$$

$$X^{NP} = \frac{(1-b)\left[ab(25b+44)+A(20b^2+91b+72)+30(2+b)(c+C+\tau)\right]}{3(25b^2+90b+68)}, \tag{1.36}$$

$$Y^{NP} = -\frac{b\left[2A(4+b-5b^2)+a(25b^2-2b-68)+60(2+b)(c+C+\tau)\right]}{3(25b^2+90b+68)}. \tag{1.37}$$

In the end, the welfare in each country can be calculated out, using the equilibrium variables. What's more, we need to make sure all the variables are non-negative at equilibrium under $NP$. We still apply the assumption of a zero transport fee, identical country size as well the same port unit cost. It gives the range of coefficients to be approximately $8c \leq a \leq 10c$.

### 1.3.3 BP

Another strategy for the Home port is to privatize it partially. The port is owned by the government that invests in reducing the port's operating cost but is operated by the private sector. In this case, to find the port charges first, we maximize the Home port profit in equation (1.9) with respect to the Home port charge set by the private port operator. Meanwhile, we derive the Foreign port fee that maximizes the Foreign port profit in equation (1.10). At this stage of the game, both port charges are determined by their private sectors, which is the same with the procedures under

$PP$. Hence, the best response of port charges, $f(m, M)^{BP}$ and $F(m, M)^{BP}$, are equal to $f(m, M)^{PP}$ and $F(m, M)^{PP}$ in equations (1.13) and (1.14).

We proceed to figure out the port investments. For the Home port, the Home government invests in the port R&D. We plug the port fees derived above into the Home national welfare in equation (1.11). We maximize the Home welfare $w$ with respect to the port R&D, $m$. It gives us the best response of Home port investment $m(M)^{BP}$ which is

$$m(M)^{BP} = \frac{ab(5b-2) - 5A(b^2+b+2) + 5(b-4)(c+C-M+\tau)}{5b+142}. \tag{1.38}$$

As for the Foreign port, its private owner maximizes the port profit in equation (1.10) with respect to its investment in port infrastructures. The derivation follows the same steps of finding the best response of Foreign port R&D under $PP$. In other words, the best response of the Foreign port investment, $M(m)^{BP}$, is equal to $M(m)^{PP}$ in equation (1.16). With the best response of port investments, we can calculate the equilibrium values, $m^{BP}$ and $M^{BP}$, which are

$$m^{BP} = \frac{2ab(4b-1) - 2A(4b^2+5b-9) + 9(b-4)(c+C+\tau)}{9(b+26)}, \tag{1.39}$$

$$M^{BP} = \frac{ab(5b+46) + A(54-49b-5b^2) - 108(c+C+\tau)}{45(b+26)}. \tag{1.40}$$

Back to the best response of port charges in equations (1.13) and (1.14), we substitute the port investments with their equilibrium values to derive the following equilibrium port usage fees, $f^{BP}$ and $F^{BP}$,

$$f^{BP} = \frac{7ab(62-5b) + A(306-341b+35b^2) + 1728c - 18(5b+34)(C+\tau)}{90(b+26)}, \tag{1.41}$$

$$F^{BP} = \frac{7ab(5b+46) - 7A(5b^2+49b-54) + 1728c - 18(-42c+88C+5bC-42\tau)}{90(b+26)}. \tag{1.42}$$

Finally, we replace the port fees in equations (1.7) to (1.8) with the equilibrium charges and find out the productions at equilibrium:

$$x^{BP} = \frac{b\left[38A(1-b) + a(47b+130) + 54(c+C+\tau)\right]}{15(b+26)}, \tag{1.43}$$

$$y^{BP} = \frac{(1-b)\{9A(3b+2) - 4\left[7ab + 9(c+C+\tau)\right]\}}{5(b+26)}, \tag{1.44}$$

$$X^{BP} = \frac{(b-1)(A(11b-56) - 2\left[7ab + 9(c+C+\tau)\right])}{5(b+26)}, \tag{1.45}$$

$$Y^{BP} = \frac{b\left[76A(b-1) - a(79b-130) - 108(c+C+\tau)\right]}{15(b+26)}. \tag{1.46}$$

In consideration of positive equilibrium values, we find the coefficients must be $9c \leq a \leq 17c$ under $BP$. Therefore, the commonly applicable relationship between the coefficients is $9c \leq a \leq 10c$ in the context of a fully privatized Foreign port. In the analysis of every other ownership combinations, we calculate the range of coefficients that ensures positive variables. To proceed the numerical comparison in Section 1.4, we employ the stringent condition of coefficients which is the intersection of the ranges from all the cases.

So far we have articulated three games composed by different Home port ownership and a completely privatized Foreign port. In order to find out the subgame Nash-equilibrium port ownership, we need to weigh up the outcomes of all the nine combinations of port ownership. The remaining cases include $PN$, $NN$, and $BN$ when Foreign port is nationalized; besides, $PB$, $NB$, and $BB$ in the event of a partially privatized Foreign port. For any port ownership combination, the calculation of the case-specific four-stage game follows the same procedures. Since we explain sufficiently the subgames related to a privatized Foreign port, we show the derivation of the other cases in Appendix.

## 1.4 Optimal Port Ownership

In the preceding section, we derive the equilibrium values of the variables in their general forms. We assume zero transport cost, identical country sizes and the same port costs in each subgame of the simultaneous port ownership structures. On the basis of these assumptions, we figure out the corresponding relationship of country size and the port cost in each case. In summary, the intersection of all these ranges that is applicable in all the subgames to guarantee positive equilibrium values is $9c \leq a \leq \frac{29}{3}c$.

Moreover, we use the national welfare to measure the port performance subject to port ownership. In a bid to assess the welfare levels cross the subgames, we employ a numerical experiment. We let the unit transport cost $\tau$ be zero, the country sizes be $a = A = 9$, and the port costs be $c = C = 1$. The assignment of coefficient values is in accordance with the requirement of positive variables. Given the numerical values of the coefficients, the equilibrium variables are only dependent on the value of population ratio $b$.

In this section, we retain the outcomes in Home country as the point of reference, which is in line with Section 1.3. We take into account three conditions of the Home population size: equal to, smaller than or greater than the Foreign population size. In other words, it is when $b = 0.5$, $0 < b < 0.5$, and $0.5 < b < 1$.

### 1.4.1 Symmetric countries

When $b = 0.5$, the Home population ratio, $b$, is equal to the population size in the Foreign country, $1-b$. It indicates that Home and Foreign are symmetric in their sizes of population. With the numerical value of $b$, we can plug it back into the equilibrium variables in each case of ownership structures and calculate out their exact values. [10]. It facilitates our analysis of the economic performance in each case.

The mathematical results indicate that if the Foreign port is privatized, Home gains the highest welfare under $NP$. The welfare under $PP$ is almost equal to but slightly higher than that out of $BP$. We have the same order of Home welfare when the Foreign port is partially privatized. That is, $w^{NB} > w^{PB} \gtrapprox w^{BB}$. If the Foreign port is nationalized, it is still a nationalized Home port that premises the greatest welfare. In the context of a privatized Home port, Home welfare is very close to but a bit lower than that under partial privatization. To be specific, $w^{NN} > w^{BN} \gtrapprox w^{PN}$. Therefore, port nationalization always leads to the highest national welfare, regardless of the simultaneous port policy in the other country. The degree of private sector participation does not show significant influence on the welfare values.

Concerning port R&D, for specific Foreign port ownership, a completely privatized Home port always receives the most port investment among the three ownership choices. In contrast, if the Home port is nationalized, it gets the least port investment. Even a partially privatized port can obtain more finance from the government than a nationalized port does. Contrary to the effects on welfare, larger the degree of private involvement in the port sector, the more port investment.

### Nationalized Home port

When Home has its port nationalized, the government cuts back on the investment in the port facility and infrastructure. It hinders the port from reducing the cost of providing port services. Therefore, a nationalized port charges the highest port usage fee, compared with the prices set by a fully or partially privatized port. The

[10]The numerical results of each variable in all the cases are shown in Table A.1 in Appendix.

expensive port service weakens the incentive of doing bilateral symmetric exports. In the context of the least imports, Home consumers dampen down their spendings. Even if the Home consumers purchase the largest amount of Home produced goods, the least imports play a decisive role in generating the lowest CS.

Meanwhile, the short of goods escalates the Home price. In result, the Home producer makes the most profit in the domestic market, taking the full advantage of the highest selling price and the largest domestic consumption. The exporting market, however, becomes the least profitable, which attributes to the highest port charges and the smallest volume of bilateral exports. Fortunately, the largest profit Home producer earns in the domestic market is adequate to cover the losses in international trade. In the end, the Home producer makes makes the highest total profit as long as Home chooses to nationalize its port for any given ownership in Foreign.

Due to the Home government's lowest port investment, the actual port cost turns out to be the highest. However, the induced least bilateral exports facilitate the achievement of the lowest total service costs. It indicates how much the exports are knocked down under port nationalization.

Now we look at the Home port revenue. There are different outcomes caused by different Foreign port structures. In particular, if the Foreign port is also nationalized, the Home port gains lower revenue under nationalization than it does with private involvement. Although the Home port charge is at its highest under $NN$, the global exports are so small that brings on the lowest port revenue. Consequently, the Home port profit is ended up as the lowest.

If the Foreign port is not nationalized, the Home port under nationalization can make the largest port revenue which benefits from the most expensive port service. In other words, the high price of port service compensates for the potential loss attributed to fewer exports, which enables the nationalized Home port to obtain the highest port revenue. Therefore, the highest port revenue with the lowest total service costs and the least investment altogether paves the path for the highest port profit.

Given that a nationalized Home port always generates the lowest total service cost and the least port investment, the order of Home port profits under three ownership structures is therefore consistent with the order of port revenues. Whether Home nationalized port gets the highest or the lowest profit depends on the simultaneous Foreign port policy. The most port profit takes place as long as the Foreign port is not nationalized, which owes to the highest Home port charge. Otherwise, it gets the least profit, since the least world exports counteract the positive effect of the most expensive port service. It is worth noting that, as a symmetric counterpart, the Foreign government also establishes the most expensive port service under nationalization. It implies that nationalization imposes a much further slash on world exports. In addition, the only component of welfare under $NN$ that reaches the highest level is Home producer's profit in domestic market, while all the other parts are at their bottom levels. The government nationalizes its port to obtain the highest welfare through exploiting the benefits from the domestic market. The most lucrative domestic market has the largest domestic consumption and the least imports. In other words, the government sets up the highest price of port service to hurt foreign exports and protect its own manufacturing sector. Additionally, the port investment is not weighed heavily by the government, which has a detrimental effect on port efficiency and even de-escalates a country's competitiveness in international transport.

**Privatized Home port**

In the context of any Foreign port policy, a privatized Home port behaves in the opposite way to what nationalization does. With the devotion of the most port investment, the private sector reduces the port operating cost to the largest extent.

Therefore, the port charge is set to be the cheapest, which stimulates bilateral exports. The volume of international trade reaches the peak. The Home producer, on the one hand, narrows down its production for domestic consumption. Since the Home country imports the largest amount of goods, its CS is at the maximum and the price of products decreases to the lowest. The Home producer's fewest domestic sales in addition to the lowest selling price makes the Home market the least profitable.

On the other hand, the Home producer expands its exports. Even if the price of goods in Foreign by symmetry is at the lowest as well, the cheapest port services help make the profit per unit of export to the highest. The export market becomes the most lucrative. Therefore, the Home producer makes the largest exports and obtains the most earnings in Foreign. However, the benefits gained abroad cannot offset its losses in the domestic market. After all, the Home producer get the lowest total profits when the Home government no longer participates in any port activity.

In the port sector, if Foreign nationalizes its port, a completely privatized Home port can produce the most port revenue. The most active international trade market compensates for the adverse effect of the lowest Home port fee on port revenue. The private port owner's most investment in port facilities and the largest amount of global exports lead to a higher total service costs than those under nationalization. However, the highest port revenue benefited from the most prosperous export market helps realize the highest port profit.

If the Foreign port is not nationalized, a privatized Home port has less port revenue than that under nationalization. So does the port profit. Although the volume of world exports under privatization is the largest, they cannot overwhelm the impact of the most expensive service of a nationalized port.

The primary factor that prevents a privatized port from making higher welfare than nationalization does is the least profit in the domestic market.

### Partially Privatized Home port

In general, the results under a privatized Home port act as an antithesis of nationalization. Each counterpart under partial privatization has the outcome that lies between the extremes, no matter what is the ownership of the Foreign port.

The reason why the degree of private participation does not manifest a significant effect on welfare is the higher total port service costs under partial privatization. Either the port is fully nationalized or privatized, it always has the least exports or the lowest actual unit operating cost to counterbalance the other part in total service costs. However, the middle-rank values of both exports and per unit cost under partial privatization are deficient in balancing the effects of each other. Thus, a partially privatized port faces the highest total service costs.

Finally, its port revenue, as well as the induced profit, in the situation where the Foreign port is nationalized, lies between the extremes out of nationalization and privatization. Since the port profits with private involvement are close, the welfare levels do not show much difference. If the Foreign port has private participation, a partially privatized Home port has the lowest port revenue as well as the lowest port profit. The difference in port revenue between full and partial privatization is ignorable. So are the port profit and the final national welfare.

In summary, countries with the same population size are inclined to nationalize the ports, regardless of the port policy in the other country. It implies that the subgame Nash-equilibrium port ownership is $NN$ from the perspective of national welfare. The government nationalizes its port for the sake of protecting domestic manufacturer. It sacrifices the CS and furthermore the port sector.

**Proposition 1.4.1** *When countries are symmetric, the optimal strategy to gain the highest national welfare is to nationalize their ports. If the government takes ac-*

*count of improving port efficiency, it should encourage private participation in port activities.*

### 1.4.2 Home as the small country

When Home population ratio $b$ is smaller than 0.5, we take the Home country as the small country with less population than Foreign. The choice of the optimal strategy in the small country depends on whether the port in the large country is nationalized or not.

#### Non-Nationalization in Large Country

On the one hand, we come to the same conclusion regarding the Home optimal port ownership strategy, no matter whether the Foreign government chooses to fully or partially privatize its port.

As Figures 1.1 and 1.2 depict, if the Home population ratio is less than 0.36, Home should partially privatize its port, which brings about the highest national welfare. Otherwise, with $0.36 < b < 0.5$, nationalizing the port is the best strategy as far as the welfare is concerned. As for the port R&D, the highest port cost-reducing investment is always in the wake of a partially privatized port.

When $0 < b < 0.36$, the results in math indicate that the values of Home welfare components under partial privatization are between the highest and lowest generated from either privatization or nationalization. In particular, if the port is under the governmental control, people in Home can enjoy the largest CS; while privatization causes the lowest CS. Same order of the producer's overseas profits. The producer's domestic profits and the port profits are ranked in the opposite order.

As demonstrated in the symmetric case, once the government owns the port, it shrinks the investment in port facilities. Under the circumstance of being a small

Figure 1.1: When $0 < b < 0.5$, Foreign privatizes its port.

(a) Home welfare differences

(b) Home port R&D

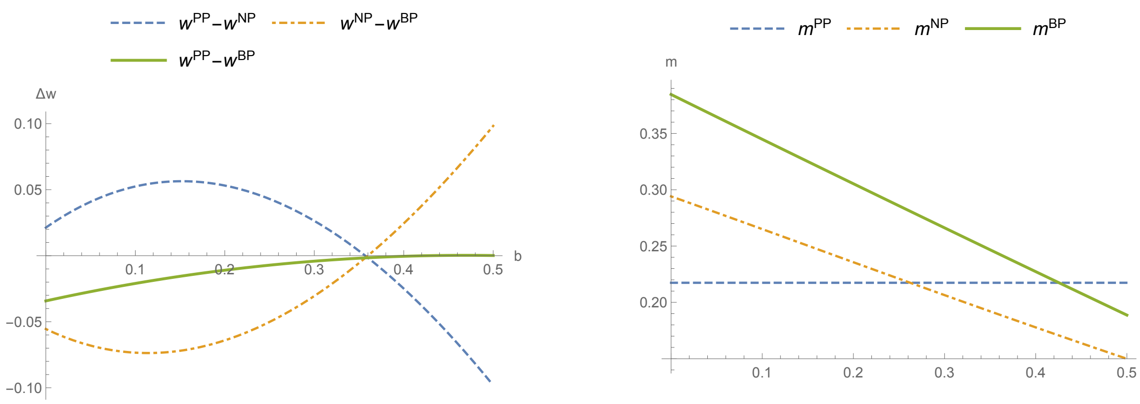
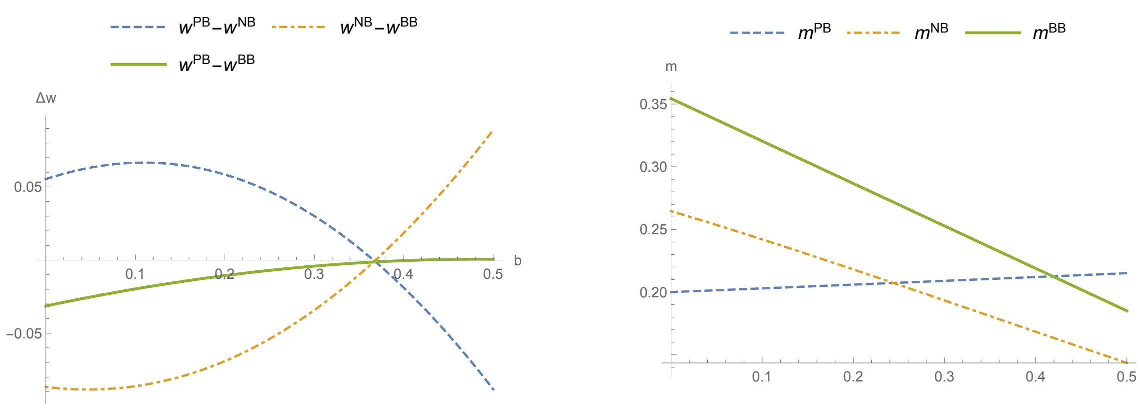



Figure 1.2: When $0 < b < 0.5$, Foreign partially privatizes its port.

(a) Home welfare differences

(b) Home port R&D




country, the government still takes the same position. Different from the symmetric case is that the government is now counting on more exports instead of expensive port services, to improve its national welfare. The cheapest port service stimulates exports from both Home and Foreign. Facing a constrained port cost reduction, even if there are the most exports, the Home port profit is overwhelmed by the highest service costs. Besides, with an increase in imports, the Home domestic price is driven down. The demand for Home produced goods is falling as well. It becomes inevitable that the Home producer gains the least profit in domestic market. Even the largest

CS and domestic profit are not sufficient to offset the losses from the lowest port and exporting profits.

As opposed to a government-owned port, the private port owner makes more port profit by virtue of limited port investment and the most expensive port service. As a result, it inhibits international trade worldwide. Fewer imports lead the CS to its lowest level; besides, fewer exports make producer's overseas business the least profitable. Benefiting from a huge demand for goods in the domestic market, the producer makes more profit in Home. The way how a private port owner behaves in a small country is in opposition to that in symmetric case.

In comparison, the performance of a setting of partially privatized port remains moderate in every component of welfare. It is worth noting that the government's largest investment in port improvement lowers down the unit service cost. So the port owner can save its expenses to the most.

When $0.36 < b < 0.5$, we reach the same conclusion as in the symmetric case that nationalization is the optimal port ownership, owing to the highest welfare. Nevertheless, the government is not dedicating to the development of port services.

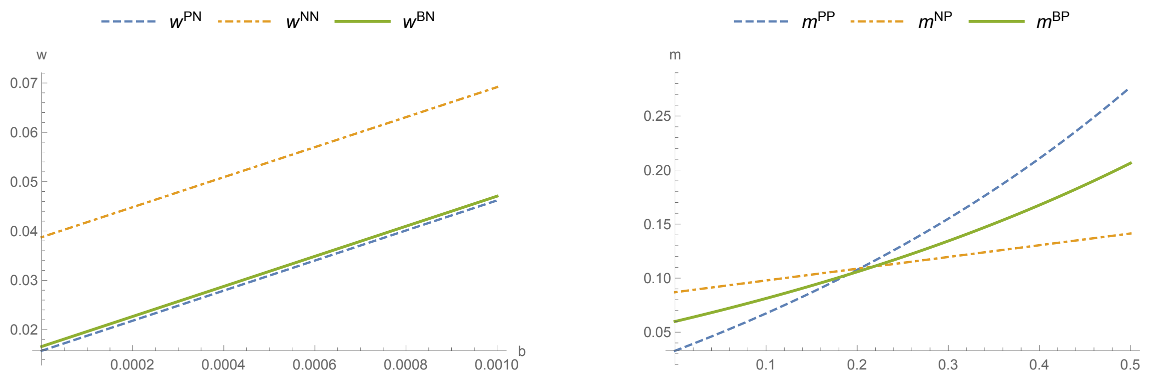
**Proposition 1.4.2** *Let the large country fully or partially privatize its port. For a small country, especially with a population less than 56% of the population in the large country, the government would better sponsor the private port owner. In doing so, not only can the highest national welfare be achieved, but also the most efficient port operations.*

### Nationalization in Large Country

On the other hand, as long as the large country has its port nationalized, Home government should nationalize its port to obtain the highest welfare, regardless of the population sizes. As for the Home port R&D, only if the population ratio $b$ is smaller than 0.2 can a nationalized port receive the most investment. Otherwise, it is the private sector as the port owner that dedicates the most to port development. All of these are shown in Figure 1.3 [11].

Figure 1.3: When $0 < b < 0.5$, Foreign nationalizes its port.

(a) Home welfare (b) Home port R&D




When Home has a small population, $b < 0.2$, the government makes every effort to stimulate the economy. As the port owner, the Home government invests the most in port cost reduction and sets the port usage fee at the lowest level. This is in contrast to the government strategies in the symmetric case. By this means, it lowers the cost of providing port services and encourages exports from both Home and Foreign. Therefore, Home customers have the largest CS; the port in this context becomes the most profitable. The Home producer gains the maximum earnings, despite the least profit in its domestic market. The highest profit realized in the Foreign country is adequate to cover the shortfall in Home market. The result of every part of the welfare stands out in the background of a nationalized port.

With population growth, $b > 0.2$, it is the private port owner, not the Home government, that invests the most in port services and charges the cheapest port usage fee. The largest amount of exports, as a result, is like a double-edged sword.

[11]To make it straightforward to read the difference between curves in the graph, we employ tiny segments within the range (0,0.5).

It enables the private sector to earn the most port revenue; however, it impedes the total service costs from falling to the bottom. In comparison, the government behaves oppositely. The least exports make a nationalized port end up with the lowest port revenue and the least total service cost. Not to mention the extreme values of port R&D, a nationalized port makes a higher profit most of the time than a privatized port does. The main cause of the lowest welfare in a setting of a privatized port is the smallest CS. The most massive imports lead to the lowest price in the Home market. Plus the least demand for Home produced goods, the CS is even lower than that obtained in the context of a partially privatized port whose results retain in between.

**Proposition 1.4.3** *Let the large country nationalize its port. If the population in the small country amounts to a quarter or less of the population in the large country, port nationalization is optimal for both national welfare and port R&D. If the population in the small country is more than that, nationalization serves the purpose of the highest welfare; while privatization puts the most emphasis on further port development.*

### 1.4.3 Home as the large country

Home is considered as the large country with more population than Foreign, given $b$ is greater than 0.5. No matter which port ownership is selected by the Foreign government, privatizing the port in the large country always brings the most port R&D investment but the lowest national welfare. In contrary, the highest welfare occurs in the setting of a nationalized port. However, the government as the port owner does not attach much importance to port improvement.

The welfare based on a partially privatized port lies in between the highest and lowest levels which are respectively generated from a nationalized and privatized ports. So does the corresponding port investment when $b$ is smaller than 0.82. More to the point, if the port in the small country is privatized, the Home government as the port owner makes the least port investment when $b$ is smaller than 0.82. If $b$ is greater than 0.82, the government invests the least to a partially privatized port. If the Foreign port is partially privatized, the division takes place at $b$ equal to 0.9. In the face of a nationalized Foreign port, a nationalized Home port is always the one that has the least R&D investment.

Regardless of the port ownership in the small country, once the Home port is nationalized, the government charges the highest port usage fee. The expensive port services constrain mutual exports to the largest degree. With a decrease in imports, the Home CS arrives at its lowest level and the domestic price of goods is knocked down. The Home producer, therefore, has to depend on the domestic market highly. Even though the exporting market becomes the least profitable, the most lucrative domestic market acts as the assurance of the producer's highest total profit.

More important, the Home domestic consumption plays a decisive role in ensuring the highest welfare, especially when the port profit reaches the bottom. The least exports drive down the cost of port services to its lowest level. It is the positive facet of reduced exports. The negative influence is that the amount of exports is so small that the port revenue is pushed down as well to the lowest. Additionally, the port R&D and the port profit are pertinent to the value of $b$.

To specify, if the Foreign port is privatized, the Home nationalized port generates the highest profit when $b$ is smaller than 0.7. With $b > 0.7$, nationalization implies the lowest port profit. If the port in the small country is partially privatized, the division of port profits occurs at $b$ equal to 0.66. If both ports are nationalized, the Home government always receives the most port profit.

**Proposition 1.4.4** *No matter who is the owner of the port in the small country, the large country is always intended to nationalize its port. By doing so, the large country maximizes its national welfare and sacrifices the port development.*

## 1.5 Conclusion

Whether port privatization makes the country better off depends on the comparison of its population size with the other countries'. We introduce three types of port ownership into the four-stage international duopoly model: nationalization, privatization, and partial privatization. Our results are predicated on the assumptions of identical country size, unit operating cost, and zero shipping cost. The theoretical findings indicate that the ratio of population sizes between countries is prominent in choosing the optimal port ownership. It also matters on how private participation affects the port efficiency.

When countries are symmetric in population size, the ports would better be nationalized to achieve the highest national welfare. However, the larger degree of governmental control in the port sector, the lower port efficiency due to the less infrastructure investment.

As for a country with less population, if the large country does not allow private participation in port activities, the small country should nationalize its port as well. Furthermore, if the population size in the small country is less than a quarter of the large country's population, nationalization makes for the realization of the highest welfare as well as the most port investment. Otherwise, the port in the small country receives the least R&D under nationalization. The most port investment is made by the private port owner.

If the large country encourages private involvement in the port sector, the small country with a population ratio lower than 56% should partially privatize its port. Partial privatization generates the highest national welfare and the greatest port investment. If the population in the small country is more than 56% of that in the large country, the small country should nationalize its port to obtain the highest welfare. But the government as the port owner invests the least in port R&D.

From the perspective of the large country, nationalization always induces the highest welfare, no matter what is the ownership of the port in the small country. However, the government in the large country makes the least investment in port facilities. The protection of domestic manufacturing industry enables the achievement of the high welfare. The government provides the most expensive port service, which restrains exports from the small country and boosts the domestic consumption of its own products.

Privatization behaves in opposite to nationalization, while partial privatization generates the outcomes lie between the extremes. To enhance the port efficiency and sustain its competitiveness in the international transport sector, the large country should encourage private entity to participate in port activities. The larger extent of private involvement, the higher port efficiency. Since the transfer of port ownership from the government to a private entity means a significant sacrifice in welfare, the large country can partially privatize its port. It mitigates the adverse effect on national welfare and contributes more to port development.

In this paper, we assume a linear relationship between the variables. To make the conclusions applicable to more general settings, a non-linear assumption should be taken into account. In the duopoly model, we assume both countries produce the homogeneous goods. Therefore, the specific type of port service is the same in both countries. We can explore the heterogeneous port services in future work. Moreover, a further extension can base on asymmetric assumptions of country sizes, transport costs, and port unit costs. It will corroborate the interaction between the shipping carriers and the port performance. More evidence can be figured out regarding how different factors influence the optimal port ownership.

CHAPTER 2

# THE EFFECT OF PORT POLLUTION REGULATION ON PORT OWNERSHIP

## 2.1 Introduction

With a growing volume of international trade, the demand for global transportation increases. In the international transportation system, ports play an essential role in providing the cargo handling services for the exports. The port services involve using the fuel-driven equipment which discharges air pollution. The port-related diesel emissions include the greenhouse gases, such as carbon dioxide [1].

To regulate the port pollution, some ports encourage to use cleaner fuels instead of the traditional diesel. For example, the Long Beach ports in California advocate substituting the diesel trucks with the natural gas and zero-emission vehicles in the next two decades.

The International Maritime Organization (IMO) imposes the regulation of fuel oil sulfur content in the Emission Control Areas (ECA). However, Chang et al. (2017) find that the ECA regulations lead to higher cost of the shipping carriers and lower the efficiency of the ports in Europe.

Given the evaluated adverse influence of purchasing low-sulfur fuels on the port sector, in this paper, we consider another way to control the port pollution. We simulate the scenarios of imposing a port pollution tax. In previous literature, Cui and Notteboom (2017) model the emission taxes in a country with competing ports. Zheng et al. (2017) introduce an environment monitor to formulate collusion-proof port emission regulations. Different from their settings, we apply the reciprocal inter-

[1] https://www.epa.gov/ports-initiative/national-port-strategy-assessment-reducing-air-pollution-and-greenhouse-gases-us

national duopoly trade model and incorporate the port emission regulation. First, we explore whether a pollution tax affects a country's optimal port ownership. Second, we assess which port ownership is the most environmentally friendly. Our analysis is mainly from the perspective of national endowment of population.

We follow Matsushima and Takauchi (2014) and assume each of the two countries in the world has one port located within its territory. The government can choose either to nationalize or to privatize the port. The former means there is no private involvement in the port sector. The latter allows the private entity to own the port. We establish the sequential games in each case of simultaneous port ownership structures. Based on the four subgames, we conclude the subgame Nash-equilibrium is to have each port owned by its government. A special case is when the two countries are almost symmetric in population sizes, to have both ports privatized is also a subgame Nash equilibrium.

Another contribution of this paper is to extend the categories of port ownership. We consider whether the government should allow the private port owner to sell out the port to foreigners. The reason why we pay attention to giving up the port ownership stems from the reality that seven of the ten largest ports worldwide are owned or operated by Chinese state-owned companies. We use the transfer of port ownership to simulate the phenomenon.

We allow the transfer of ownership on the condition that the private sector owns the port. We compare the national welfare levels in both countries before and after the selling of the privatized port to the foreign government or the foreign private firm. The findings indicate that selling out the port is always beneficial to the original country the port seller belongs to. However, it makes the other country that purchases the port worse off. The monopoly power in the port sector only occurs if it is the small country that buys the port in the large country. In particular, the small country has the population less than two-thirds of the number of people in the large country. It demonstrates the policy suggestion that is contrary to what is actually in effect.

The remainder of this paper is organized as follows: Section 2.2 explains the setup of the model. Section 2.3 delineates the sequential games under different port ownership structures. Section 2.4 introduces the cases where there exists the transfer of port ownership. Section 2.5 concludes the theoretical findings and suggests the direction of further study.

## 2.2 Model

Similar to how we set up the model in Chapter 1, we continue our theoretical analysis within the framework of an international duopoly trade model. We maintain the assumption of two countries in the world, Home and Foreign. Each country has a manufacturing firm. Both firms produce the homogeneous goods [2]. Each firm serves both markets.

### 2.2.1 Consumer

The price of goods consumer faces in each country is in the form of an inverse-demand function. We denote the Home indicators in lower case and the Foreign ones in upper case. Let $p$ be the price of goods in Home, and $P$ be the counterpart in Foreign. We have the prices

$$p = a - \frac{1}{b}(x + Y), \tag{2.1}$$

$$P = A - \frac{1}{1-b}(X + y), \tag{2.2}$$

[2]Homogeneous goods require the same type of port services. It is then reasonable to compare the service charges.

where the positive constants $a$ and $A$ represent the initial national income; $x$ and $X$ are the consumption of the goods produced domestically; $y$ and $Y$ are the exports to the other country.

We aim to explore the effect of port pollution regulation on the optimal port ownership policy in different-sized countries. We take the endowment of population as a measurement of country size. We assume the world population equals to one. Let $b$ $(0 < b < 1)$ be the ratio of Home population to the world entirety, and $1 - b$ be the Foreign population ratio. We compare the population ratios to distinguish the small and big countries. By so doing, we exclude the possibility of facing a population explosion worldwide in a given period [3].

### 2.2.2 Producer

We assume there is only one shipping carrier in the world and it does not belong to any country. Each manufacturing firm pays for the shipping service to deliver its exports. The shipper charges $\tau$ $(\geq 0)$ per unit of goods it carries.

Meanwhile, each producer exports to the other country and requires cargo handling services at ports upon departure and arrival. We assume there is only one port located in each country. To use the services at the port in Home country, the producer needs to pay the per unit port usage fee $f$. The port charge in the Foreign country is $F$ per unit of goods [4]. There is no discrimination of port charges between the exporters.

[3]Different from our assumption, Matsushima and Takauchi (2014) assume Home has a unit amount of population and Foreign has $b$ units.

[4]In this paper, we treat the port industry in each country as a whole. We do not distinguish "port charge", "port fee", and "price" as Hidalgo-Gallego et al. (2017) do.

Given the costs of shipping and cargo handling, the profits of Home and Foreign manufacturing firms are respectively written as

$$\pi = px + (P - \tau - f - F)y, \tag{2.3}$$

$$\Pi = PX + (p - \tau - f - F)Y. \tag{2.4}$$

### 2.2.3 Government

The cargo operations at ports inevitably involve the employment of the fuel-driven equipment which emits air pollution. We assume the port in each country is the only source of local pollution [5]. Each government imposes a pollution tax on emissions from the port located within the country's territory.

We assume each government has two executive departments. One is the environment-related institution; one is the transport division. We assume the former is obliged to formulate the pollution tax rate and the latter supervises the transport sector. Both executives aim at maximizing the national welfare. If the government owns a port, there is no need to have both departments establish the pollution tax rate and port charge separately. Since the governmental institutions share the same optimality objective, we let the transport department set up a "two-in-one" port usage fee to maximize the national welfare.

If the private sector owns a port, the environmental department is responsible for setting the pollution tax. The private port owner has the right to determine the port charge that maximizes its profit. We follow the prevailing assumption in literature to specify the optimality objective of each player. That is, the government as a port owner targets maximum welfare, while a private port owner concerns itself with the port profit.

[5] We do not consider the transboundary pollution.

To be specific, if the Home government owns its port, the transport department chooses the port charge $f$ to maximize the welfare. Let $w$ denote Home national welfare. It is written as

$$
\begin{aligned}
w &= \left[\int_0^{x+Y} (a - \frac{q}{b})\ dq - p*(x+Y)\right] + \pi + f*(y+Y) - \delta*(y+Y) \\
&= \frac{1}{2b}(x+Y)^2 + \pi + (f-\delta)*(y+Y), \qquad (2.5)
\end{aligned}
$$

where $\delta$ is the rate of pollution damage, and we do not consider the fixed unit cost of port services. The national welfare consists of the consumer surplus, producer's profit, port profit, and the damages caused by pollution.

Likewise, in the case of a nationalized Foreign port, the Foreign transport division determines a port charge $F$ to maximize its welfare $W$ which is

$$
\begin{aligned}
W &= \left[\int_0^{X+y} (A - \frac{q}{1-b})\ dq - P*(X+y)\right] + \Pi + F*(y+Y) - \Delta*(y+Y) \\
&= \frac{1}{2(1-b)}(X+y)^2 + \Pi + (F-\Delta)*(y+Y), \qquad (2.6)
\end{aligned}
$$

where $\Delta$ is the rate of pollution damage in Foreign.

If the Home government allows private participation in the port sector, the environment institution imposes a pollution tax on the private port owner. The government charges $t$ per unit of emissions generated from port operations, to maximize the national welfare. The components of welfare include consumer surplus, producer's profit, port profit, tax revenue, and the pollution damages. The pollution taxes paid by the private entity is equal to the tax revenue that the government collects. Therefore, those two parts cancel out, and the welfare is equivalent to that in equation (2.5).

Similarly, if the Foreign private entity owns the port, the Foreign environment institution regulates the port pollution by charging a pollution tax $T$. The government maximizes the national welfare as in equation (2.6).

### 2.2.4 Port

If the Home government owns the port in Home country, the port profit equals to $f * (y + Y)$ and accounts for the Home welfare. If the port in Foreign country is nationalized, it makes the profit of $F * (y + Y)$ which contributes to the Foreign national welfare.

If the Home port is privatized, given the pollution tax rate $t$, the private port owner determines the port usage fee $f$ to maximize its profit. The private port profit in Home can be written as

$$r = (f - t) * (y + Y). \tag{2.7}$$

Likewise, the Foreign private port owner charges $F$ for cargo services to maximize its profit

$$R = (F - T) * (y + Y). \tag{2.8}$$

With the responsibilities of all the players, we design a four-stage game to find the optimal port policy.

Stage 1: Each government decides the ownership of its port, nationalization or privatization.

Stage 2: Given the simultaneous port ownership structures, each government establishes the port pollution tax to maximize the country's welfare.

Stage 3: Given the pollution taxes, each port owner determines the port usage fee to maximize its port profit.

Stage 4: Given the port usage fees, each manufacturing firm decides its output to maximize the firm's profit.

It is worth noting that, in the case of a nationalized port, the second and the third stages merge into one. The game is simplified to be three-stage. Given the nationalized port ownership, the governmental transport institution sequentially issues a "two-in-one" port charge with the intention of maximizing the national welfare.

There are four cases of the simultaneous port structures: both ports are not privatized, both are privatized, only the Home or Foreign port is privatized. We use $NN$, $PP$, $PN$, and $NP$ to denote each case. As in Matsushima and Takauchi (2014), the first letter indicates whether the Home port is non-privatized, while the second letter is used for the Foreign port's ownership. We apply the backward induction in each case to figure out the subgame Nash equilibrium.

## 2.3 Stage Game

In this section, we specify how to use backward induction to derive the equilibrium values under each subgame. Then, we conclude the optimal port policy in small and big countries.

### 2.3.1 Backward Induction

According to the backward induction, the first step is to find each producer's productions that are determined in the final stage of the game. Taking the port charges as given. the Home manufacturing firm decides the quantities of production, $x$ and $y$, to maximize its profit $\pi$ in equation (2.3). The Foreign producer simultaneously determines its productions, $X$ and $Y$, to maximize the profit $\Pi$ as shown in equation (2.4). Therefore, the first-order condition of $\pi$ with respect to $x$, $y$, and $\Pi$ with respect to $X$, $Y$ gives us the best response functions of productions which are

$$x_{BR} = \frac{b}{3}(a + f + F + \tau),\ y_{BR} = \frac{1-b}{3}(A - 2f - 2F - 2\tau), \tag{2.9}$$

$$X_{BR} = \frac{1-b}{3}(A + f + F + \tau),\ Y_{BR} = \frac{b}{3}(a - 2f - 2F - 2\tau). \tag{2.10}$$

The second step is to figure out the port charges, taking the pollution taxes as given. If a port is privatized, its private owner chooses the port usage fee to maximize the port profit. The third step is to calculate the pollution tax issued by each environment department.

If a port is nationalized, there is only one more step of backward induction. That is, the governmental transport institution sets up the port charge, taking into account regulating the port pollution. By so doing, the transport department aims to maximize the national welfare. We explain the steps of derivation in each of the following subgames.

### 2.3.2 Subgames

***NN***: When both ports are nationalized, each governmental transport department simultaneously sets the port usage fee $f$ and $F$ to maximize the national welfare in equation (2.5) and (2.6) respectively. We plug the best response of productions in equations (2.9) to (2.10) back to the welfare functions. The first-order condition of a country's welfare with respect to its port charge gives the best response of port charge in each country:

$$f_{BR}^{NN} = \frac{3ab + Ab - A - 5bF - 5b\tau + 6\delta + 2F + 2\tau}{5b + 4}, \tag{2.11}$$

$$F_{BR}^{NN} = \frac{ab + 3Ab - 3A - 5bf - 5b\tau - 6\Delta + 3f + 3\tau}{5b - 9}. \tag{2.12}$$

Then, with the best response functions of port charges, we can calculate out the port charges at equilibrium. Once we plug the equilibrium port charges back to the best response of productions, it gives the equilibrium outputs. Finally, with the equilibrium port charges and outputs, we can calculate out the national welfare in each country at equilibrium.

***PP***: When both ports are privatized, each private port owner chooses the port charge to maximize the individual port profit, taking the pollution taxes as given. We replace the productions in port profit functions (2.7) and (2.8) with their best responses. Then, we take the first-order condition of the Home port profit $\pi$ with respect to the private port charge $f$. By symmetry, we maximize the Foreign port profit $\Pi$ with respect to the Foreign port charge $F$. It gives the best response of private port charges as

$$f_{BR}^{PP} = \frac{1}{6}[ab + A(-b) + A + 4t - 2\tau - 2T], \tag{2.13}$$

$$F_{BR}^{PP} = \frac{1}{6}[ab + A(-b) + A - 2t - 2\tau + 4T]. \tag{2.14}$$

The next step is to substitute the best response of productions and port charges into the welfare functions (2.5) and (2.6). The environment institution in each government sets up the pollution tax to maximize the national welfare. Therefore, we take the first-order derivative of welfare, $w$ and $W$, with respect to the pollution tax, $t$ and $T$, respectively. We obtain the best response of pollution taxes as follows:

$$t_{BR}^{PP} = \frac{a(11 - 5b)b + A\left(5b^2 - 4b - 1\right) - 5b\tau - 5bT + 18\delta + 2\tau + 2T}{5b + 16}, \tag{2.15}$$

$$T_{BR}^{PP} = \frac{a(6 - 5b)b + A\left(5b^2 + b - 6\right) - 5bt - 5b\tau - 18\Delta + 3t + 3\tau}{5b - 21}. \tag{2.16}$$

Using the best response of taxes, we can derive their equilibrium values. Substituting the equilibrium taxes into the port charges in (2.13) and (2.14), we can calculate out the port usage fees at equilibrium. With the equilibrium port fees, we can plug them back into the production functions (2.9) to (2.10) to derive the equilibrium productions. Then, we can plug these equilibrium variables into the equations (2.5) and (2.6) to derive the equilibrium national welfare.

***PN***: If only the Home port is privatized, the Home environment institution determines the port pollution tax in the second stage of the game. Then, the Home private entity can set up the port usage fee. In contrary, the nationalized Foreign port has the "two-in-one" port charge which is chosen by the Foreign transport department.

Although the governments determine the Home pollution tax and the Foreign charge, we specify the order of movements taken by different executives. Since the Game Theory is a matter of commitment, we assume the environment department executes before the transport institution does. Therefore, in the case of only one port is privatized, the game is, strictly speaking, extended to be five-stage.

To be specific, given the port ownership, in the second stage of the game, the environment department in the country that privatizes its port chooses the pollution tax. In the third stage, the other country which nationalizes its port has the transport department to determine the "two-in-one" port charge. In the fourth stage, given the pollution tax, the private port owner sets its port usage fee. In the end, the manufacturing firms decide their productions, facing the port charges in both countries.

In this context, the next step of backward induction under $PN$ is to derive the Home port charge that maximizes the private port profit. Using the best response of productions in equations (2.9) to (2.10), we take the first-order condition of Home port profit $w$ with respect to the port usage fee $f$. It gives the best response of Home private port charge which is

$$f_{BR}^{PN} = \frac{1}{4}(ab + A(-b) + A - 2F + 2t - 2\tau). \tag{2.17}$$

The following maximization problem becomes to maximize the Foreign welfare with respect to the Foreign "two-in-one" port charge. Substituting the best response of the Home port fee and the productions into (2.6), we derive the first-order derivative of $W$ with respect to $F$. That is, the best response of the Foreign port charge is

$$F_{BR}^{PN} = \frac{a\,(b - 5b^2) + 5A\,(b^2 + 2b - 3) - 2(5bt + 5b\tau + 12\Delta - 9t - 9\tau)}{10b - 42}. \tag{2.18}$$

The last step is to figure out the Home pollution tax. Given the best response of both port charges and the productions, the Home environment institution sets the pollution tax that maximizes the Home national welfare in equation (2.5). The first-order condition gives us the equilibrium Home pollution tax.

With the equilibrium value of Home tax, we can plug it back into the best response function (2.18) of the Foreign port charge, which gives the equilibrium Foreign fee. Accordingly, we can derive the equilibrium Home private port charge by using the equilibrium Foreign charge to the best response function (2.17). Substituting the equilibrium pollution tax and port charges into the best response of productions gives the equilibrium amounts of goods. Therefore, the equilibrium welfare in each country can be derived with the equilibrium variables.

***NP***: Symmetric to the case $PN$, we first derive the Foreign private port charge that maximizes the Foreign port profit. Plugging the production functions (2.9) to (2.10) into $\Pi$, the first-order condition of Foreign port profit with respect to the port charge $F$ gives the best response:

$$F_{BR}^{NP} = \frac{1}{4}(ab + A(-b) + A - 2f - 2\tau + 2T). \tag{2.19}$$

Substituting the best response of Foreign port fee and the productions into the Home welfare function (2.5), we derive the best response of Home "two-in-one" port charge by taking the first-order condition of $w$ with respect to $f$. It gives

$$f_{BR}^{NP} = \frac{-5a(b-4)b + A\,(5b^2 - 9b + 4) - 2(5b\tau + 5bT - 12\delta + 4\tau + 4T)}{10b + 32}. \tag{2.20}$$

Using the best response of the port charges and the productions, we maximize the Foreign welfare $W$ in equation (2.6) with respect to Foreign pollution tax $T$. It gives the equilibrium Foreign port pollution tax. Then, we can plug this equilibrium value into $f_{BR}^{NP}$ and calculate the equilibrium Home port charge. Substituting the equilibrium pollution tax and the Foreign charges into $F_{BR}^{NP}$ gives us the equilibrium Foreign port fee. To obtain the equilibrium productions, we replace the port charges with their equilibrium values in equations (2.9) to (2.10). In the end, the national welfare at equilibrium can be derived by using the equilibrium variables.

### 2.3.3 Results

Since we focus on the effect of population size in this paper, we assume the unit shipping cost $\tau$ of the third-party carrier is equal to zero. Without losing generosity, we also assume the port pollution in each country leads to the same degree of welfare damage, which means $\delta = \Delta$. In addition, we assume the initial national incomes to be the same, $a = A$.

With these assumptions, to have all the variables being positive in each case, we find the relationship between the initial income and the pollution damage rate. The intersection that applies to all the cases is that the initial income must be greater than 8 times of the damage rate and smaller than or equal to 22 times of it. Therefore, we let the pollution damage rate be one and the initial income be 9. Such an assignment of values simplifies the derivation in the next numerical experiment and does not lose the generosity.

As a result, we can figure out the equilibrium values under all cases by applying the numerical values of the coefficients. Table 2.1 shows the equilibrium productions in each case of port ownership. Table 2.2 shows the equilibrium port charges and pollution taxes. Moreover, Table 2.3 represents the national welfare in each country at equilibrium.

Table 2.1: Subgame equilibrium productions

| | (x) | (y) | (X) | (Y) |
|---|---|---|---|---|
| NN | $x^{NN} = \frac{31b}{7}$ | $y^{NN} = \frac{1-b}{7}$ | $X^{NN} = \frac{31-31b}{7}$ | $Y^{NN} = \frac{b}{7}$ |
| PN | $x^{PN} = \frac{b(45b-197)}{2(5b-22)}$ | $y^{PN} = \frac{b-1}{5b-22}$ | $X^{PN} = \frac{-45b^2+242b-197}{2(5b-22)}$ | $Y^{PN} = \frac{-b}{5b-22}$ |
| NP | $x^{NP} = \frac{b(45b+152)}{2(5b+17)}$ | $y^{NP} = \frac{1-b}{5b+17}$ | $X^{NP} = \frac{-45b^2-107b+152}{2(5b+17)}$ | $Y^{NP} = \frac{b}{5b+17}$ |
| PP | $x^{PP} = \frac{85b}{19}$ | $y^{PP} = \frac{1-b}{19}$ | $X^{PP} = \frac{85-85b}{19}$ | $Y^{PP} = \frac{b}{19}$ |

Table 2.2: Subgame equilibrium port charges and pollution taxes

| | (t) | (f) | (T) | (F) |
|---|---|---|---|---|
| NN | N/A | $f^{NN} = \frac{13+34b}{14}$ | N/A | $F^{NN} = \frac{47-34b}{14}$ |
| PN | $t^{PN} = \frac{45b^2-178b-89}{4(5b-22)}$ | $f^{PN} = \frac{45b^2-178b-95}{4(5b-22)}$ | N/A | $F^{PN} = \frac{-45b^2+268b-295}{4(5b-22)}$ |
| NP | $f^{NP} = \frac{45b^2+178b+72}{4(5b+17)}$ | N/A | $T^{NP} = \frac{-45b^2-88b+222}{4(5b+17)}$ | $F^{NP} = \frac{-45b^2-88b+228}{4(5b+17)}$ |
| PP | $t^{PP} = \frac{88b+37}{38}$ | $f^{PP} = \frac{44b+20}{19}$ | $T^{PP} = \frac{125-88b}{38}$ | $F^{PP} = \frac{64-44b}{19}$ |

Table 2.3: Subgame equilibrium welfare

| | (w) | (W) |
|---|---|---|
| NN | $w^{NN} = \frac{1}{98}(1 + 2978b)$ | $W^{NN} = \frac{1}{98}(2979 - 2978b)$ |
| PN | $w^{PN} = \frac{1}{8(5b-22)}(1215b^2 - 5346b - 1)$ | $W^{PN} = \frac{1}{8(5b-22)^2}(117633 - 171077b + 59535b^2 - 6075b^3)$ |
| NP | $w^{NP} = \frac{1}{8(5b+17)^2}(6075b^3 + 41310b^2 + 70232b + 16)$ | $W^{NP} = \frac{1}{8(5b+17)}(-1215b^2 - 2916b + 4132)$ |
| PP | $w^{PP} = \frac{2}{361}(5483b + 1)$ | $W^{PP} = \frac{2}{361}(5484 - 5483b)$ |

By comparing the welfare levels, we can figure out the optimal port ownership for small and big countries. First of all, we suppose Home is the small country which has the population, $b$, less than the other country's, $1 - b$. That is, $0 < b < 0.5$. If the big country, Foreign, nationalizes its port, the small country can obtain higher welfare under $NN$. If the big country allows the private entity to own the port, the optimal port ownership in the small country depends on its population size. To be specific, when $0 < b < 0.4$, nationalization brings higher welfare than privatization. However, if $0.4 < b < 0.5$, then the small country should privatize the port.

Secondly, we suppose Home is the large country. That is, $0.5 < b < 1$. If the government in the small country owns the port, the large country gains greater welfare by port nationalization. If the small country privatizes its port, the large country should also privatize the port for the sake of higher welfare.

In summary, the Home country should nationalize its port, as long as the other country chooses port nationalization. If the other port is privatized, the Home country with a population less than 40% of the world total population should nationalize its port. Otherwise, to nationalize the Home port can generate higher welfare.

**Proposition 2.3.1** *The subgame Nash Equilibrium is to have both ports nationalized. Only when the population in the small country accounts for about 40% to a half of the world total can $PP$ be another subgame Nash Equilibrium.*

If the government owns a port, the port usage fee facing the producers is lower than the charge set by a private owner. Because the governmental institution only aims to maximize the welfare when it formulates the port charge with the consideration of pollution control. If the private sector owns the port, how much it charges for its port services is influenced by the pollution tax imposed on it. The pollution tax is the one that maximizes the welfare. When the private owner chooses the port charge to maximize the port profit, it takes into account the welfare-maximizing pollution tax.

In other words, the private port charge is based on the maximization of port profit as well as the national welfare. As a result, the port services under privatization are more expensive than the services provided by a nationalized port.

Therefore, when both ports are nationalized, the producers pay the lowest fees for port services and make the largest amount of exports. Although it benefits the welfare, the port pollution generated from handling the commodities becomes the most.

## 2.4 Transfer of Port Ownership

In the preceding section, we analyze the four subgames of port ownership structures. In this section, we further discuss whether the government should allow the transfer of port ownership to the foreigners. We proceed our analysis from the perspective of the Home country. On the basis that the Home government allows the Home private entity to own the port, is it beneficial for the country if the private owner sells out the port to the foreigners?

We mainly focus on the cases where the Home port is privatized, $PN$ and $PP$. If the Home government allows the private sector to sell out the port, $PN$ becomes $FNB$ where the Foreign government owns both ports, and $PP$ turns out to be $FPB$ that the Foreign private entity owns both ports. We compare the results of the original cases with their extensions respectively. Then, we conclude the conditions where a transfer of port ownership is good for the country.

### 2.4.1 FNB

Suppose the Home government let the private firm own the Home port and the private owner is allowed to sell out the port to the Foreign government. When the Foreign port is nationalized, the Home private port owner sells the port to the Foreign government. In the next stage of the game, the Home environment institution establishes a pollution tax, $t$, to regulate the emissions generated from the port located in the Home territory. Given the tax rate, the Foreign transport department determines the charges of both ports, $f$ and $F$. Finally, the producers decide their productions, given the port usage fees.

Therefore, in the backward induction, the first step is to derive the best response of productions. It is the same as what we do for the subgames in equations (2.9) to (2.10).

The second step is to find the port charges that the Foreign transport department sets to maximize its national welfare. We assume the Home private port owner does not sell out the port unless it receives the payment not less than what it earns under $PN$. Considering the payment to the Home private firm, the maximization problem of the Foreign government becomes to maximize the welfare which is

$$\begin{aligned} W^* &= \left[\int_0^{X+y} (A - \frac{q}{1-b})\, dq - P * (X+y)\right] + \Pi + (f-t) * (y+Y) + F * (y+Y) \\ &\quad - \Delta * (y+Y) - \frac{3}{2(5b-22)^2} \\ &= \frac{1}{2(1-b)}(X+y)^2 + \Pi + (f+F-t-\Delta) * (y+Y) - \frac{3}{2(5b-22)^2}, \end{aligned} \tag{2.21}$$

where the last item is the Home port profit under $PN$ according to the the equation (2.7). We take the first-order condition of $W^*$ with respect to $f$ and $F$ respectively. It gives the best response of port charges:

$$f_{BR}^{FNB} = \frac{ab + 3Ab - 3A - 5bF - 5b\tau - 6\Delta + 9F - 6t + 3\tau}{5b-9}, \tag{2.22}$$

$$F_{BR}^{FNB} = \frac{ab + 3Ab - 3A - 5bf - 5b\tau - 6\Delta + 9f - 6t + 3\tau}{5b-9}. \tag{2.23}$$

Since the Foreign government owns both ports, the port charges can be taken as a whole. That is, $f + F$ means the total port fees that each exporter needs to pay.

We use $z$ to denote each exporter's total amount of payment to the port owner and it turns out to be equal to

$$z_{BR}^{FNB} = -\frac{-ab - 3Ab + 3A + 5b\tau + 6\Delta + 6t - 3\tau}{5b - 9}. \tag{2.24}$$

The third step is to figure out the Home pollution tax. With the sale of the Home port, the Home national welfare becomes

$$\begin{aligned} w^* &= \left[\int_0^{x+Y} (a - \frac{q}{b})\, dq - p * (x + Y)\right] + \pi + t * (y + Y) - \delta * (y + Y) + \frac{3}{2(5b - 22)^2} \\ &= \frac{1}{2b}(x + Y)^2 + \pi + (t - \delta) * (y + Y) + \frac{3}{2(5b - 22)^2}. \end{aligned} \tag{2.25}$$

Substituting the best response of productions in equations (2.9 to (2.10) and the total port fee in equation (2.24) into $w^*$, we take the first-order derivative of Home welfare with respect to $t$. It gives us the equilibrium Home pollution tax.

Then, we can use the equilibrium pollution tax to calculate the total port charge at equilibrium. The equilibrium port charge can be applied to figure out the equilibrium productions. In the end, we can derive the individual national welfare at equilibrium by substituting the equilibrium variables.

The assumptions and the assigned numerical values of the coefficients are also applicable in this case. The simplified equilibrium values under $FNB$ are shown in the following tables: Table 2.4 shows the equilibrium productions. Table 2.5 shows the equilibrium port charge and pollution tax in this case. The equilibrium welfare is shown in Table 2.6.

If Home is a small country, from the perspective of national welfare, the Home private port owner should sell out the port to the large country. It gains the small country the highest welfare in the condition that the large country nationalizes its port. However, to own both ports does not bring about higher welfare in the large country. The welfare under $FNB$ in the large country is even lower than the level under $PN$.

In contrast, if Home is the large country, selling the Home port to the small government makes both countries better off. The welfare in each country reaches a higher level under $FNB$ than $PN$. In doing so, the small country obtains the monopoly power in the port sector.

**Proposition 2.4.1** *If the population in the small country is less than two-thirds of the population in the large country, having both ports owned by the government in the large country is mutually beneficial.*

Table 2.4: Equilibrium productions under $FNB$ and $FPB$

| | (x) | (y) | (X) | (Y) |
|---|---|---|---|---|
| FNB | $x^{FNB} = \frac{b(45b-89)}{10(b-2)}$ | $y^{FNB} = \frac{b-1}{5(b-2)}$ | $X^{FNB} = \frac{-45b^2+134b-89}{10(b-2)}$ | $Y^{FNB} = -\frac{b}{5(b-2)}$ |
| FPB | $x^{FPB} = \frac{58b}{13}$ | $y^{FPB} = \frac{1-b}{13}$ | $X^{FPB} = \frac{58-58b}{13}$ | $Y^{FPB} = \frac{b}{13}$ |

Table 2.5: Equilibrium charges under $FNB$ and $FPB$

| | (t) | (T) | (z) |
|---|---|---|---|
| FNB | $t^{FNB} = \frac{45b^2-70b-41}{20(b-2)}$ | N/A | $z^{FNB} = \frac{3(15b-29)}{10(b-2)}$ |
| FPB | $t^{FPB} = \frac{28+61b}{26}$ | $T^{FPB} = \frac{83-61b}{26}$ | $z^{FPB} = \frac{57}{13}$ |

Table 2.6: Equilibrium charges under $FNB$ and $FPB$

| | (w) | (W) |
|---|---|---|
| FNB | $w^{FNB} = \frac{205335b^2-410610b-289}{6760(b-2)}$ | $W^{FNB} = \frac{-1026675b^3+5133075b^2-8213045b+4107021}{33800(b-2)^2}$ |
| FPB | $w^{FPB} = \frac{3706748b+1951}{122018}$ | $W^{FPB} = \frac{1853301-1853374b}{61009}$ |

### 2.4.2 FPB

In the case of $PP$, if the Home private firm sells the port to the Foreign private firm, then both ports are privatized by the Foreign private sector. In the next stage of the game, the governmental environment institution in each country sets up the port pollution rate to control the emissions from the port within its territory. Given the pollution taxes, the Foreign private owner determines the charges at both ports. The last stage is to have the producers decide their productions.

In the backward induction, we first derive the best response of productions, which is the same as the equations (2.9) to (2.10). The next step is to find out the port charges that maximize the Foreign owner's joint port profit. The joint profit is the sum of $r$ and $R$ in equations (2.7) and (2.8). We take the first-order condition of the joint profit with respect to $f$ and $F$ respectively. It gives the best response of port charges as

$$f_{BR}^{FPB} = \frac{1}{4}(ab + A(-b) + A - 4F + 2t - 2\tau + 2T), \tag{2.26}$$

$$F_{BR}^{FPB} = \frac{1}{4}(ab + A(-b) + A - 4f + 2t - 2\tau + 2T). \tag{2.27}$$

Since the Foreign firm owns both ports, we take the sum of the port fees as a total charge of cargo services. Let $z$ denote the sum of $f$ and $F$. It implies the total port charge that the producers need to pay. Given this, the best response of the total charge is

$$z_{BR}^{FPB} = \frac{1}{4}(ab + A(-b) + A + 2t - 2\tau + 2T). \tag{2.28}$$

The last step of backward induction is to derive the pollution tax rate in each country that maximizes the national welfare. With a purchase of the Home port, the

Foreign welfare becomes to be

$$
\begin{aligned}
W^{**} &= \left[\int_0^{X+y} (A - \frac{q}{1-b})\, dq - P * (X+y)\right] + \Pi + r + R + T * (y+Y) \\
&\quad - \Delta * (y+Y) - \frac{3}{722} \\
&= \frac{1}{2(1-b)}(X+y)^2 + \Pi + (f + F - t - \Delta) * (y+Y) - \frac{3}{722}, \qquad (2.29)
\end{aligned}
$$

where the last term is the port profit obtained by the Home private port owner under $PP$.

Substituting the best response of productions and total port fee into $W^{**}$, we take the first-order condition of Foreign welfare with respect to $T$. It generates the best response of Foreign pollution tax which is

$$
T_{BR}^{FPB} = \frac{ab(5b-13) + A\left(-5b^2 + 2b + 3\right) + 2(5bt + 5b\tau + 12\Delta + 3t + 3\tau)}{18 - 10b}. \qquad (2.30)
$$

Correspondingly, the Home welfare under the circumstance of selling the port to the Foreign private firm is equal to

$$
\begin{aligned}
w^{**} &= \left[\int_0^{x+Y} (a - \frac{q}{b})\, dq - p * (x+Y)\right] + \pi + t * (y+Y) - \delta * (y+Y) + \frac{3}{722} \\
&= \frac{1}{2b}(x+Y)^2 + \pi + (t - \delta) * (y+Y) + \frac{3}{722}. \qquad (2.31)
\end{aligned}
$$

The first-order condition of $w^{**}$ with respect to $t$ gives the best response of Home pollution tax which is

$$
t_{BR}^{FPB} = \frac{-5a(b-4)b + A\left(5b^2 - 9b + 4\right) - 2(5b\tau + 5bT - 12\delta + 4\tau + 4T)}{10b + 32}. \qquad (2.32)
$$

Therefore, using the best response of pollution taxes, we can derive their equilibrium values. Then, we can calculate the equilibrium total port charge and the productions step by step. The assumptions and the numerical values of the coefficients are also valid under $FPB$. We simplified the equilibrium values and show them in the Table 2.4 to Table 2.6.

By comparing the results of $PN$ and $FPB$, we come to the conclusion that, regardless of Home population size, selling the Home port to the Foreign private firm is always good for the Home welfare. However, it lowers down the Foreign welfare level.

## 2.5 Conclusion

In this paper, we introduce the environmental regulation of the pollution from port cargo handling into the international duopoly trade model. The governments control the port emissions in the form of a pollution tax. The subgame Nash Equilibrium is to have both ports owned by the governments. We further extend our analysis to the cases of transferring the private port ownership to the other country. Although it induces greater national welfare to the country whose port is sold, the country as the port buyer is worse off. The monopoly power of the port sector does not bring about higher national welfare. The exception is to have the government in the small country own both ports. In that case, both countries can be better off.

Since we mainly focus on the effect of population endowment on the optimal port ownership, we simplify the assumptions of the coefficients and set symmetric values. In the future study, more comprehensive analysis of the interaction between different economic agents should shed light on the selection of port policy.

CHAPTER 3

# INTERNATIONAL TRANSFER OF PORT OWNERSHIP

## 3.1 Introduction

In the paper, we concentrate on two primary questions: Is it good for the country to privatize its port? To privatize a port, who should be the private port owner? The domestic private entity or the foreign firm?

First, there is no unequivocal agreement on the effect of private port ownership on business efficiency. Some scholars believe that more private involvement in the port sector can enhance the port efficiency (Tongzon and Heng, 2005; Gonzalez and Trujillo, 2008; Cheon et al., 2010). However, some empirical study indicates that the type of ownership does not act as a significant factor of production or cost efficiency (Liu, 1995). For example, both Singapore and Hong Kong have high port efficiency, though they are under different types of ownership (Trujillo and Nombela, 1999).

Therefore, we compare the performance of different port ownership structures from the perspective of national welfare in this study. We start from the basic port ownership: nationalization and privatization. We do not consider other policy issue or regulation on the port sector, which means we do not separate the authority and operating agents of a port. That is, we take the port area in each country as a whole. So if a port is nationalized, the government of the country where the port locates serves as the port owner and no private participation is allowed. If the government privatizes its port, the private entity is the port owner and the government no longer interferes with the port activities.

Second, as the report by the United Nations Conference on Trade and Development (UNCTAD) shows, some private newcomers have entered the overseas port market and increased the competition in the port sector, such as China's international port acquisitions [1], in recent years. China has taken over six of the top ten largest global cargo throughput ports.

It has been controversial whether the port, as a strategic industry, should be run by foreign companies. For example, the Chinese company, Landbridge Group, purchased Panama's largest port, Margarita Island Port, in May 2016. In addition, people who encourage port privatization believe that the U.S. ports should be run by U.S. companies. However, the fact is a vast majority of U.S. ports are leased and operated by foreign companies. To provide evidence to the discussion of port ownership by foreign agents, we simulate the sale and purchase of port as the transfer of private ownership in the extension part of the paper.

To be consistent with the models in the other chapters in this dissertation, our theoretical setting is on the basis of the reciprocal international duopoly model. The population size is the only factor of influence that we consider. We analyze the three-stage games under different types of simultaneous port ownership. Then, we figure out the Nash Equilibrium ownership structures by weighing up the corresponding welfare levels. In the end, we base on the cases with privatized port(s) and introduce the transfer of port ownership by private firm to the private port owner or government in the other country.

The remainder of this paper is organized as follows: Section 3.2 introduces the basic model setup. Section 3.3 explains the three-stage games under each port ownership structure. Section 3.4 analyzes the results of each case and summarizes the equilibrium ownership. Section 3.5 concludes the theoretical findings and gives suggestion on further study.

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[1] For instance, in June 2017, the state-owned China Ocean Shipping (Group) Company (COSCO) had a partnership with the Nortum ports in Spain on the sale and purchase of the container terminals and dry ports.

## 3.2 Model

We develop the theoretical setup based on the international duopoly trade model. We continue with the assumption that Home and Foreign are the only two countries in the world. Each country has a manufacturing firm that produces the homogeneous goods. The producers serve both markets in the manner of Cournot Competition. The price of goods in each country is given as

$$p = a - \frac{1}{b}(x + Y), \tag{3.1}$$

$$P = A - \frac{1}{1-b}(X + y). \tag{3.2}$$

We use lower case letters to denote the indicators in Home country, while upper cases for the counterparts in Foreign. Therefore, $p$ is the price of goods in Home and $P$ is the price in Foreign. The positive constants $a$ and $A$ indicate each initial national income. $x$ and $y$ are Home producer's productions which are consumed by the domestic customers and exported to the Foreign market. Analogously, the Foreign manufacturing firm produces $X$ for domestic consumption and exports $Y$ to the Home market.

We keep using the population ratio as the measurement of country size. $b$ is the ratio of Home population endowment to the unit world population. $1 - b$ is the Foreign population ratio which is obtained by comparing the number of people in Foreign with the global population. In doing so, no matter how the distribution of population changes between the two countries, the total amount of people worldwide remains the same.

For each producer, its total profit consists of two parts each of which comes from domestic and the overseas markets. To be specific, the Home manufacturing firm earns $px$ of Home consumption and the Foreign firm gains $PX$ in its domestic market, where we assume zero marginal cost of production.

We assume each country has a port. Since the exports require the use of both ports in departure and arrival countries, each port owner sets up a port usage fee as the charge of cargo handling services. Suppose the per-unit Home port fee is $f$ and the Foreign port charges $F$ per unit of goods. There is no price discrimination between the exporters from different origins [2]. Therefore, the Home producer makes the export profit of $(P - \tau - f - F)y$, where $\tau$ is the per-unit transport fee charged by the monopolistic transporter from the third party. Likewise, the export business brings out a profit of $(p - \tau - f - F)Y$ to the Foreign producer.

Therefore, let $\pi$ and $\Pi$ denote the profit of the Home and Foreign firms respectively. Then, we have the producers' total profit functions which are

$$\pi = px + (P - \tau - f - F)y, \tag{3.3}$$

$$\Pi = PX + (p - \tau - f - F)Y. \tag{3.4}$$

Correspondingly, each port can make a profit by providing the cargo services for the exporters. Let $r$ be the Home port's profit and $R$ be the profit of the Foreign port. With zero marginal cost of port services, we have the port profit functions as

$$r = f * (y + Y), \tag{3.5}$$

$$R = F * (y + Y). \tag{3.6}$$

Taking into account the above agents, the national welfare in each country consists of the consumer surplus, producer's profit, and the port profit. Different from the setting of governmental institutions in Chapter 2, we do not distinguish the executives

[2] It obeys the General Agreement on Tariffs and Trade (GATT) that requires no different treatment between domestic and foreign agents. See also, Czerny et al. (2011), Matsushima and Takauchi (2014).

in a government but take the government as a whole. Therefore, the Home welfare $w$ can be written as

$$\begin{aligned} w &= \left[\int_0^{x+Y} (a - \frac{q}{b})\ dq - p * (x+Y)\right] + \pi + f * (y+Y) \\ &= \frac{1}{2b}(x+Y)^2 + \pi + f * (y+Y). \end{aligned} \tag{3.7}$$

Similarly, the national welfare in the Foreign country is equal to

$$\begin{aligned} W &= \left[\int_0^{X+y} (A - \frac{q}{1-b})\ dq - P * (X+y)\right] + \Pi + F * (y+Y) \\ &= \frac{1}{2(1-b)}(X+y)^2 + \Pi + F * (y+Y), \end{aligned} \tag{3.8}$$

We assume the optimality objective of a port is determined by the role of its owner. If a port is nationalized, the government as the port owner aims at maximizing the national welfare. However, if the private entity is the port owner, its objective is to maximize the port profit.

## 3.3 Stage Game

We build up the three-stage game as follows: First, each government simultaneously chooses whether private involvement in its port sector is allowed or not. That is, to nationalize or privatize its port. Second, each port owner simultaneously determines its port charge to realize its optimality objective. Third, each producer, taking the port usage fees, simultaneously chooses its outputs.

There are four cases of simultaneous port ownership structures: both ports are not privatized, both are privatized, only the Home or Foreign port is privatized. We use $NN$, $PP$, $PN$, and $NP$ to denote the cases. We solve the game under each ownership structures by backward induction.

In order to simulate the transfer of port ownership, we extend the cases where the Home port is owned by its private entity to the situations where the private owners are allowed to sell out the port to the Foreign government or Foreign private sector. Then, we can evaluate whether it is good to authorize the transfer of port ownership. We use $FNB$ to denote the extension of the case $PN$, as the Foreign government is taking over the Home private port. Similarly, $FPB$ indicates that the Foreign private port owner possesses the ownership of both ports.

According to backward induction, the first step is to derive the number of outputs that manufacturing firms simultaneously produce in the last stage of the game. Taking the port charges as given, we maximize the Home producer's profit $\pi$ in equation (3.3) with respect to the Home domestic consumption $x$ and Home exports $y$ respectively. Meanwhile, we take the first-order condition of the Foreign producer's profit $\Pi$ in equation (3.4) with respect to the Foreign outputs $X$ and $Y$. It gives us the best response of productions as

$$x_{BR} = \frac{b}{3}(a + f + F + \tau),\ y_{BR} = \frac{1-b}{3}(A - 2f - 2F - 2\tau), \tag{3.9}$$

$$X_{BR} = \frac{1-b}{3}(A + f + F + \tau),\ Y_{BR} = \frac{b}{3}(a - 2f - 2F - 2\tau). \tag{3.10}$$

With the productions in equations (3.9) to (3.10), we can derive out the port charges that port owners determine in the second stage of the game. If a port is owned by the private entity, we maximize the port profit in equation (3.5) or (3.6) with respect to its own port usage fee, $f$ in Home or $F$ in Foreign. Otherwise, if the government owns its port, we maximize the national welfare in equation (3.7) or (3.8) with respect to individual port charge.

### 3.3.1 NN

If the government in each country owns its port, its port usage fee is the one that maximizes the national welfare. Therefore, substituting the best response of productions into equation (3.7), we take the first-order condition of the Home welfare $w$

with respect to the Home port charge $f$. Since the Foreign government sets up its port fee simultaneously in the same stage of the game, we plug the best response of productions into equation (3.8) and maximize the Foreign welfare $W$ with respect to $F$. It generates the best response of the port charges which is

$$f_{BR}^{NN} = \frac{3ab + Ab - A - 5bF - 5b\tau + 2F + 2\tau}{5b + 4}, \tag{3.11}$$

$$F_{BR}^{NN} = \frac{ab + 3Ab - 3A - 5bf - 5b\tau + 3f + 3\tau}{5b - 9}. \tag{3.12}$$

With the best response of the port charges, we can calculate out their equilibrium values. Substituting the equilibrium port charges into the best response of productions in equation (3.9) to (3.10), we have the equilibrium outputs when both ports are nationalized. In the end, with all these equilibrium values, we can calculate the corresponding national welfare in each country.

Since we are interested in the relationship between optimal port ownership and the national population endowment, we assume the countries have the same initial income $a = A$. To simplify the following calculation, we suppose their values are equal to one without losing generosity. In addition, we assume the per-unit transport cost is zero.

Given the numerical values of the exogenous variables, the equilibrium port usage fee in each country is equal to

$$f^{NN} = \frac{6b - 1}{14}, \ F^{NN} = \frac{5 - 6b}{14}. \tag{3.13}$$

Then, we can calculate the values of outputs at equilibrium and the national welfare thereafter. The equilibrium results can be found in Table 3.1 and Table 3.2.

### 3.3.2 PN

Suppose the Home government allows the private entity to participate in port activities and own the Home port. Simultaneously, the Foreign government chooses to nationalize its port. The Home private port owner's objective is to maximize its port profit. Therefore, in the second step of backward induction, we take the first-order condition of the Home port profit $\pi$ in equation (3.5) with respect to the port charge $f$. It gives the best response of the Home port usage fees which is

$$f_{BR}^{PN} = \frac{1}{4}(ab + A(-b) + A - 2F - 2\tau). \tag{3.14}$$

Meanwhile, we maximize the Foreign welfare $W$ with respect to $F$ to have the best response of the Foreign port charge. As long as the Foreign port is nationalized, the best response of its usage fee is the same as what we derive under $NN$. Therefore, $F_{BR}^{PN}$ is equal to $F_{BR}^{NN}$ in equation (3.12).

Then, with the best response functions, we can calculate the equilibrium port charges. The outputs at equilibrium can be figured out after that, as well as the national welfare levels. Considering the numerical values of the initial income and transport cost, we simplified the equilibrium port charges to be

$$f^{PN} = -\frac{3(b+1)}{10(b-3)}, \; F^{PN} = -\frac{11b-9}{10(b-3)}. \tag{3.15}$$

The corresponding equilibrium productions and national welfare are shown in Table 3.1 and 3.2.

### 3.3.3 FNB: Extension of PN

Same as the case $PN$, the governments choose the port ownership simultaneously in the first stage of the game. Furthermore, we assume the Home private port owner is allowed to sell out the port to the Foreign government who is in charge of the Foreign port sector. Selling out the Home port brings the Home private firm a revenue no less than what it earns under $PN$ where there is no transfer of port ownership. The profit of Home private port owner under $PN$ is equal to $\frac{3(b+1)^2}{50(b-3)^2}$, calculated by using the equilibrium Home port charge in equation (3.15) and bilateral exports shown in Table 3.1.

The next step of backward induction is to find the port charges which are determined by the Foreign government to maximize the Foreign welfare. Given the purchase of Home port, the Foreign welfare becomes

$$\begin{aligned} W^* &= \left[\int_0^{X+y} (A - \frac{q}{1-b})\ dq - P*(X+y)\right] + \Pi + (f+F)*(y+Y) - \frac{3(b+1)^2}{50(b-3)^2} \\ &= \frac{1}{2(1-b)}(X+y)^2 + \Pi + (f+F)*(y+Y) - \frac{3(b+1)^2}{50(b-3)^2}. \qquad (3.16) \end{aligned}$$

Correspondingly, the Home welfare is now written as

$$\begin{aligned} w^* &= \left[\int_0^{x+Y} (a - \frac{q}{b})\ dq - p*(x+Y)\right] + \pi + \frac{3(b+1)^2}{50(b-3)^2} \\ &= \frac{1}{2b}(x+Y)^2 + \pi + \frac{3(b+1)^2}{50(b-3)^2}. \qquad (3.17) \end{aligned}$$

Therefore, substituting the productions in equations (3.9) to (3.10) into $W^*$, we take the first-order condition of the Foreign welfare with respect to $f$ and $F$ respectively. It gives us the best response of port charges as

$$f_{BR}^{FNB} = \frac{ab + 3Ab - 3A - 5bF - 5b\tau + 9F + 3\tau}{5b-9}, \qquad (3.18)$$

$$F_{BR}^{FNB} = \frac{ab + 3Ab - 3A - 5bf - 5b\tau + 9f + 3\tau}{5b-9}. \qquad (3.19)$$

With the symmetric port charges, we can derive the total charge of the cargo services at both ports. Let $z$ be the entire port fee which is equal to $f + F$. Taking the values of coefficients, the equilibrium port charge as a whole is calculated to be

$$z^{FNB} = \frac{4b-3}{5b-9}. \qquad (3.20)$$

Substituting the equilibrium port charge into the best response of productions and the welfare functions, we can calculate their equilibrium values which are demonstrated in Table 3.1 and 3.2.

### 3.3.4 NP

Similar with the case of $PN$, we consider only the Foreign port is privatized. Substituting the best response of productions into equation (3.7) and (3.6), we take the first-order condition of Home welfare $w$ with respect to the Home port charge $f$, and maximize the Foreign port profit $\Pi$ with the Foreign port fee $F$. It generates the best response of Home port charge $f_{BR}^{NP}$ as same as $f_{BR}^{NN}$ in equation (3.11).

To derive the best response of the Foreign port charge, we maximize $\Pi$ with respect to $F$ and it gives

$$F_{BR}^{NP} = \frac{1}{4}(ab + A(-b) + A - 2f - 2\tau). \tag{3.21}$$

The best response functions of port charges can generate the equilibrium values. Given the numerical values of the coefficients, the port fees at equilibrium under $PN$ are calculated to be

$$f^{NP} = \frac{11b - 2}{10(b+2)}, \ F^{NP} = \frac{3(2-b)}{10(b+2)}. \tag{3.22}$$

The equilibrium values of outputs and welfare are shown in Table 3.1 and 3.2 as well.

### 3.3.5 PP

The other port ownership structure is to have both ports operated by the private firms. In this context, we substitute the best response of productions into the private port profits in equations (3.5) and (3.6). Then, we take the first-order condition of $\pi$ with respect to $f$ and $\Pi$ with respect to $F$. It derives the best response of the port charges established by each private port owner, which implies the best response $f_{BR}^{PP}$ is equal to $f_{BR}^{PN}$ in equation (3.14) and $F_{BR}^{PP}$ is equal to $F_{BR}^{NP}$ in equation (3.21).

We can calculate the equilibrium port charges with their best response functions. Taking into account the numerical coefficients, the port charges at equilibrium are equal to

$$f^{PP} = F^{PP} = \frac{1}{6}. \tag{3.23}$$

The equilibrium values of productions and welfare are also presented in Table 3.1 and 3.2.

### 3.3.6 FPB: Extension of PP

We assume both governments choose to privatize their ports in the first stage of the game. Besides, the Home government allows its private port owner to sell out the port to the Foreign private entity. If the Home private firm transfers the port ownership to the Foreign, it obtains a revenue which is as much as what it earns under $PP$. Taking the equilibrium Home port charge in equation (3.23) and the productions shown in Table 3.1 under $PP$, we calculate the profit of Home private port in equation (3.5) to be $\frac{1}{54}$. Therefore, in the context of taking over the Home port, the Foreign private port owner pays for the transaction and faces a new profit which is

$$R^* = (f + F) * (y + Y) - \frac{1}{54}. \tag{3.24}$$

Substituting the best response of exports into $R^*$, we take the first-order condition of the Foreign port profit with respect to port charges $f$ and $F$ respectively. It derives the best response of the port fees which are

$$f_{BR}^{FPB} = \frac{1}{4}(ab + A(-b) + A - 4F - 2\tau), \; F_{BR}^{FPB} = \frac{1}{4}(ab + A(-b) + A - 4f - 2\tau). \tag{3.25}$$

Therefore, we can calculate the total port charge at equilibrium by using their symmetric best response functions. The entire port fee $z$, equal to $f + F$, at equilibrium is

$$z^{FPB} = \frac{1}{4}. \tag{3.26}$$

The corresponding outputs at equilibrium can be calculated with the total port charge and listed in Table 3.1.

Due to the transfer of Home port ownership, the national welfare in each country now becomes to be

$$\begin{aligned} w^{**} &= \left[\int_0^{x+Y} (a - \frac{q}{b})\ dq - p * (x+Y)\right] + \pi + \frac{1}{54} \\ &= \frac{1}{2b}(x+Y)^2 + \pi + \frac{1}{54}, \end{aligned} \tag{3.27}$$

and

$$\begin{aligned} W^{*} &= \left[\int_0^{X+y} (A - \frac{q}{1-b})\ dq - P * (X+y)\right] + \Pi + (f+F) * (y+Y) - \frac{1}{54} \\ &= \frac{1}{2(1-b)}(X+y)^2 + \Pi + (f+F) * (y+Y) - \frac{1}{54}. \end{aligned} \tag{3.28}$$

Therefore, the equilibrium welfare can be calculated using the total port charge and equilibrium productions. The results are shown in Table 3.2.

Table 3.1: Equilibrium productions under each case

| | (x) | (y) | (X) | (Y) |
|---|---|---|---|---|
| NN | $x^{NN} = \frac{3b}{7}$ | $y^{NN} = \frac{1-b}{7}$ | $X^{NN} = \frac{3-3b}{7}$ | $Y^{NN} = \frac{b}{7}$ |
| PN | $x^{PN} = \frac{b(3b-7)}{5(b-3)}$ | $y^{PN} = \frac{b^2-1}{5(b-3)}$ | $X^{PN} = \frac{-3b^2+10b-7}{5(b-3)}$ | $Y^{PN} = \frac{-b^2-b}{5(b-3)}$ |
| FNB | $x^{FNB} = \frac{b(3b-4)}{5b-9}$ | $y^{FNB} = \frac{b^2-1}{5b-9}$ | $X^{FNB} = \frac{-3b^2+7b-4}{5b-9}$ | $Y^{FNB} = \frac{-b^2-b}{5b-9}$ |
| NP | $x^{NP} = \frac{b(3b+4)}{5(b+2)}$ | $y^{NP} = \frac{b^2-3b+2}{5(b+2)}$ | $X^{NP} = \frac{-3b^2-b+4}{5(b+2)}$ | $Y^{NP} = \frac{2b-b^2}{5(b+2)}$ |
| PP | $x^{PP} = \frac{4b}{9}$ | $y^{PP} = \frac{1-b}{9}$ | $X^{PP} = \frac{4(1-b)}{9}$ | $Y^{PP} = \frac{b}{9}$ |
| FPB | $x^{FPB} = \frac{5b}{12}$ | $y^{FPB} = \frac{1-b}{6}$ | $X^{FPB} = \frac{5(1-b)}{12}$ | $Y^{FPB} = \frac{b}{6}$ |

Table 3.2: Equilibrium welfare under each case

| | (w) | (W) |
|---|---|---|
| NN | $w^{NN} = \frac{1}{98}(1 + 38b)$ | $W^{NN} = \frac{1}{98}(39 - 38b)$ |
| PN | $w^{PN} = \frac{1}{10(b-3)^2}(4b^3 - 23b^2 + 34b + 1)$ | $W^{PN} = \frac{171 - 20b^3 + 131b^2 - 278b}{50(b-3)^2}$ |
| FNB | $w^{FNB} = \frac{1}{50}\left(20b - \frac{7}{9-5b} - \frac{24}{3-b} - \frac{49}{(9-5b)^2} + \frac{48}{(3-b)^2} + 5\right)$ | $W^{FNB} = \frac{-100b^4 + 835b^3 - 2578b^2 + 3339b - 1548}{50(b-3)^2(5b-9)}$ |
| NP | $w^{NP} = \frac{1}{50(b+2)^2}(20b^3 + 71b^2 + 76b + 4)$ | $W^{NP} = \frac{1}{10(b+2)^2}(-4b^3 - 11b^2 + 16)$ |
| PP | $w^{PP} = \frac{5}{162}(11b + 1)$ | $W^{PP} = \frac{5}{162}(12 - 11b)$ |
| FPB | $w^{FPB} = \frac{1}{864}(273b + 40)$ | $W^{FPB} = \frac{1}{864}(317 - 273b)$ |

## 3.4 Results

### 3.4.1 Basic Cases

First of all, we explore the Nash Equilibrium for the original ownership structures which are $NN$, $PN$, $NP$, and $PP$ by comparing the welfare levels between the cases. The range of values of $b$ is approximately from 0.18 to 0.82. In this context, if the Foreign government chooses to nationalize its port, the Home government should privatize the Home port to obtain higher welfare under $PN$ than that under $NN$. Likewise, in the face of a nationalized Home port, the Foreign government should privatize its port from the perspective of Foreign welfare.

Now we consider the situation where the Foreign (Home) is privatized. If the population in the other country, Home (Foreign), is less than 1.33 times of the population in Foreign (Home), the government should privatize its port as well for greater national welfare. Otherwise, if its population ratio is larger than 0.57, then the government should own its port. Therefore, we can conclude the following proposition:

**Proposition 3.4.1** *If a country has population greater than* 1.33 *times of the population in the other country, it should choose the different port ownership from that in the other country. Otherwise, both countries should privatize their ports at equilibrium.*

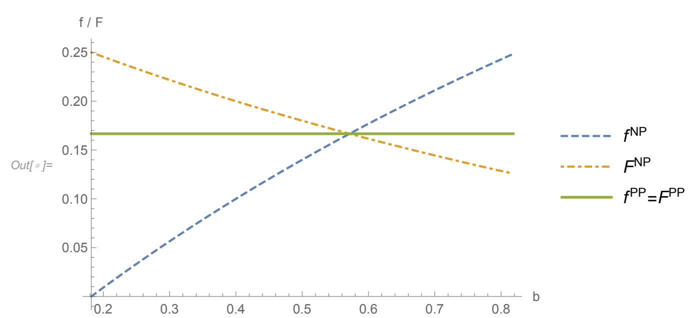
Take the Home country as an example. The results of $NN$ and $PN$ indicate that a private owner of the Home port would set up a higher port usage fee with the aim to maximize its port profit. However, the government as the port owner may lower down the port charge, since it aims to get higher national welfare instead of the port earnings only. Under $PN$, in the context of a higher Home port fee, the Foreign government chooses a lower Foreign port charge in order to mitigate the adverse effect of the higher Home port fee on its exports.

However, the decrease in $F$ cannot trade off the increase in $f$. As a consequence, both producers reduce their exports. It leads to a less consumer surplus in Home and fewer export profits. More Home produced products remain for domestic consumption. Therefore, the Home producer obtains more profits from its local market. Besides, the more expensive Home port services make for larger port profit which is the objective of the Home private owner. In the end, there is a higher welfare level in Home which is obtained by the sacrifice of the export market.

Under the circumstance of a privatized Foreign port, the order of Home welfare under $NP$ and $PP$ reverses at $b$ approximately equal to 0.57. To be specific, when $b$ is smaller than the threshold value, the Home country has greater welfare with a privatized port. Otherwise, if the Home population size is larger than the threshold, the Home government would better own its port for the purpose of higher welfare.

The critical value of Home country size that affects the port policy is due to the change of order in port charges under $NP$ and $PP$. According to the equilibrium values in equations (3.22) and (3.23), we illustrate the relationship of the port charges on the condition where the Foreign port is privatized in Figure 3.1.

Figure 3.1: Port charges under NP and PP




It shows that, with a population ratio less than 0.57 in Home country, the price of Home port services under $PP$ is higher than that under $NP$. It is because that the private port owner only pursues port profit. As a result, there is greater port profit under $PP$ than $NP$. The Home producer reduces its exports and gains more profits in the domestic market. Therefore, to privatize the Home port brings higher welfare than nationalization does.

On the contrary, if the Home country size proceeds 0.57, it is the Home government that charges a higher price of port services. The Home port fee under $NP$ is larger than that under $PP$. It indicates that, as the country size becomes larger, the Home government prefers to lifting up the port usage fee. The more expensive port services impede the export from Foreign. By so doing, the Home government protects its own manufacturer.

We can conclude that when the country size is relatively small, less than 1.33 times of that in the other country, the government would set up a low price of its port services to stimulate its exports at the cost of welfare. If the country is relatively large, with a population more than 1.33 times of the other country's, its government would be apt to trade protectionism by raising the port usage fee. It also holds if we analyze the cases from the perspective of the Foreign country. Hence, we summarize the Nash equilibria for the simultaneous port ownership structures.

### 3.4.2 Extension Cases

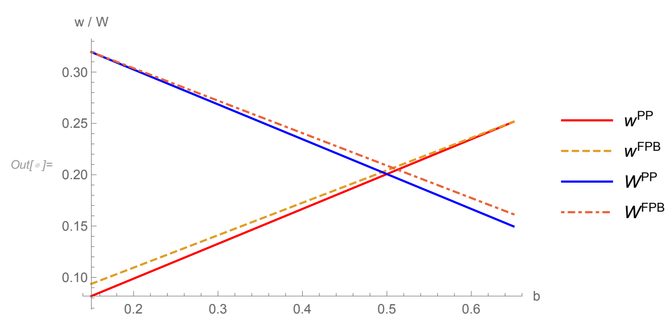
Secondly, we consider whether a government should allow its private port owner to transfer the port ownership to the other country. That is, whether $FNB$ ($FPB$) makes both countries better off, in comparison with the outcomes of $PN$ ($PP$).

As for $FNB$, the equilibrium welfare in Table 3.2 implies that to have the Foreign government own both ports is beneficial for both countries. The Foreign government would lower down the total charges, $z = f + F$, of using the port services at both ports. Then, both Home and Foreign producers make more exports to the other country compared with the volume of exports under $PN$. Therefore, the consumer surplus in each country becomes larger and the producers gain more profits in the exporting markets. Finally, each country enjoys higher welfare standard.

**Proposition 3.4.2** *The country with a population less than about* 3 *times of the people in the other country should consider transferring its port ownership to the other government. To have the government in the other country own the ports brings higher welfare for both.*

When a private entity owns the port in each country, the government should allow the private port owner to transfer the port ownership on the condition that its population is more than 18% and smaller than 1.86 times of the population in the other country. Within this population range, to have the private port owner in the other country own both ports can induce higher welfare for both countries as shown in Figure 3.2. With a lower total port usage fee charged by the sole private port owner promote bilateral exports. A greater consumer surplus and more profitable export markets make for the higher welfare levels.

Figure 3.2: Home and Foreign welfare levels under PP and FPB




**Proposition 3.4.3** *If a country's population is approximately within* 0.18 *to* 1.86 *times of the population in the other country, it is suggested that the government allows its private port owner to transfer the port ownership to have both ports possessed by the private sector in the other country.*

## 3.5 Conclusion

In this paper, we explore the effect of country size on the optimal port ownership and the conditions where the transfer of port ownership is beneficial. The theoretical results of the international duopoly model suggest that privatization of both ports is a Nash equilibrium when the ratio of population sizes is less than 1.33. If there is a larger difference in population size, each country should choose the ownership different from the other country's.

From the perspective of national welfare, the government of the country whose population is less than 3 times of the other country's should allow private port ownership transfer to the other government. If the country's population is within 0.18 to 1.86 times of the other country's, to sell out its privatized port to the private port owner in the other country is suggested.

Further study can focus on the model extension of multiple countries and take into account the market pricing power of the carriers. It will complement the theoretical model with more general and comprehensive setup.

CHAPTER 4

# CONCLUSION

According to the World Trade Statistical Review (2016), the value of world merchandise trade in 2015 almost doubled the level in 2005. Even if there is a steady growth rate of trade in the recent few years, a positive trend in trade growth is still significant. An increasing volume of global merchandise trade stimulates the demand for international transport services. Moreover, the International Maritime Organization summarizes that more than 90% of the international trade is transported by sea. Therefore, the international maritime transportation has a significant influence on the global trade volume.

The maritime transport services require the usage of fuel-driven vehicles which are pollution intensive. Most of the pollutants are greenhouse gases that cause planet warming. An empirical study shows that almost 33% of the worldwide trade-related emissions are from international transportation (Cristea et al., 2013). Besides, it is predicted that the emissions caused by international shipping could increase by 50% to 250% by 2050, depending on the economic and energy development in the future. Therefore, it is necessary to control the transport emissions.

With the above concerns, this dissertation consists of three studies regarding the relationship between international trade and the environmental regulation on transport emissions. The first study focuses on the policy of port ownership and the effect on port R&D investment. The second study investigates the relationship between port pollution regulation and the optimal port ownership. The third study explores the conditions where the transfer of private port ownership is beneficial.

To be specific, the first chapter investigates whether private participation in the port sector induces greater port R&D investment and further makes a country better off. According to the degree of private involvement, we categorize the port ownership into three main classes: complete nationalization, partial privatization, and complete privatization.

We specify the duties of the government and the private entity, regarding the port R&D investment and port usage charge, subject to each of the three ownership structures. If the government does not allow the private sector to participate in the port activities, the government as the port owner invests in port R&D and sets the port fee. If the port is partially privatized, the government makes the port cost-reducing investment, while the private port operator chooses how much to charge for using the port. If the private firm is the port owner, it makes the investment in port future development and determines the port charge. The optimality objective varies with the port owners: the government aims to maximize the national welfare, while the private firm maximizes the port profit.

The theoretical analysis is based on the framework of international duopoly trade model. We establish a four-stage sequential game to delineate the trade in each case of simultaneous port ownership combinations. We derive the equilibrium values out of nine circumstances. The theoretical findings suggest the significant influence of the endowment of the population on the optimal port policy.

It indicates that countries which are symmetric in population size should nationalize their ports to obtain the highest welfare. However, the nationalized ports receive the least R&D investment. As a result, the port services become the most expensive. The government should encourage private involvement in the port sector to improve the port efficiency and future development.

In addition, if the large country allows the private entity to participate in the port activities, the small country, which has the population less than half of the number in the large country, should partially private its port. It is beneficial from the perspective of both national welfare and the port cost-reducing investment. Otherwise, if the large country does not allow private involvement in the port sector, the small country, with the population less than a quarter of the large country's, should nationalize its port to gain the highest welfare and most R&D investment.

In the second study, we incorporate the environmental regulation of port pollution from cargo handling in the form of a pollution tax. This chapter explores the effect of port pollution regulation of the strategic port policy. We assume each government has two different executives: environment institution and transport institution. The former is in charge of formulating the pollution tax to control the domestic port emissions. The latter supervises the transport sector. Both aim to maximize the national welfare.

If the government owns the port, the transport institution sets a "two-in-one" port usage fee which has the intention of pollution control included. If the private firm owns the port, the environment institution formulates the pollution tax. Then, the private port owner chooses its port charge. The theoretical results imply the subgame Nash-equilibrium is to nationalize each port. Only when the countries have almost the same population sizes should them consider to privatize the ports.

Furthermore, we simulate the transfer of private port ownership to the government or the private entity in the other country. In the stage games, we assume the environment institution always moves before the transport department does. The conclusions indicate that to sell out the privatized port to the other country is not suggested in most cases, except for a small country with less than two-thirds of the population in the large country. Having both ports owned by the government in the large country is beneficial for both countries' welfare.

Finally, in the third chapter, we mainly answer the questions whether port privatization induces higher welfare and whether a country's port should by owned and run by the foreign agents. Different from the model setup in the second chapter, we leave out the other policy issues and regulation on the port sector to consider the sole effect of country size on port ownership.

This study contains two parts, with and without international port ownership transfer. If the private sectors as the port owners are not allowed to sell out the ports, there are only two types of ownership to be considered, nationalization and privatization. The Nash Equilibrium exists when both ports are privatized, given the ratio of country sizes is less than 1.33. Otherwise, if the population in a country is more than 1.33 times of the population in the other country, the governments should implement the ownership different from the other port's.

The other part is when the government allows the private entity to not only participate in the port activities but also sell out the port to the foreign port owner. We assess whether ownership transfer is suggested by comparing the welfare levels before and after the transaction. The theoretical findings indicate that if a country's population is less than 3 times of the scale in the other country whose port is owned by the government, the sale and purchase of the country's privatized port makes for greater welfare in both nations. It is beneficial to sell out the private port to the other country's private owner only when the country of the sold port has the population within 0.18 to 1.86 times of that in the other country.

In summary, my dissertation concentrates on international trade related to the port sector and the environmental regulation on transport pollution. In future research, I am going to extend the theoretical models to more general cases. I will also do empirical work to verify and improve the models. In addition, I have interest in both the manufacturing industry and the service sector. A topic that I would like to explore is the relationship between pollution and tourism. Does the air quality condition affect the tourists' decision of where to travel?

# APPENDIX

## A.1 Nationalized Foreign Port

Continued with Section 1.3, we assume the Foreign government chooses to nationalize its port. In this situation, what is the best strategy for the Home government: to privatize, nationalize or partially privatize its port? As long as the Foreign port is nationalized, its port charge $F$ and the port cost-reducing investment $M$ are both determined by its government in separate stages of the game.

### A.1.1 PN

Let the Home government privatize its port. In the second step of the backward induction, we need to find out the best response of port charges. Since the Home port is owned by its private sector, we maximize its port profit function (1.9) with respect to the port charge $f$. The nationalized Foreign port has the Foreign government to decide the port charge $F$ which maximizes the Foreign national welfare in equation (1.12). Therefore, given the critical port charges generated from the maximization problems, we can derive the best response of the Home port fee, $f(m,M)^{PN}$, and the Foreign port charge, $F(m,M)^{PN}$:

$$\begin{aligned} f(m,M)^{PN} = \frac{1}{10(b-3)}[&ab(5b-11) - A(5b^2-8b+3) + 2(-9c+5bc+6C+9m \\ &- 5bm - 6M + 6\tau)], \end{aligned} \tag{A.1}$$

$$\begin{aligned} F(m,M)^{PN} = \frac{1}{10(b-3)}[&ab(7-5b) + A(5b^2+4b-9) + 2(3c-5bc-12C-3m \\ &+ 5bm + 12M + 3\tau - 5b\tau)]. \end{aligned} \tag{A.2}$$

Plugging the above port charges back into the Home port profit function (1.9), we maximize the Home port profit with respect to its private port R&D. Simultaneously, we substitute the port charges into the Foreign welfare function (1.12) and maximize the welfare with respect to its government investment in port. Therefore, we have the best response of the port investments, $m(M)^{PN}$ and $M(m)^{PN}$, which are

$$m(M)^{PN} = \frac{2\left[ab(11-5b)+A(5b^2-8b+3)-12(c+C-M+\tau)\right]}{25b^2-150b+201},$$

$$M(m)^{PN} = \frac{(5b-9)\left[ab(5b-11)-A(5b^2-8b+3)+12(c+C-m+\tau)\right]}{6(25b^2-140b+207)}. \quad \text{(A.3)}$$

Given the best response of port investments, the equilibrium port R&D can be derived as

$$m^{PN} = \frac{2\left[ab(11-5b)+A(5b^2-8b+3)-12(c+C+\tau)\right]}{25b^2-140b+183},$$

$$M^{PN} = \frac{(5b-9)\left[ab(5b-11)-A(5b^2-8b+3)+12(c+C+\tau)\right]}{6(25b^2-140b+183)}.$$

Then, taking the equilibrium port investments back to the port charges in equations (A.1) and (A.2), the equilibrium port fees are equal to

$$\begin{aligned} f^{PN} &= \frac{1}{50b^2-280b+366}[a(5b-11)^2+A(33-103+95b^2-25b^3)+2c(117-110b \\ &\quad +25b^2)+12(C+\tau)(5b-11)], \end{aligned}$$

$$\begin{aligned} F^{PN} &= \frac{1}{50b^2-280b+366}\{ab(-25b^2+100b-103)+5A(5b^3-9b^2-17b+21) \\ &\quad -2[(c+\tau)(25b^2-80b+27)+12C(5b-13)]\}. \end{aligned}$$

Finally, with the use of equilibrium port charges $f^{PN}$ and $F^{PN}$, we replace the port fees in production functions (1.7) to (1.8). The equilibrium productions are calculated to be

$$x^{PN} = \frac{b\left[a(20b^2-131b+183)+A(25b^2-94b+69)+30(3-b)(c+C+\tau)\right]}{75b^2-420b+549},$$

$$y^{PN} = \frac{(b-1)\left[2ab(9-5b) + A(25b^2-48b-45) + 60(3-b)(c+C+\tau)\right]}{75b^2-420b+549},$$

$$X^{PN} = \frac{(b-1)\left[ab(5b-9) - A(50b^2-234b+252) - 30(3-b)(c+C+\tau)\right]}{75b^2-420b+549},$$

$$Y^{PN} = \frac{b\left[a(35b^2-158b+183) - 2A(25b^2-94b+69) - 60(3-b)(c+C+\tau)\right]}{75b^2-420b+549}.$$

### A.1.2 NN

When both ports are nationalized, the port charges and R&D are both determined by each government. Therefore, in the next stage of the backward induction, we maximize each country's national welfare in equations (1.11) and (1.12), with respect to its port charge $f$ and $F$ respectively. It generates the best response of port charges as

$$f(m,M)^{NN} = \frac{1}{42}[5ab(5-2b) + A(10b^2-7b-3) - 6(-9c+5bc-2C+5bC+9m - 5bm + 2M - 5bM - 2\tau + 5b\tau)], \quad (A.4)$$

$$F(m,M)^{NN} = \frac{1}{42}[ab(10b-13) - 5A(2b^2+b-3) + 6(-3c+5bc+4C+5bC+3m - 5bm - 4M - 5bM - 3\tau + 5b\tau)]. \quad (A.5)$$

Substituting the port investments into the welfare functions, we maximize each national welfare with respect to individual port R&D. The best response functions of port investments are derived to be

$$m(M)^{NN} = \frac{(5b+4)\left[A(b-1) - ab + 4(c+C-M+\tau)\right]}{20b-82},$$

$$M(m)^{NN} = \frac{(5b-9)\left[A(b-1) - ab + 4(c+C-M+\tau)\right]}{20b+62}.$$

Therefore, using the best response of port investments, we can calculate out the equilibrium values, $m^{NN}$ and $M^{NN}$, which are

$$m^{NN} = -\frac{5b+4}{46}\left[A(b-1) - ab + 4(c+C+\tau)\right],$$

$$M^{NN} = \frac{5b-9}{46}\left[A(b-1) - ab + 4(c+C+\tau)\right].$$

Taking the equilibrium port investments back to the best response functions (A.4) and (A.5) of the port charges, we can calculate out the port fees at equilibrium.

$$f^{NN} = \frac{1}{138}ab(59-20b) + A(20b^2+13b-33) - 6\left[5c(5b-9) + (C+\tau)(25b-22)\right],$$

$$F^{NN} = \frac{1}{138}ab(20b-53) - A(20b^2+19b-39) + 6\left[5C(5b+4) + (c+\tau)(25b-3)\right].$$

Hence, plugging the equilibrium port charges back into the best response functions (1.7) to (1.8) of the productions, we can get the equilibrium productions as follows:

$$x^{NN} = \frac{b}{69}\left[A(1-b) + a(b+23) + 42(c+C+\tau)\right],$$

$$y^{NN} = \frac{b-1}{69}\left[2ab - A(2b+21) + 84(c+C+\tau)\right],$$

$$X^{NN} = \frac{b-1}{69}\left[A(b-24) - ab - 42(c+C+\tau)\right],$$

$$Y^{NN} = \frac{b}{69}\left[2A(b-1) + a(23-2b) - 84(c+C+\tau)\right].$$

### A.1.3 BN

Now we consider the case where the Home port is partially privatized, while the Foreign port is nationalized. The way to find out the port charges is the same as what we do in the case of $PN$. That is, we need to derive the Home port fee that maximizes the Home port profit, and the Foreign port charge set by its government to maximize the Foreign welfare. Therefore, the best response of the port fees, $f(m,M)^{BN}$ and $F(m,M)^{BN}$, are the same ones in equations (A.1) and (A.2).

Plug the best response functions of the port charges back to the Home port profit function (1.9) and the Foreign welfare function (1.12). Then, we take the first-order derivative of the Home port profit with respect to Home port investment. It gives us the best response of Home port investment, $m(M)^{BN}$, which equals to

$$m(M)^{BN} = \frac{2\left[ab(5-2b) + A(2b^2-5b+3) + 3(b-4)(c+C-M+\tau)\right]}{3(5b^2-28b+37)}.$$

To find out the best response of the Foreign port R&D, we need to maximize the Foreign welfare with respect to the Foreign port investment. Since the best response of the port charges are identical with the ones under $PN$, substituting these port charges into the Foreign welfare gives us the same objective function as we use in the third step of $PN$. Therefore, the best response of the Foreign port investment $M(m)^{BN}$ is equal to $M(m)^{PN}$ in equation (A.3). Then, with the best response of the port investments, we can calculate out the equilibrium port R&D, $m^{BN}$ and $M^{BN}$, as follows:

$$\begin{aligned} m^{BN} &= \frac{1}{15(b-3)(25b^2-130b+167)}[ab(-822+635b-125b^2) + 5A(25b^3-124b^2 \\ &\quad + 189b - 90) + 150(b^2-7b+12)(c+C+\tau)], \end{aligned}$$

$$\begin{aligned} M^{BN} &= \frac{1}{30(b-3)(25b^2-130b+167)}\{(5b-9)[ab(25b^2-120b+149) - 5A(5b^3 \\ &\quad - 21b^2 + 25b - 9) + 60(b-3)(c+C+\tau)]\}. \end{aligned}$$

Taking the above equilibrium port investments back to the best response of port charges, we can derive the equilibrium port fees, $f^{BN}$ and $F^{BN}$:

$$f^{BN} = \frac{1}{30(b-3)(25b^2-130b+167)}\{ab(375b^3-2675b^2+6365b-5061)-5A(75b^4 - 490b^3+1072b^2-882b+225)+30(b-3)[c(25b^2-110b+117)+10(C + \tau)(2b-5)]\},$$

$$F^{BN} = \frac{1}{30(b-3)(25b^2-130b+167)}\{ab(4251-5645b+2525b^2-375b^3)+5A(75b^4 - 340b^3+106b^2+1032b-873)-30(b-3)[(c+\tau)(25b^2-80b+27)+10C (5b-14)]\}.$$

In the end, substituting the equilibrium port charges into equations (1.7) to (1.8), we finally get the equilibrium productions under $BN$.

$$x^{BN} = \frac{b\left[a(20b^2-121b+167)+A(25b^2-86b+61)-30(b-3)(c+C+\tau)\right]}{75b^2-390b+501},$$

$$y^{BN} = \frac{(b-1)\left[2ab(9-5b)+A(25b^2-42b-45)-60(b-3)(c+C+\tau)\right]}{75b^2-390b+501},$$

$$X^{BN} = \frac{(b-1)\left[ab(5b-9)-A(50b^2-216b+228)+30(b-3)(c+C+\tau)\right]}{75b^2-390b+501},$$

$$Y^{BN} = \frac{b\left[a(35b^2-148b+167)-2A(25b^2-86b+61)+60(b-3)(c+C+\tau)\right]}{75b^2-390b+501}.$$

## A.2 Partially Privatized Foreign Port

In this section, we consider Home government's port strategies when the Foreign port is partially privatized. Being partially privatized means that the Foreign port R&D is invested by the Foreign government. However, its port charge is determined by its private port operator.

### A.2.1 PB

Suppose the Home port is privatized. In the second step of the backward induction, to find the port charges, each port's private sector maximizes its port profit with respect to its port charge. Since both the critical values of the port charges are determined by the private sectors, the calculated best response of the port fees, $f(m,M)^{PB}$ and $F(m,M)^{PB}$, are equal to the ones in equations (1.13) and (1.14).

In the third step, we plug the best response of the port fees back to the Home port profit function (1.9) and the Foreign welfare function (1.12). To derive the port R&D, we maximize the Home port profit with respect to the Home port R&D, which is the same with the procedure under $PP$. Therefore, the best response of the Home port investment is the one in equation (1.15). Meanwhile, we maximize the Foreign welfare with respect to its investment $M$. It gives the best response of the Foreign port investment $M(m)^{PB}$, which is

$$M(m)^{PB} = \frac{5ab(b-3) - A(5b^2 - 8b + 3) + 5(b+3)(c + C - m + \tau)}{5b - 147}.$$

Given the best response of the port investments, we can calculate out their equilibrium values, $m^{PB}$ and $M^{PB}$.

$$m^{PB} = \frac{ab(5b-9) - A(5b^2 - 56b + 51) + 108(c + C + \tau)}{45(b-27)},$$

$$M^{PB} = \frac{2ab(4b-13) - 2A(4b^2 - 7b + 3) + 9(b+3)(c + C + \tau)}{9(b-27)}.$$

Taking the equilibrium port investments back to the best response of the port charges, we have the port fees at equilibrium, $f^{PB}$ and $F^{PB}$.

$$f^{PB} = \frac{7ab(5b-59) - 7A(5b^2 - 56b + 51) + 18c(5b-93) + 756(C+\tau)}{90(b-27)},$$

$$F^{PB} = -\frac{ab(35b+271) - 7A(5b^2 + 52b - 57) + 18\left[(c+\tau)(5b-39) + 96C\right]}{90(b-27)}.$$

Hence, substituting the equilibrium port charges into the best response of productions in equations (1.7) to (1.8), we have the equilibrium productions as follows:

$$x^{PB} = \frac{b\left[14A(b-1) - a(11b+45) - 18(c+C+\tau)\right]}{5(b-27)},$$

$$y^{PB} = \frac{(b-1)\left[A(79b+51) - 76ab - 108(c+C+\tau)\right]}{15(b-27)},$$

$$X^{PB} = \frac{(b-1)\left[A(177-47b) + 38ab + 54(c+C+\tau)\right]}{15(b-27)},$$

$$Y^{PB} = \frac{b\left[28A(1-b) + 9a(3b-5) + 36(c+C+\tau)\right]}{5(b-27)}.$$

### A.2.2 NB

We assume the Home port is nationalized, while the Foreign port is partially privatized. Given this, in the second step of the backward induction, we need to maximize the Home welfare with respect to its port charge, and simultaneously maximize the Foreign port profit with respect to the Foreign port charge set by its private sector. This derivation is the same that under $NP$. Therefore, the best response of the port charges, $f(m,M)^{NB}$ and $F(m,M)^{NB}$, are identical with the ones in equation (1.26) and (1.27) under $NP$.

With the best response of the port charges, we substitute the port charges in the Home welfare function (1.11) and the Foreign welfare function (1.12). In the next step of the backward induction, we need to maximize the Home welfare with respect to its port R&D. Up to this point, the backward derivation in the Home country is consistent with the steps taken in the case of $NP$. Therefore, the best response of the Home port investment, $m^{NB}$, is equal to the one in equation (1.28) under $NP$. Meanwhile, we maximize the Foreign national welfare with respect to the Foreign port

R&D which is carried out by the Foreign government. It gives us the best response of the Foreign port fee, $M(m)^{NB}$, which is

$$M(m)^{NB} = \frac{2ab(2b+1) - 2A(2b^2+b-3) - 6(b+3)(c+C-m+\tau)}{15b^2+54b+42}.$$

Therefore, with the best response of the port fees, we derive their equilibrium values, $m^{NB}$ and $M^{NB}$, which are equal to

$$\begin{aligned} m^{NB} = & \frac{1}{30(b+2)(25b^2+80b+62)}\{(5b+4)[5ab(5b^2+6b-2) - A(25b^3+45b^2-16b \\ & - 54) - 60(b+2)(c+C+\tau)]\}, \end{aligned}$$

$$\begin{aligned} M^{NB} = & \frac{1}{15(b+2)(25b^2+80b+62)}[5ab(25b^2+49b+16) - A(125b^3+260b^2-73b \\ & - 312) - 150(b^2+5b+6)(c+C+\tau)]. \end{aligned}$$

Then, taking the equilibrium port investments back to the best response functions of the port charges, we can get the equilibrium port fees $f^{NB}$ and $F^{NB}$:

$$\begin{aligned} f^{NB} = & \frac{1}{30(b+2)(25b^2+80b+62)}\{A(375b^4+1025b^3+320b^2-964b-756) - 5\{ab \\ & (75b^3+40b^2-464b-524) + 6(b+2)[-10c(5b+9) + (C+\tau)(25b^2+30b \\ & - 28)]\}\}, \end{aligned}$$

$$\begin{aligned} F^{NB} = & \frac{1}{30(b+2)(25b^2+80b+62)}\{-A(375b^4+1175b^3+590b^2-1144b-996) + 5ab \\ & (75b^3+190b^2+52b-92) + 30(b+2)[-10(c+\tau)(2b+3) + C(25b^2+60b \\ & + 32)]\}. \end{aligned}$$

In the last step, we use the equilibrium port fees in the production functions (1.7) to (1.8). As a result, we figure out the equilibrium productions as follows:

$$x^{NB} = \frac{b\,[2a(25b^2+58b+31) - A(5b^2-b-4) + 30(b+2)(c+C+\tau)]}{3(25b^2+80b+62)},$$

$$y^{NB} = \frac{(b-1)\left[2ab(25b+36) - A(35b^2+78b+54) + 60(b+2)(c+C+\tau)\right]}{3(25b^2+80b+62)},$$

$$X^{NB} = \frac{(1-b)\left[ab(25b+36) + A(20b^2+81b+66) + 30(b+2)(c+C+\tau)\right]}{3(25b^2+80b+62)},$$

$$Y^{NB} = \frac{b\left[-a(25b^2-8b-62) + 2A(5b^2-b-4) - 60(b+2)(c+C+\tau)\right]}{3(25b^2+80b+62)}.$$

### A.2.3 BB

Suppose the Home port has the same ownership with the Foreign port. In order to find out the best response of the port charges, we need to maximize each port's profit with respect to its port charge set by the private operator. That is, to take the first-order condition of the Home port profit in equation (1.9) with respect to $f$ and maximize the Foreign port profit in equation (1.10) with respect to $F$. This is the same derivation as what we do in the case of $PP$. In other words, the best response of the port charges when both ports are partially privatized are the ones in equations (1.13) and (1.14).

Having the best response of the port fees, the next step is to find out the best response of the port investments. We need to maximize the Home welfare in equation (1.11) with respect to the Home port R&D made by the government. It is the same procedure with the third step of induction under $BP$. Moreover, the best response of the port fees in this case are equal to the ones under $PP$. Given these, the best response of the Home port R&D, $m(M)^{BB}$, is the same with $m(M)^{BP}$ in equation (1.38). Correspondingly, we maximize the Foreign welfare with respect to the Foreign port investment, using the best response of the port charges in the welfare function (1.12). It gives us the best response of the Foreign port R&D, $M(m)^{BB}$, which is

$$M(m)^{BB} = \frac{5ab(b-3) - A(5b^2-8b+3) + 5(b+3)(c+C-m+\tau)}{5b-147}.$$

With the best response of the port investments, now we can calculate out the equilibrium port investments, $m^{BB}$ and $M^{BB}$:

$$m^{BB} = \frac{1}{3429}\left[ab(95b+1) - 5A(19b^2+32b-51) + 135(b-4)(c+C+\tau)\right],$$

$$M^{BB} = \frac{1}{3429}\{A(19b^2-191b+96) - 5\left[ab(19b-70) + 27(b+3)(c+C+\tau)\right]\}.$$

Then, taking the equilibrium port investments, we use them in the best response of the port charges which we derived in the prior step of induction. The equilibrium port charges, $f^{BB}$ and $F^{BB}$, are calculated to be

$$f^{BB} = \frac{1}{6858}\{5ab(275-38b) + A(190b^2-1057b+867) - 54[c(5b-93) + (C+\tau)(5b + 34)]\},$$

$$F^{BB} = \frac{1}{6858}\{ab(190b+677) - 5A(38b^2+199b-237) + 54[(c+\tau)(5b-39) + C(5b + 88)]\}.$$

In the end, substituting the equilibrium port charges into the production equations (1.7) to (1.8), we can get the productions at equilibrium when both ports are partially privatized.

$$x^{BB} = \frac{b}{381}\left[a(38b+127) + 38A(1-b) + 54(c+C+\tau)\right],$$

$$y^{BB} = \frac{b-1}{381}\left[76ab - A(76b+51) + 108(c+C+\tau)\right],$$

$$X^{BB} = \frac{1-b}{381}\left[38ab - A(38b-165) + 54(c+C+\tau)\right],$$

$$Y^{BB} = \frac{b}{381}\left[76A(b-1) - a(76b-127) - 108(c+C+\tau)\right].$$

Table A.1 Numerical results of the symmetric case

| **Ownership Combinations** | **Variables** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | m | M | f | F | x | y | X | Y |
| **PP** | $\frac{5}{23}$ | $\frac{5}{23}$ | $\frac{81}{46}$ | $\frac{81}{46}$ | $\frac{48}{23}$ | $\frac{15}{46}$ | $\frac{48}{23}$ | $\frac{15}{46}$ |
| **NP** | $\frac{143}{954}$ | $\frac{44}{159}$ | $\frac{217}{106}$ | $\frac{505}{318}$ | $\frac{2009}{954}$ | $\frac{275}{954}$ | $\frac{2009}{954}$ | $\frac{275}{954}$ |
| **BP** | $\frac{10}{53}$ | $\frac{57}{265}$ | $\frac{943}{530}$ | $\frac{929}{530}$ | $\frac{1107}{530}$ | $\frac{171}{530}$ | $\frac{1107}{530}$ | $\frac{171}{530}$ |
| **PN** | $\frac{44}{159}$ | $\frac{143}{954}$ | $\frac{505}{318}$ | $\frac{217}{106}$ | $\frac{2009}{954}$ | $\frac{275}{954}$ | $\frac{2009}{954}$ | $\frac{275}{954}$ |
| **NN** | $\frac{13}{92}$ | $\frac{13}{92}$ | $\frac{93}{46}$ | $\frac{93}{46}$ | $\frac{50}{23}$ | $\frac{7}{46}$ | $\frac{50}{23}$ | $\frac{7}{46}$ |
| **BN** | $\frac{2234}{10825}$ | $\frac{3107}{21650}$ | $\frac{35107}{21650}$ | $\frac{44393}{21650}$ | $\frac{1829}{866}$ | $\frac{239}{866}$ | $\frac{1829}{866}$ | $\frac{239}{866}$ |
| **PB** | $\frac{57}{265}$ | $\frac{10}{53}$ | $\frac{929}{530}$ | $\frac{943}{530}$ | $\frac{1107}{530}$ | $\frac{171}{530}$ | $\frac{1107}{530}$ | $\frac{171}{530}$ |
| **NB** | $\frac{3107}{21650}$ | $\frac{2234}{10825}$ | $\frac{44393}{21650}$ | $\frac{35107}{21650}$ | $\frac{1829}{866}$ | $\frac{239}{866}$ | $\frac{1829}{866}$ | $\frac{239}{866}$ |
| **BB** | $\frac{47}{254}$ | $\frac{47}{254}$ | $\frac{225}{127}$ | $\frac{225}{127}$ | $\frac{531}{254}$ | $\frac{81}{254}$ | $\frac{531}{254}$ | $\frac{81}{254}$ |

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