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ABBREVIATIONS

FDI	**:** Foreign Direct Investment
JV	**:** Joint Venture
DC	**:** Domestic Cournot
IC	**:** International Cournot
Type-L	**:** Type of the firm with low marginal cost
Type-H	**:** Type of the firm with high marginal cost
CS	**:** Consumer Surplus in the South

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LIST OF SYMBOLS

c_{ji}	: Marginal cost of the Type-i firm in the country j
μ	: The probability of Type-L firm
P	: Market price
Q	: Market demand
α	: Autonomous market parameter
q_{ji}	: The production of the Type-i firm in the country j
$\bar{q}_j$	: The expected production of the firm in the country j
$\bar{c}_j$	: The expected marginal cost of the firm in the country j
e_j	: Emission tax of the country j
t_j	: Import tariff of the country j
π_{ji}	: The profit of the Type-i firm in the country j
q_{ji}^{DC}	: Equilibrium output of the Type-i firm in the country j under DC
q_{ji}^{IC}	: Equilibrium output of the Type-i firm in the country j under IC
π_{ji}^{DC}	: Profit level of the Type-i firm in the country j under DC
π_{ji}^{IC}	: Profit level of the Type-i firm in the country j under IC
EW_j^{DC}	: The expected welfare of the country j under DC
EW_j^{IC}	: The expected welfare of the country j under IC
d	: Marginal damage of the pollution to the South
$D_{e_j} EW_j^{DC}$	: Derivative of EW_j^{DC} with respect to the emission tax of the country j
$D_{e_l} EW_j^{IC}$	: Derivative of EW_j^{IC} with respect to the emission tax of the country j
$D_{t_l} EW_j^{IC}$	: Derivative of EW_j^{IC} with respect to the import tariff of the country j
e_j^{DC}	: Equilibrium emission tax level of the country j under DC
e_j^{IC}	: Equilibrium emission tax level of the country j under IC
t_j^{IC}	: Equilibrium import tariff level of the country j under IC
$\tilde{e}$	: Boundary level of the emission tax for the South
$\partial e_j^{DC} / \partial \mu$	: Derivative of e_j^{DC} with respect to the probability of Type-L firm
$\partial e_j^{IC} / \partial \mu$	: Derivative of e_j^{IC} with respect to the probability of Type-L firm
$\partial t_j^{IC} / \partial \mu$	: Derivative of t_j^{IC} with respect to the probability of Type-L firm
Q_j^{DC}, Q_j^{IC}	: Total production/pollution in the country j under DC and IC
Q_j^{DC-IC}	: Difference between pollution levels in the country j under DC and IC

STRATEGIC TRADE POLICIES AND THE ENVIRONMENT UNDER INCOMPLETE INFORMATION

SUMMARY

As a result of the growing concern on environmental pollution, governments of developed countries may sometimes impose tougher environmental policies than their trading rivals, which may bring about a competitive disadvantage for the domestic producers. From the point of view of a developing country, it can also be argued that it is crucial to be attractive for FDI. This dilemma between competitiveness and pollution in the pollution-intensive industries made the location decisions of the firms a current issue. Hence, a welfare analysis for the governments requires a well understanding of the effects of trade and environmental policies together.

The aim of this paper is to analyze optimal trade and environmental policies using a two-stage game theoretic model. There is a domestic developing country (the South), which reveals the level of import tariff and emission tax in the first stage. The foreign firm from a developed country (the North) decides where to locate in the second stage. The foreign firm can either stay in its own country and exports to the South or invest and produce in the South (FDI). Domestic firm's marginal cost is publicly known however, foreign firm can either have a low or a high cost technology.

Analyzing this model, it is found that the optimal environmental policies, under both domestic Cournot and international Cournot competition, depend on the foreign firm's technology. Welfare comparison for the South between these two types of competition indicated that, South is better off in the case of domestic Cournot if and only if marginal damage of pollution for the South is less than the emission tax in the North. Moreover, considering the environmental pollution in the domestic country, domestic competition always creates a higher level of pollution than international competition.

EKSİK BİLGİ ALTINDA STRATEJİK DIŞ TİCARET POLİTİKALARI VE ÇEVRE

ÖZET

Çevre kirliliği üzerine artan kaygının bir sonucu olarak, gelişmiş ülkelerin hükümetleri bazen, ticari rakiplerinden daha sıkı çevresel politikalar uygulayabilmekte; bu ise yerel üreticiler için rekabete dayanan bir dezavantaja sebep olabilmektedir. Gelişmekte olan bir ülke açısından da, doğrudan yabancı sermaye yatırımı için cazip olmanın önemli olduğu iddia edilebilir. Kirlilik-yoğun endüstrilerde rekabet ve kirlilik arasındaki bu ikilem, firmaların yer seçimlerini güncel bir konu haline getirmiştir. Dolayısıyla; hükümetler için bir refah analizi, ticaret ve çevre politikalarının etkilerinin birlikte iyice anlaşılmasını gerektirir.

Bu tezin amacı; iki aşamalı oyun teorik bir model kullanarak, optimum ticaret ve çevre politikalarını incelemektir. Birinci aşamada ithalat tarifesi ve emisyon vergisini açıklayan, gelişmekte olan yerel bir ülke vardır. Gelişmiş bir ülkeden olan yabancı firma, ikinci aşamada üretimini nerede gerçekleştireceğine karar verir. Yabancı firma ya kendi ülkesinde kalabilir ve gelişmekte olan ülkeye ihracat yapabilir ya da yatırım yapar ve üretimini gelişmekte olan ülkede gerçekleştirir (DYY). Yabancı firmanın marjinal maliyeti herkes tarafından bilinmekte fakat yerli firma düşük veya yüksek maliyetli bir teknolojiye sahip olabilmektedir.

Bu model analiz edilerek, hem yerel hem de uluslararası Cournot rekabeti durumunda, optimum çevre politikalarının yabancı firmanın teknolojisine bağlı olduğu bulunmuştur. Güney ülkesi için yapılan refah karşılaştırması her iki rekabet şeklinde de göstermiştir ki, sadece ve sadece kirliliğin Güney için marjinal zararı, Kuzey'deki emisyon vergisinden daha az ise, Güney ülkesi yerel Cournot'da daha iyi durumdadır. Ayrıca, yerel ülkedeki çevre kirliliği ile ilgili olarak, yerel rekabet her zaman uluslararası rekabetten daha yüksek kirlilik yaratır.

1. INTRODUCTION

Strategic trade policies have become the most debated issues of the new trade theory and policy during the second half of the 1980s. Several papers focused on the trade policy as a means of shifting profits towards domestic firms when markets are imperfectly competitive. Recently, the idea of supporting domestic producers by the way of setting low pollution abatement requirements, introduced the process of environmental policy-making into this literature.

It is argued that environmental standards should be relaxed as openness increases since strict environmental policies reduce the competitiveness of an open economy and derive mobile factors out of the country. This argument also triggered a dispute whether environmental issues should be included in the WTO agenda or not. Developed countries often blame developing countries of using lax environmental standards as a strategic tool for shifting market conditions in favor of local firms. On the other hand, though environmental standards used as non-tariff barriers can exclude foreign competitors from local market. Hence, developing countries often accuse developed countries of this type of abuse (Rivera-Batiz, Oliva, 2003: 614).

Considering the growing concern on the location decisions of the firms in the pollution-intensive industries, this study aims to analyze optimal trade and environmental policies by using a two-stage game theoretic model.

There are two main purposes of this study: First is to investigate how trade and environmental policies and the location choice of the foreign firm are related, and the other is to analyze the effects of these decisions on the environmental pollution of the domestic country under uncertainty on foreign firm’s technology.

This study is organized in five parts: Section 2 reviews theoretical studies on the strategic trade policy models in the relevant literature. Theoretical models are discussed respectively on the basis of assumptions on the asymmetric information, relationship to the environmental policies and the location decisions of the firms.

In Section 3, the model is constructed. First, the general assumptions and the stages of the model are introduced. Then, some of the propositions are derived from the market and policy stage games under two alternative modes of competition. At last, the location decision of the foreign firm and welfare comparison are analyzed with respect to the results of the previous parts.

Section 4 presents comparisons of the optimal pollution levels under two modes of competition. Finally, Section 5 provides summary of the analysis and some concluding remarks.

2. LITERATURE REVIEW: THEORETICAL STUDIES

Since the second half of the 1980s, there has been an extensive literature on the strategic trade policies in the imperfectly competitive markets. One of the most-important models in this literature is the well-known Brander and Spencer (1985) model, in which there are two firms; a domestic and a foreign one, competing in a third country's market. It is shown that a government adopts an export subsidy if the competition is in terms of quantity. However, Eaton and Grossman (1986) illustrate that in the case of price competition an export tax is the optimal policy.

These studies showed that, the model is sensitive to a number of special assumptions, such as mode of competition, that is, whether the firms compete by setting quantities or prices, and also open to a number of special contributions. In this section, research papers based on these two studies will be grouped into three groups and examined in the subsequent parts.

2.1 Assumptions on Asymmetric Information

The first group of the studies includes the models assuming information asymmetries instead of full information. It can be argued that policymakers have less information than firms concerning either the markets (demand uncertainty) or cost structures of the firms (cost uncertainty).

Introducing a demand uncertainty to a third country model; Cooper and Riezman (1989), aim to contrast the use of export subsidies with direct quantity interventions. They assume an inverse demand curve as in (2.1);

$$p = a - bQ + \Theta \qquad \textbf{(2.1)}$$

where Q is the total output of the homogenous commodity and Θ is a random variable with mean zero. In the first stage of the game, governments simultaneously decide on either using subsidies or direct quantity controls. In the second stage, each government chooses the level of intervention taking the policy levels chosen by the other government as given. Finally, after the state of the nature (Θ) is revealed to the firms, firms select output levels to maximize their profits.

Solving this game, they show that, governments should use subsidies in markets with highly volatile demands. On the other hand, when the uncertainty is not too severe, the optimal policy is found as direct quantity controls. As a consequence, countries with few firms will subsidize their exports while countries with many firms will tax.

Instead of demand uncertainty, Qiu (1994) assumes cost uncertainty such that, the home firm's marginal cost is private information while that of foreign firm is common knowledge. Firm 1 is of either high cost, c_H, or low cost, c_L, with $\text{Prob}(c = c_L) = \mu$. Firm 2's marginal cost is assumed known to all parties and equal to zero for simplicity.

At the first stage, home government has two policy options; a uniform policy or a menu of policies. Under the uniform policy, the government sets a specific export subsidy rate, s, for the home firm regardless of its type and foreign firm receives no information from policy stage.

Alternatively, a menu of policies gives the home firm make a policy choice which is observed by the foreign firm and in the market stage they compete as if there were full-information. A policy menu is denoted as $t = (t_L; t_H)$, where t_L is a policy intended for the low-cost firm and t_H for the high-cost firm. Moreover, each policy $t_i = (s_i, \tau_i)$ for $i = L, H$ consist of two elements; a specific export subsidy rate, s_i, and a lump-sum tax, τ_i.

With his model, Qiu (1994) investigates screening and signaling problem of the policy game. It is shown that while the government prefers information revealing menu policy under the Cournot competition, he chooses information concealing uniform policy under the Bertrand competition.

Orbay (1996) also focuses on cost uncertainty but differs from the others in two dimensions. First, home consumption is introduced by letting two countries trade with each others and second, while the governments have full information about domestic firms' costs, the foreign firms' costs are private information. Formally, firm i's marginal cost is represented by $\widetilde{c}_i$ which is a random variable that can take two values c_l and c_h where $c_l < c_h$.

It is further assumed that country i's publicly known inverse demand function for the homogenous good is;

$$p^i = a - x^i \qquad \textbf{(2.2)}$$

where $x^i = x_i^i + x_j^i$ is the total output and x_i^i and x_j^i represent the amount of outputs produced by firm i and firm j, respectively, in country i's market. The efficiency of each firm is defined by $\widetilde{\theta}_i = a - \widetilde{c}_i$. High efficiency is denoted by $\alpha = a - c_l$ and low efficiency is denoted by $\alpha = a - c_h$, where $\theta_i \in \{\alpha, \beta\}$.

In the model, governments choose policy types in the first stage under incomplete information and the policy levels in the second stage under complete information. Governments can either impose a tariff on imports or subsidize exports. Firms decide how much to produce and where to sell at the third stage.

Firms' decisions are analyzed under two different scenarios; first is Cournot competition in both domestic and foreign market, and the other is Stackelberg leaders at home. Welfare comparisons between the protectionist and non-protectionist environment indicate that a country is always better off signing a free trade agreement and subsidizing both firms unless the domestic firms are very inefficient.

The last and the most recent study which is included in the first group is the study of Caglayan and Usman (2004). They follow Cooper and Riezman (1989) and investigate strategic trade policy design when governments are incompletely informed about the market demand. Their contribution to the previous study is that the governments observe a noisy signal on the true market demand after they determine the policy regime but before they determine the policy level. After the form and the level of intervention are decided, the state of nature Θ given in the equation (2.1) is revealed to the firm, so that firms are better informed than the governments and in the last stage each firm selects quantities.

The demand shock Θ is normally distributed with mean zero and variance σ^2. For simplicity, both governments receive a common private observation on Θ in the form of a noisy signal, $Z = \Theta + \varepsilon$, where ε is also normally distributed with mean zero, variance τ^2, and $\mathrm{cov}(\Theta, \varepsilon) = 0$. Therefore, the expectation of Θ conditional on the signal is $E(\Theta / Z) = \lambda Z$, where $\lambda = \mathrm{cov}(\Theta, Z) / \mathrm{var}(Z) = \sigma^2 / (\sigma^2 + \tau^2)$. It is noted that as the variance of the noise gets larger, in other words, as the information content of the signal deteriorates, the government estimates demand less precisely.

Contrary to what common sense would suggest, they show that both countries will be better off if governments are less informed on the stochastic market demand. Furthermore, they state that the perception of governments' market conditions will affect their trade policy choice between subsidy and quantity controls.

2.2 Environmental Policies

Another approach to this literature has been introduced by the possibility of giving hidden subsidies by means of low pollution abatement requirements. The studies taking this possibility into account in the cases that production creates local or cross-border externalities will be examined in this part.

In the Barrett's (1994) study, it is assumed that environmental damage is local so that the governments of consumer countries have no means of influencing environmental standards in producer countries. He denotes the domestic firm's output by x and the foreign firm's output by y, assuming that two outputs are substitutes. Total revenues and production cost functions are $R(x, y)$ and $C(x)$ for the domestic firm while $R^*(x, y)$ and $C^*(y)$ for the foreign firm. The abatement cost functions for the two firms are given as, respectively, $A(x, e), A^*(y, \varepsilon)$, with

$$A_x \geq 0, A_e \leq 0, A_{xe} \leq 0; A_y^* \geq 0, A_\varepsilon^* \leq 0, A_{y\varepsilon}^* \leq 0 \qquad \textbf{(2.3)}$$

where e is the domestic emission standard and ε is the foreign standard.

The governments choose their emission standards so as to maximize their net benefits, which are the difference between the firms' profits and the environmental damages $D(e)$ and $D^{*}(\varepsilon)$ suffered by the domestic and foreign countries, respectively. Barrett defines these standards as the "*environmentally optimal emission standards*" (EOSs) and these standards obey the usual optimality rule in environmental economics: pollution is reduced to the level where the marginal damage caused by the pollution just equals the marginal cost of abatement. He also investigates the strategic behavior of the governments and defines the emission standards as the *"strategically optimal emission standards"* (SOSs) and compare them with (EOSs).

He finds that, in contrast to the price competition, when firms compete in quantities, governments do have incentives to impose weak environmental standards, where "weak" means that marginal cost of abatement is lower than the marginal damage from pollution. As a final remark, he also notes that, in fact, governments would rather prefer industrial policy to the environmental policy for improving competitiveness.

Instead of emission standards as an environmental policy, Ludema and Wooton (1994) are concerned with an emission tax on the externality, e, and a process standard, z, which is an upper bound on the level of externality produced per unit of the good manufactured. In their model, the production of the good in the foreign country generates local externality, while the home production of the good is assumed to create no externality.

Their model also diverges from the previous one such that all consumption takes place in the home country instead of a third country, while production occurs in both countries. Hence, home-country welfare is the sum of consumer surplus, domestic producer surplus and tariff revenue less the externality. It is assumed that foreign production results in an externality at the fixed level $\overline{m}$ per unit of output and the per-unit cost of reducing the externality to a level m is $c(m)$. Thus, total cost to the firm of pollution is $\{c(m)+e(m)\}x$.

They investigate the interaction of the externality tax and the process standard and show that, the process standard will always be binding in the trading equilibrium.

They also state that, competition between the two governments results in highly restrictive policies and very low levels of both pollution and trade.

A similar study concerning the strategic trade and environmental policies is Tanguay (2001). There is an economy with one good and two symmetric regions. The firms' outputs generate pollution which may be costly for both regions. For simplicity, each unit of output is assumed to produce one unit of pollution. In this model, governments play a Nash game in the first stage using two choice variables; pollution taxes and tariffs on imports. In the second stage, two firms (one in each region) compete à la Cournot-Nash in both markets.

For all cooperative and non-cooperative solutions, he finds that free-trade leads to a decrease in welfare, which brings him to a conclusion that pollution taxes on their own are not capable of correcting the problems of pollution, imperfect competition and inefficient exchanges it causes.

As the last one, Furusawa, Higashida, and Ishikawa (2004) make a comparison between tariffs and quotas by introducing both cross-border externalities and asymmetry of information on the foreign firm's production method. They specifically investigate a case where the domestic market is served by a foreign monopolist.

They presume a domestic inverse demand function $P(x)$, which exhibits the constant elasticity of the scope denoted by $\varepsilon \equiv -P^{''}(x)x / P^{'}(x)$. Furthermore, disutility from cross-border externalities enters into the social welfare function in the form of $\alpha Z(x)$, where $\alpha \geq 0$ is a parameter that measures the seriousness of cross-border externalities.

The main result inferred from this study is that; if there exist both cross-border externalities and asymmetry of information on the foreign firm's technology, government prefers import quotas to tariffs; since quotas discriminately affect firm's behavior depending on its type.

2.3 Location Choices of the Firms

In the third and final group, the main focus of the studies becomes the location decisions of the firms in the pollution-intensive industries and the relevant welfare effects of strategic environmental policies.

Markusen, Morey, and Olewiler (1993) introduce a different dimension to the existing analyses of environmental policy by allowing firms to enter or exit, and to change the number and location of their plants in response to environmental policies. In their model, a firm incorporated in Region A produces X with increasing returns and a firm in Region B produces Y. Z is a homogenous good produced in both regions and creates no externality. Each region is endowed with an identical amount of a homogenous factor input, L.

The cost functions for both potential firms are identical and denoted as $F \equiv$ firm specific fixed costs, $G \equiv$ plant specific fixed costs, $m \equiv$ constant marginal cost, $s \equiv$ per unit transport costs between the regions, and $t_a \equiv$ per unit pollution tax in Region A. It is assumed that profits from the firms and pollution tax revenues are equally distributed amongst the N individuals in each region. Moreover, all the individuals in each region have identical preferences represented by the same quadratic utility function. Hence, the inverse aggregate demand functions for each region is found by maximizing individual utility with respect to the individual budget constraints.

In stage one of the game, firms make a choice among no production, a plant only in their home region, or a plant in both regions. In the second stage, firms play a one-shut Cournot game. It is found that, firms are likely to prefer exporting to the other market when the fixed costs of a new plant are high relative to the unit transport costs. They also reach to a conclusion that the domestic firm can open a foreign branch if it is expelled from its original location by high emission taxes.

Ulph and Valentini (1997) extend the analysis of strategic environmental policy and plant location decisions by adding inter-sectoral linkages between different industries reflecting the input-output structure of the economy. In their model, there are two countries denoted by $m = 1,2$ and two industries, an upstream industry and a downstream industry. In each industry there are two firms denoted by $f = U1, U2, D1, D2$.

They proceed the analysis with a three-stage game. In the first stage governments set their environmental policies. It is assumed that there are fixed emission/output coefficients and governments control pollution by an emission tax t_m. Additionally, a profits tax at a rate T_m is imposed by the government to the plants located in country m. In the second stage the firms decide whether or not to build a plant in market m; in the last stage producers choose their outputs. It is further stated that the demand for the upstream firms are determined endogenously by the production decision of the downstream firms.

All the conclusions are drawn from numerical simulations. For plausible parameters, their model generates quite strong incentives for "ecological dumping", which is interpreted in their study as that governments set environmental taxes below marginal damage costs.

The study by Abe and Zhao (2005) examine the welfare effects of environmental policies when the choice between an international joint venture and a full-ownership FDI, and firm location are endogenously determined. They assume that a firm in the South has lower abatement technology than that in the North. The emission per unit of output of firm j is e_j, while emission tax in country i is t_i.

In stage 1, given the abatement technologies and the North's emission tax, South decides unilaterally to its emission tax level. In stage 2, the firms bargain to form an international joint venture whose production emits pollution. If the JV is formed; profit is shared and output is consumed in a third country, if bargaining breaks down; both firms can choose to locate in either country. If bargaining breaks down and firm N becomes a monopoly in the South, a full-ownership FDI arises.

They demonstrate that the optimal policy for a developing country with a relatively good abatement technology is to set a low emission tax to induce JV. On the other hand, the optimal policy for a developing country with a relatively bad abatement technology is to set a relatively higher emission tax so as to attract FDI.

Finally, Kayalica & Lahiri (2005) analyze the interaction between environmental standards and FDI. In their benchmark model, there are two firms (one from each country) competing under a Cournot duopoly to export a homogenous good to a third country. They denote constant average (marginal) cost of each i firm as;

$$\kappa_i = c_i + \mu(\theta_i - z_i), \qquad i = 1, 2$$

where c_i is the constant per unit cost determined by technological and factor market conditions, θ_i is the gross pollution before abatement, μ is the constant unit cost of abatement, and $z_i \in (0, \theta_i)$ is the maximum quantity of pollution per unit of output that the firms are allowed to emit into the atmosphere.

They assume that there is unemployment in both countries, and the profits of FDI are repatriated to the source countries. That is country 1 benefits from FDI only through the employment generated by foreign firms.

They find that, the non-cooperative equilibrium always generates a higher level of pollution per unit of output than the cooperative equilibrium. Moreover, when trade and environmental policies are simultaneously applied; market structure in the form of endogenous number of foreign firms has no effect on environmental policies; however, it has important implications when the countries are not allowed to use trade policies.

The studies of the subject authors have important contributions to the literature, in which the models are based on the third country model of Brander & Spencer (1985) and Eaton & Grossman (1986).

The main characteristic of the models examined in the first group is the inclusion of information asymmetries either on market demand or cost structures of the firms. It is shown that optimal trade policy choice of the government is sensitive to the form and severity of information asymmetries and even sometimes it is also optimal for the government to let the firm conceal its private cost information.

Another part of this literature focused on the effects of strategic environmental policies on the patterns of trade and pollution. One of the studies in this group incorporates the idea of information asymmetries and trade policies in the case that there exist cross-border externalities. However, by doing this Furusawa, Higashida, and Ishikawa (2004) lost the chance to analyze strategic environmental policies.

As a result of the growing concern on the environmental issues and ecological dumping, the location choice of the firms constitutes the focus of the third group. Studies following this approach diverge from each others in their methods used to analyze the models. Conclusions are derived either from equilibrium analysis, or simulation results or analytical interpretations depending on the nature of the study.

The studies examined above present insightful explanations to their questions. In our study, we aim to combine three approaches and see the connection among them more clearly.

3. THE MODEL

3.1 General Assumptions and Stages of the Model

The aim of the present study is to focus on the strategic use of trade and environmental policies to control pollution and the location choice of the foreign firm in the case of cost uncertainty.

In our model, there are two countries, a developing country (the South) and a developed country (the North). Each country has one firm producing a homogenous good of which production process generates local pollution. For simplicity, each unit of output is assumed to produce one unit of pollution. Furthermore, fixed costs and transportation costs are taken as zero.

Since the North is a developed country, North firm has more efficient technology than the South firm such that $c_S > c_N$, where $c_j, j = S, N$, represents the firm j's constant marginal production cost. It is assumed that, marginal cost of the South firm is publicly known however that of the North firm can take either a low value with probability of $\mu \in (0,1)$ or a relatively high value with probability $(1-\mu)$. That is $c_{NH} > c_{NL}$, where c_{Ni}, $i = L, H$, denotes Type i's marginal cost. Consumption takes place only in the South and inverse demand function is;

$$P = \alpha - Q \qquad \textbf{(3.1)}$$

where $Q = q_S + q_{Ni}$ is the total output and q_S and q_{Ni} are the amounts produced by the South firm and North firm with Type i respectively.

Timing of the model is illustrated in Figure 3.1. In the first stage of the game, the South determines the level of import tariff and emission tax, given the emission tax in the North. In the second stage, the North firm decides on the location choice for its production; the firms compete under Domestic Cournot (DC) if the North firm decides on engaging in a full-ownership FDI in the South and the firms compete under International Cournot (IC) if the North firm decides on staying at home.

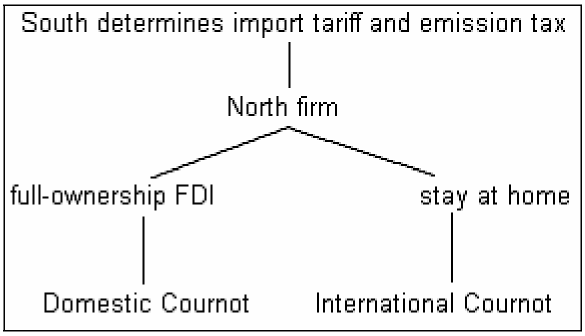

Figure 3.1: Timing of the Model

3.1.1 Market Stage Game under Domestic Cournot

First, it is considered that North firm engages in a full-ownership FDI in the South and firms play a Cournot-Nash game in the domestic country. Since the marginal cost of the foreign firm is private information, the problem South firm faces is maximizing the expected profit function with respect to its output as in (3.2);

$$\max_{(q_S)} \pi_S = \mu[(\alpha - (q_S + q_{NL}) - c_S - e_S)q_S] + (1-\mu)[(\alpha - (q_S + q_{NH}) - c_S - e_S)q_S] \qquad \textbf{(3.2)}$$

where e_S is the emission tax rate imposed by the South. The profit maximization problem of the North firm can be formulated as in (3.3);

$$\max_{(q_{Ni})} \pi_{Ni} = (\alpha - (q_S + q_{Ni}) - c_{Ni} - e_S)q_{Ni}, \quad \text{i=L,H} \qquad \textbf{(3.3)}$$

The reaction functions of the firms derived from the first order conditions are[1]

[1] Second order and stability conditions are satisfied.

$$q_S(\bar{q}_N) = \frac{1}{2}(\alpha - c_S - e_S - \bar{q}_N) \quad \textbf{(3.4)}$$

$$q_{Ni}(q_S) = \frac{1}{2}(\alpha - c_{Ni} - e_S - q_S), \quad \text{i=L,H} \quad \textbf{(3.5)}$$

where $\bar{q}_N$ stands for the expected value of the North firm's output, that is $\bar{q}_N = \mu q_{NL} + (1-\mu)q_{NH}$. Thus, solving the reaction functions simultaneously yields the market stage equilibrium outputs under DC as follows;

$$q_S^{DC} = \frac{1}{3}(\alpha + \bar{c}_N - 2c_S - e_S) \quad \textbf{(3.6)}$$

$$q_{Ni}^{DC} = \frac{1}{6}(2\alpha - \bar{c}_N - 3c_{Ni} + 2c_S - 2e_S), \quad \text{i=L,H} \quad \textbf{(3.7)}$$

where $\bar{c}_N$ represents the expected value of the North firm's marginal cost, such that $\bar{c}_N = \mu c_{NL} + (1-\mu)c_{NH}$. Taking optimal level of the outputs found as in (3.6) and (3.7) into account, we reach the profit levels under DC;

$$\pi_S^{DC} = \frac{1}{9}(\alpha + \bar{c}_N - 2c_S - e_S)^2 \quad \textbf{(3.8)}$$

$$\pi_{Ni}^{DC} = \frac{1}{36}(2\alpha - \bar{c}_N - 3c_{Ni} + 2c_S - 2e_S)^2, \quad \text{i=L,H} \quad \textbf{(3.9)}$$

3.1.2 Market Stage Game under International Cournot

As a second alternative, North firm may prefer to stay at home and export to the developing country. Then, firms engage in an International Cournot competition. The South firm's maximization problem does not change and be equivalent to the expression in (3.2).

On the other hand, by staying at home, North firm has to give an emission tax imposed by its own government and an import tariff determined by the South. Hence, this time the maximization problem of the North firm is;

$$\max_{(q_{Ni})} \pi_{Ni} = (\alpha - (q_S + q_{Ni}) - c_{Ni} - e_N - t_S) q_{Ni}, \quad \text{i=L,H} \tag{3.10}$$

Reaction functions derived from the First Order Conditions for the maximization problem of the firms are;

$$q_S(\overline{q}_N) = \frac{1}{2}(\alpha - c_S - e_S - \overline{q}_N) \tag{3.11}$$

$$q_{Ni}(q_S) = \frac{1}{2}(\alpha - c_{Ni} - e_S - t_S - q_S), \quad \text{i=L,H} \tag{3.12}$$

Taking the others reaction function into account, firms decide how much to produce and sell in the domestic market. Hence, the following market stage equilibrium outputs under IC are reached;

$$q_S^{IC} = \frac{1}{3}(\alpha + \overline{c}_N - 2c_S + e_N - 2e_S + t_S) \tag{3.13}$$

$$q_{Ni}^{IC} = \frac{1}{6}(2\alpha - \overline{c}_N - 3c_{Ni} + 2c_S - 4e_N + 2e_S - 4t_S), \quad \text{i=L,H} \tag{3.14}$$

Substituting the optimal output levels given by (3.13) and (3.14) into the profit functions, equilibrium levels of profits for each firm are derived;

$$\pi_S^{IC} = \frac{1}{9}(\alpha + \overline{c}_N - 2c_S + e_N - 2e_S + t_S)^2 \tag{3.15}$$

$$\pi_{Ni}^{IC} = \frac{1}{36}(2\alpha - \overline{c}_N - 3c_{Ni} + 2c_S - 4e_N + 2e_S - 4t_S)^2, \quad \text{i=L,H} \tag{3.16}$$

While deciding where to locate, North firm compares the profit levels it can attain under DC and IC, which are found as in (3.9) in the previous part and in (3.16) given above. In order for the North firm to engage in a full-ownership FDI, North firm must have $\pi_{Ni}^{DC} > \pi_{Ni}^{IC}$, which can be simplified as;

$$(e_N - e_S + t_S)(\bar{c}_N + 3c_{Ni} - 2(c_S - e_N - t_S + \alpha)) < 0, \quad \text{i=L,H} \qquad \textbf{(3.17)}$$

Second term in this inequality is always negative, considering the conditions which are necessary for the equilibrium outputs under both types of market structure to be positive[2]. Hence, first term in (3.17) must be positive for $\pi_{Ni}^{DC} > \pi_{Ni}^{IC}$ to be correct, and this result forms the basis for the following proposition.

Proposition 1: North firm prefers a full-ownership FDI in the South to stay at home iff; $e_N + t_S > e_S$ is satisfied.

This result is also intuitively clear. While the North firm has to pay $(e_N + t_S)$ per unit of output in the case of exporting from home, he has to pay only e_S per unit of output in the case of engaging in a full-ownership FDI.

3.1.3 Optimal Policies under Domestic Cournot

In this part, the domestic government chooses the optimal levels of import tariff and emission tax, first under DC, knowing the reactions of both firms in the second stage. As it is common in this literature, this means that, domestic government acts in fact as a Stackelberg strategic leader relative to the firms which play a Cournot-Nash game in the market stage.

Given the emission tax in the North, the domestic government tries to maximize social welfare which consists of three parts; (1) consumer surplus in the country, (2) profit of the South firm, and (3) pollution tax revenues net of total damage of pollution to the country. Here d is marginal damage of pollution to the South. Since

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[2] See Appendix-A for mathematica commands.

it is presumed that there is a cost uncertainty on the North firm's production technology; South government maximizes the expected social welfare function.

Starting with the case that, there is a domestic competition between the firms in the market stage game, the expected social welfare function of the South under DC can be written as;

$$EW_S^{DC} = \mu[\frac{(q_S + q_{NL})^2}{2} + \pi_S + (e_S - d)(q_S + q_{NL})]$$

$$+ (1-\mu)[\frac{(q_S + q_{NH})^2}{2} + \pi_S + (e_S - d)(q_S + q_{NH})] \quad \textbf{(3.18)}$$

Recalling that the inverse demand function is linear, the first terms in the brackets are consumer surpluses of the domestic country in the cases of the North firm with Type L and Type H, and represented simply by $CS = Q^2 / 2 = (q_S + q_{Ni}) / 2$. Profit function of the domestic firm is given before in the equation (3.2). Finally, since both of the firms produce in the South and production causes pollution on a one to one basis, pollution tax revenues net of marginal damage is $(e_S - d)(q_S + q_{Ni})$. Here, d is the constant marginal cost of pollution. To have a meaningful analysis, it is assumed that $\alpha > c_S + d$.

After substituting the equilibrium output levels under DC given by equations (3.6) and (3.7) into (3.18), we obtain the first order condition of the government maximization problem under DC as;

$$\frac{d\ EW_S^{DC}(e_S)}{d\ e_S} = 0 \quad \textbf{(3.19)}$$

After rearranging (3.19), the optimal emission tax under DC is found as in (3.20), from which the second proposition is also derived;

$$e_S^{DC} = \frac{1}{2}(c_S - \bar{c}_N + 2d) \quad \textbf{(3.20)}$$

Proposition 2: While the marginal cost of the South firm converges to the expected marginal cost of the North firm, the optimal level of the emission tax under DC converges to the marginal damage of pollution in the South.

Since we assumed that, the firm from the developed country has more efficient technology than the firm from the developing country, $(c_S > c_{NH} > \overline{c}_N > c_{NL})$ should be valid. Hence, it is inferred from the second proposition that the optimal emission tax level under DC is higher than the marginal damage of pollution in the South. Although it seems that there is an over taxation, e_S is actually not only used to control pollution but also serves as an excise tax, because of the nature of the market structure.

Additionally, after substituting $\overline{c}_N = \mu c_{NL} + (1-\mu)c_{NH}$ into (3.20), it can be easily seen that $\partial e_S^{DC} / \partial \mu = (c_{NH} - c_{NL})/2 > 0$, which is interpreted in the following proposition.

Proposition 3: The optimal emission tax level under DC increases, as the probability of the marginal cost of the North firm to be Type L (low) increases.

It is intuitively clear that; since having a low marginal cost is an advantage for the North firm, it can produce a high level of the output and hence creates a high level of pollution under DC, which can be controlled by the South government with a high emission tax.

3.1.4 Optimal Policies under International Cournot

Secondly, the firms play an international Cournot-Nash game in the second stage. This time, the expected social welfare of the South is;

$$EW_S^{IC} = \mu[\frac{(q_S + q_{NL})^2}{2} + \pi_S + (e_S - d)q_S + t_S q_{NL}]$$

$$+ (1-\mu)[\frac{(q_S + q_{NH})^2}{2} + \pi_S + (e_S - d)q_S + t_S q_{NH}] \quad \textbf{(3.21)}$$

The equation in (3.21) includes also import tax revenue depending on the Type of the firm in the North but excludes pollution tax revenue net of marginal damage from the production of the North firm; because, its production takes place in its own country and it is assumed that there is no cross-border externality. After substituting the equilibrium output levels under IC given by the equations (3.13) and (3.14) into (3.21), the First Order Conditions of the government maximization problem are given as;

$$\frac{d\ EW_S^{IC}(e_S, t_S)}{d\ e_S} = 0 \qquad \textbf{(3.22a)}$$

$$\frac{d\ EW_S^{IC}(e_S, t_S)}{d\ t_S} = 0 \qquad \textbf{(3.22b)}$$

By solving the equations (3.22a) and (3.22b) simultaneously, the optimal emission tax and import tariff under IC are derived as;

$$e_S^{IC} = \frac{1}{2}(3c_S - \bar{c}_N + 5d - e_N - 2\alpha) \qquad \textbf{(3.23a)}$$

$$t_S^{IC} = \frac{1}{2}(c_S - \bar{c}_N + d - e_N) \qquad \textbf{(3.23b)}$$

After substituting $\bar{c}_N = \mu c_{NL} + (1-\mu)c_{NH}$ into (3.23a) and (3.23b), and then taking the derivative of both of them with respect to μ, it is found that $\partial e_S^{IC} / \partial\mu = \partial t_S^{IC} / \partial\mu = (c_{NH} - c_{NL})/2 > 0$. This result is interpreted in the following proposition.

Proposition 4: The optimal emission tax and import tariff under IC increases, as the probability of the marginal cost of the North firm to be Type L (low) increases.

It is also intuitive that; North firm with a low marginal cost has a comparative advantage in the case of international competition, hence South government may try to protect its own firm by imposing a high level import tariff to the North firm.

Furthermore, the proposition above implies that, the level of emission tax under IC also depends on the foreign firm's technology as in the case of DC.

Up to now, the optimal levels of trade and environmental policies for the South are derived by solving the two-stage game theoretic model of this study. There is one more thing to check for the efficiency of the optimal policy levels. Is the decision of engaging in a full-ownership FDI in the South also the best response of the North firm to the case that the government of the South imposes the optimal level of the emission tax under DC? Similarly, does the North firm prefer staying at home if the government of the South imposes the optimal level of the emission tax under IC? If the answers are no, the minimum or maximum levels of taxes that is compatible with South governments aim should be specified.

3.2 Location Decision of the Foreign Firm

In the previous section, it is proposed that North firm prefers playing a domestic Cournot-Nash game in the second stage iff $e_N + t_S > e_S$ is satisfied. Since the import tariff does not enter into the maximization problem of the domestic government if the firms play a domestic Cournot-Nash game, the government has only one optimal level for that policy variable. Hence, if the optimal import tariff under IC given by (3.23b) is substituted into the inequality above, it becomes;

$$\frac{1}{2}(e_N + c_S - \bar{c}_N + d) > e_S \qquad \textbf{(3.24)}$$

If the left hand side of this inequality is denoted by $\tilde{e}_S$, it is seen that the maximum level domestic government can impose to make North firm produce in the South is just a little less than $\tilde{e}_S$.

$$\tilde{e}_S = \frac{1}{2}(e_N + c_S - \bar{c}_N + d) \qquad \textbf{(3.25)}$$

Any emission tax higher than $\tilde{e}_S$, changes the direction of the inequality in (3.24), which means that in that case the North firm prefers to stay at home. Moreover, if optimal emission tax under DC given by (3.20) is substituted into the inequality (3.24), $(d < e_N)$ is obtained. This condition brings about the Proposition 5 and the idea is summarized in Figure 3.2.

Proposition 5: The government of the South can impose the optimal emission tax level under DC iff the marginal damage of the pollution for the South is less than the emission tax level of the North; such that $(d < e_N)$. Otherwise, the maximum level domestic government can impose to make North firm produce in the South is just a little less than $\tilde{e}_S$.

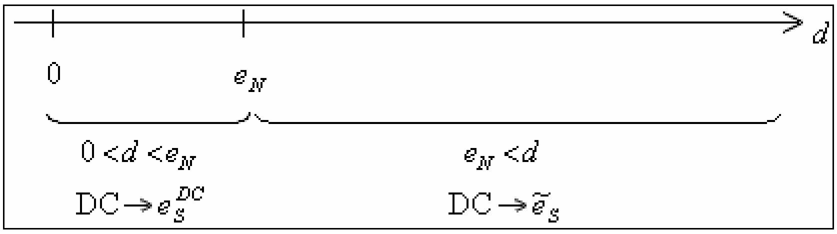

Figure 3.2: Efficiency Interval for the Optimal Policy Variable under DC

Moreover, after putting the equilibrium output levels into (3.18); if $\tilde{e}_S$ is substituted into the partial differential of the expected social welfare under DC with respect to the emission tax, it is found that;

$$\frac{d\ EW_S^{DC}}{d\ e_S}(\tilde{e}_S) = \frac{1}{3}(d - e_N) \qquad \textbf{(3.26)}$$

The equation in (3.26) implies that, $\tilde{e}_S$ is on the decreasing part of the expected social welfare function under DC in the case $(d < e_N)$. This is also represented in Figure 3.3 graphically.

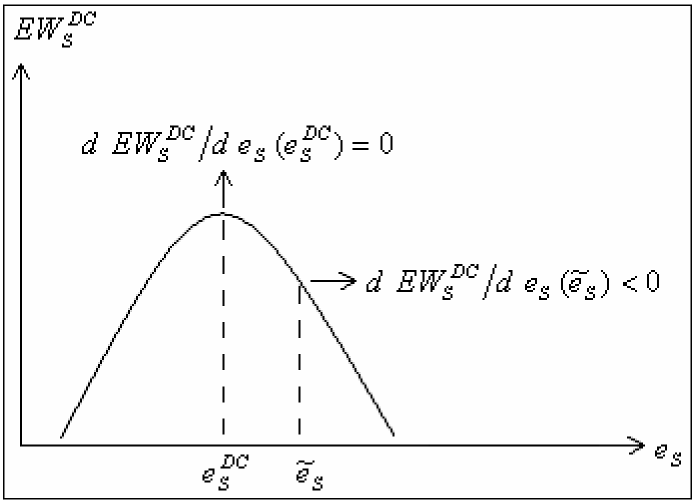

Figure 3.3: Expected Welfare Function under DC in the case $(d < e_N)$

Let's consider the other case, in which North firm prefers playing an international Cournot-Nash game in the second stage. This is possible iff $e_N + t_S < e_S$ is satisfied. If optimal emission tax and optimal import tariff under IC given by (3.23a) and (3.23b) are substituted into this inequality, it is obtained that ($d > (e_N + \alpha - c_S)/2$). Similarly, this result is illustrated in Figure 3.4 and interpreted in Proposition 6.

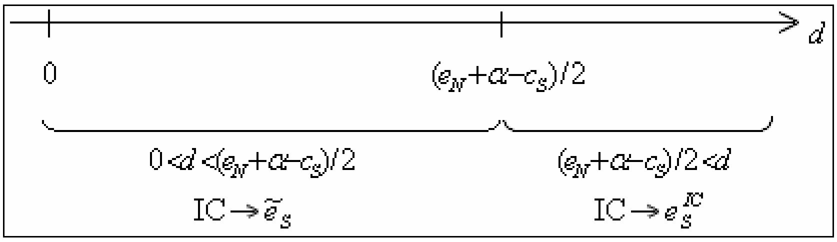

Figure 3.4: Efficiency Interval for the Optimal Policy Variable under IC

Proposition 6: The government of the South can impose the optimal emission tax level under IC iff the marginal damage of the pollution for the South is sufficiently high, $d > (e_N + \alpha - c_S)/2$. Otherwise, the minimum level domestic government can impose to make North firm produce in its own country is just a little higher than $\tilde{e}_S$.

Similarly, after putting the equilibrium output levels into (3.18); if $\tilde{e}_S$ and t_S^{IC} are substituted into the partial differential of the expected social welfare under IC with respect to the emission tax;

$$\frac{d\ EW_S^{IC}}{d\ e_S}(\tilde{e}_S, t_S^{IC}) = \frac{1}{3}(c_S + 2d - \alpha - e_N) \qquad \textbf{(3.27)}$$

This time, it is found that $\tilde{e}_S$ is on the increasing part of the expected social welfare function under IC in the case $d > (e_N + \alpha - c_S)/2$. Figure 3.5 illustrates this result graphically.

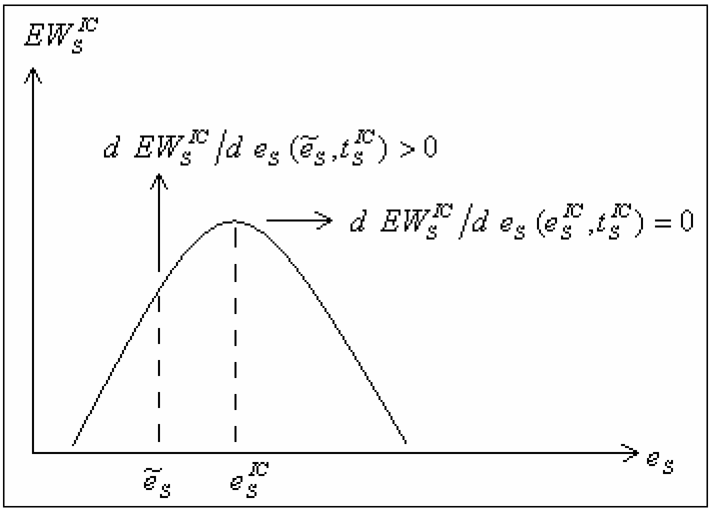

Figure 3.5: Expected Welfare Function under IC in the case $d > (e_N + \alpha - c_S)/2$

Note that emission taxes as just a little less than $\tilde{e}_S$ or a little higher than $\tilde{e}_S$ make a difference in the welfare levels of the South government, which can be ignored. Thus, in the preceding figures and in the following Figure 3.6, which summarizes the Proposition 5 and the Proposition 6, the boundary levels of emission taxes are shown as simply $\tilde{e}_S$.

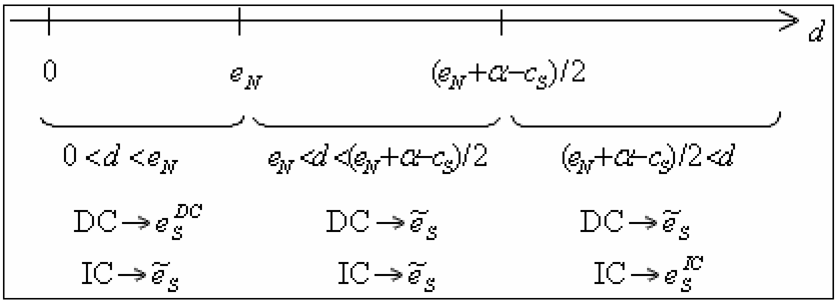

Figure 3.6: Efficiency Interval for the Optimal Policy Variable

Also not that, to have a meaningful interval, in Figure 3.6 it is taken as $e_N < (e_N + \alpha - c_S)/2$. The proof is simple: Considering the necessary conditions found in Appendix-B, $e_N < (e_N + \alpha - c_S)/2$ is possible iff $\alpha > c_S + e_N$ is satisfied. It was already assumed that $\alpha > c_S + d$ to have a meaningful model. Hence, if $d > e_N$ and $\alpha > c_S + d$; $\alpha > c_S + e_N$ is already satisfied.

3.3 Welfare Comparison

As it is derived in the preceding section, there are three intervals for the marginal damage of the pollution for the South to be considered while deciding the welfare levels for the South.

In the case that the first interval $(0 < d < e_N)$ is satisfied, the South government imposes optimal emission tax under DC, e_S^{DC}, given by (3.20), to make the North firm prefer a full-ownership FDI. Alternatively, to make the North firm prefer to stay at home, the government can impose an emission tax as the boundary level $\tilde{e}_S$ given by (3.25). After substituting these levels into the expected welfare functions under DC and IC, it is possible to find which case (DC or IC) is preferable for the government from the following welfare differences[3];

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[3] See Appendix-B for the mathematica commands.

$$EW_S^{DC}(e_S^{DC}) - EW_S^{IC}(\tilde{e}_S) = \frac{1}{12}(d - e_N)(-2c_S + 3d + e_N - 4\alpha + 6\bar{c}_N) > 0 \qquad \textbf{(3.28)}$$

Proposition 8: The government of the South attain a higher welfare under DC by imposing the optimal emission tax under DC, if the marginal damage of the pollution for the South is less than the emission tax level of the North, $(d < e_N)$.

From the proposition 8, it is inferred that if $(d < e_N)$ is the case, South government prefers DC to the IC and hence decides to impose the optimal emission tax level under DC, e_S^{DC}, given by (3.20), in the first stage of the game.

Secondly, the marginal damage of the pollution for the South may be in the interval $(e_N, (e_N + \alpha - c_S)/2)$. In this case, the South government imposes an emission tax as the boundary level $\tilde{e}_S$ given by (3.25) for both of the situations, hence the expected welfare level gap is[4];

$$EW_S^{IC}(\tilde{e}_S) - EW_S^{DC}(\tilde{e}_S) = \frac{1}{6}(d - e_N)(-c_S + d + e_N - 2\alpha + 3\bar{c}_N) > 0 \qquad \textbf{(3.29)}$$

Proposition 9: The government of the South attains a higher welfare under IC by imposing the boundary level of the emission tax, if the marginal damage of the pollution for the South is in the interval of $(e_N, (e_N + \alpha - c_S)/2)$.

If $(e_N, (e_N + \alpha - c_S)/2)$ is the case, this time firms play IC in the second stage, since South government prefers IC to DC and hence decides to reveal an emission tax level just a little higher than $\tilde{e}_S$.

Finally, if $(e_N + \alpha - c_S)/2 < d)$ is satisfied, the South government imposes an emission tax as the boundary level $\tilde{e}_S$ again given by (3.25), to make the North firm engage in a full-ownership FDI in the South. Alternatively, to make the North firm stay at home, the policy makers in the South can charge an emission tax as the

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[4] See Appendix-B for the mathematica commands.

optimal level under IC e_S^{IC} given by (3.23a). After substituting these levels into the expected welfare functions under DC and IC, the expected welfare level gap is as;

$$EW_S^{IC}(e_S^{IC}) - EW_S^{DC}(\tilde{e}_S) = \frac{1}{6}[c_S^2 + 3d^2 - 4de_N + 2e_N^2 - 2d\alpha + \alpha^2$$

$$+ c_S(5d - 3e_N - 2\alpha) - 3\bar{c}_N(d - e_N)] \qquad \textbf{(3.30)}$$

which is greater than zero iff following condition is satisfied[5];

$$(c_S^2 + 5c_S d + 3d^2 + 3\bar{c}_N e_N + 2e_N^2 + \alpha^2) > (3\bar{c}_N d + 3c_S e_N + 4de_N + 2(c_S + d)\alpha) \qquad \textbf{(3.31)}$$

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5 See the Appendix-B for the mathematica commands. Because of the complexity of the expression in (3.31), this case is only analyzed in the Appendix-C numerically.

4. COMPARISON OF POLLUTION LEVELS

To compare local pollution stemmed from the production process of the firms in the South, the production levels will be calculated given the policy levels decided by the South in the first stage. If the firms play a domestic Cournot-Nash game, then, outputs of both of the firms result in local pollution. Since the pollution is assumed on a one to one basis, the pollution under DC is then;

$$Q_S^{DC}(e_S) = q_S^{DC}(e_S) + \bar{q}_N^{DC}(e_S) \qquad \textbf{(4.1)}$$

where $\bar{q}_N^{DC}$ is the expected level of the North firm's output.

However, if there is an international Cournot competition, only the output of the South firm causes to pollution as;

$$Q_S^{IC}(e_S, t_S^{IC}) = q_S^{IC}(e_S, t_S^{IC}) \qquad \textbf{(4.2)}$$

As in the welfare comparison, three cases will be considered separately for the internals of d [6]. First suppose that $(0 < d < e_N)$ is satisfied, the domestic government imposes either e_S^{DC} for a domestic Cournot competition or $\tilde{e}_S$ for an international Cournot competition. By substituting e_S^{DC} into (4.1), and $\tilde{e}_S$ into (4.2) for the emission tax level, and then subtracting them it is obtained;

$$Q_S^{DC-IC} = \frac{1}{6}(c_S - 3d + e_N + 2\alpha - 3\bar{c}_N) > 0 \qquad \textbf{(4.3)}$$

[6] See Appendix-D for the mathematica commands.

Secondly, considering the case with $(e_N < d < (e_N + \alpha - c_S)/2)$, the South imposes either just a little less or higher than $\tilde{e}_S$. Hence, after substituting $\tilde{e}_S$ both into (4.1) and (4.2), and then subtracting them, it is found;

$$Q_S^{DC-IC} = \frac{1}{6}(c_S - d - e_N + 2\alpha - 3\bar{c}_N) > 0 \qquad \textbf{(4.4)}$$

Finally, for the case of $(e_N + \alpha - c_S)/2 < d$, $\tilde{e}_S$ is substituted into (4.1) and e_S^{IC} into (4.2). After subtracting them;

$$Q_S^{DC-IC} = \frac{1}{6}(5c_S + 7d - 5e_N - 2\alpha - 3\bar{c}_N) > 0 \qquad \textbf{(4.5)}$$

Proposition 10: Domestic Cournot competition between the firms results in a higher total production and hence higher local pollution in the South than the case of international Cournot competition.

5. SUMMARY AND CONCLUSIONS

This study aimed to focus on the strategic use of trade and environmental policies to control pollution and the location choice of the foreign firm in the case of uncertainty on the foreign firm's technology. A two-stage game theoretical model is utilized to reach the intended goal.

The study followed in three main parts: In the first part, theoretical studies on the strategic trade policy models in the relevant literature were explained briefly into three groups. In the first group, the studies of Cooper & Riezman (1989), Qiu (1994), Zeki-Orbay (1996) and Caglayan & Usman (2004).had special assumptions on the asymmetric information.

The studies performed by Barrett (1994), Ludema & Wooton (1996), Tanguay (2001), and Furusawa, Higashida & Ishikawa (2004) were considered in the second group with their environmental policy contributions to this literature.

Finally, the studies of Markusen, Morey, and Olewiler (1993), Ulph & Valentini (1997), Abe & Zhao (2005) and Kayalica & Lahiri (2005) focusing on the location decisions of the firms were taken in the third group. The common characteristic of all these studies was the fact that they were taking their basis from the well-known third country models of Brander & Spencer (1985) and Eaton & Grossman (1986).

In the second part, we constructed a two-country model. First, the general assumptions and the stages of the model were introduced, and then some of the propositions were derived from the analysis of the model.

The third part presented comparison of pollution levels under the domestic Cournot and the international Cournot cases.

The analysis of the model indicated that; FDI in the pollution-intensive industries could result in welfare gains in the home country, only if the marginal damage of the pollution for the South is sufficiently small, which is also common in the literature. In that case, South government prefers imposing an emission tax level which motivates FDI.

Although it is crucial for developing countries to be attractive for FDI, our analysis demonstrated that it may not be always optimal to impose an emission tax level that motivates FDI. We have seen that; being the host country for FDI in pollution intensive industries results always in a higher level of total production and hence local pollution in the South than a competition in the international market. As a result, if the marginal damage of pollution is high, than South country should choose the emission tax level which motivates the North firm export from home for an international competition.

Instead of using trade and environmental policies simultaneously; which are import tariff and emission tax in our model, the governments of developing countries have to control the problems of pollution and imperfect competition only with emission taxes in the case of domestic competition. If the damage of pollution to the country is severe, this situation causes welfare losses compared to the international competition, which is mainly because of the fact that emission taxes on their own are not capable of correcting all these problems.

Furthermore, if there is incomplete information about the foreign firm's technology, which affect the optimal levels of emission taxes, the welfare losses could be even larger. Hence, developing countries should take all these into account while deciding to attract FDI in the pollution-intensive industries.

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APPENDIX-A

MATHEMATICA COMMANDS FOR THE PROOF OF PROPOSITION 1

```
----In order to have a meaningful analysis,
the optimal levels of equilibrium outputs under DC and IC have to be positive,
where cN = μ cnl + (1 - μ) cnh
represents the expected marginal cost of the North firm.----
```

$$\text{Reduce}\left[\frac{1}{3}\ (cN - 2\,cs - es + \alpha) \geq 0\right]$$

$$(cs\ |\ es\ |\ \alpha) \in \text{Reals}\ \&\&\ cN \geq 2\,cs + es - \alpha$$

$$\text{Reduce}\left[\frac{1}{6}\ (-cN - 3\,cni + 2\,cs - 2\,es + 2\,\alpha) \geq 0\right]$$

$$(cni\ |\ cs\ |\ es\ |\ \alpha) \in \text{Reals}\ \&\&\ cN \leq -3\,cni + 2\,cs - 2\,es + 2\,\alpha$$

$$\text{Reduce}\left[\frac{1}{3}\ (cN - 2\,cs + en - 2\,es + ts + \alpha) \geq 0\right]$$

$$(cs\ |\ en\ |\ es\ |\ ts\ |\ \alpha) \in \text{Reals}\ \&\&\ cN \geq 2\,cs - en + 2\,es - ts - \alpha$$

$$\text{Reduce}\left[\frac{1}{6}\ (-cN - 3\,cni + 2\,cs - 4\,en + 2\,es - 4\,ts + 2\,\alpha) \geq 0\right]$$

$$(cni\ |\ cs\ |\ en\ |\ es\ |\ ts\ |\ \alpha) \in \text{Reals}\ \&\&\ cN \leq -3\,cni + 2\,cs - 4\,en + 2\,es - 4\,ts + 2\,\alpha$$

----Hence, these conditions have to be always satisfied :

$$\{cN \geq 2\,cs + es - \alpha,\ cN \leq -3\,cni + 2\,cs - 2\,es + 2\,\alpha,$$
$$cN \geq 2\,cs - en + 2\,es - ts - \alpha,$$
$$cN \leq -3\,cni + 2\,cs - 4\,en + 2\,es - 4\,ts + 2\,\alpha\}\ ----$$

$$dpni = \frac{1}{36}\ (-cN - 3\,cni + 2\,cs - 2\,es + 2\,\alpha)^2;$$

$$IPNi = \frac{1}{36}\ (cN + 3\,cni - 2\,cs + 4\,en - 2\,es + 4\,ts - 2\,\alpha)^2;$$

```
----where dpni and IPNi are the optimal profit levels of the North firm with
Type - i under DC and IC respectively----

FullSimplify[dpni > IPNi]
```

$$(en - es + ts)\ (cN + 3\,cni - 2\,(cs - en - ts + \alpha)) < 0$$

```
FullSimplify[(cN + 3 cni - 2 (cs - en - ts + α)) ≤ 0,
 {cN ≥ 2 cs + es - α, cN ≤ -3 cni + 2 cs - 2 es + 2 α, cN ≥ 2 cs - en + 2 es - ts - α,
  cN ≤ -3 cni + 2 cs - 4 en + 2 es - 4 ts + 2 α}]

True

----Hence; for (dpni > IPNi) be true,
it has to (en - es + ts) > 0 ----
```

APPENDIX-B

MATHEMATICA COMMANDS FOR THE WELFARE COMPARISON

```
----The conditions found in Appendix - A are :
    {cN ≥ 2 cs + es - α, cN ≤ -3 cnl + 2 cs - 2 es + 2 α,
        cN ≤ -3 cnh + 2 cs - 2 es + 2 α, cN ≥ 2 cs - en + 2 es - ts - α,
        cN ≤ -3 cnl + 2 cs - 4 en + 2 es - 4 ts + 2 α,
        cN ≤ -3 cnh + 2 cs - 4 en + 2 es - 4 ts + 2 α} ----

----After subsitituting the optimal levels of emission taxes and
 import tariff under DC and IC into these conditions :

{es = 1/2 (cs - cN + 2 d);, ts = -1/2 (cN - cs - d + en)};
FullSimplify[{cN ≥ 2 cs + es - α, cN ≤ -3 cnl + 2 cs - 2 es + 2 α,
  cN ≤ -3 cnh + 2 cs - 2 es + 2 α, cN ≥ 2 cs - en + 2 es - ts - α,
  cN ≤ -3 cnl + 2 cs - 4 en + 2 es - 4 ts + 2 α,
  cN ≤ -3 cnh + 2 cs - 4 en + 2 es - 4 ts + 2 α}]

{3 cN + 2 α ≥ 5 cs + 2 d, 3 cnl + 2 d ≤ cs + 2 α, 3 cnh + 2 d ≤ cs + 2 α,
 3 cN + en + 2 α ≥ 5 cs + 3 d, 3 cnl + 2 en ≤ cs + 2 α, 3 cnh + 2 en ≤ cs + 2 α}

----Since cnh > cN > cnl and cN = μ cnl + (1 - μ) cnh ;
{3 cnh + 2 α ≥ 5 cs + 2 d, 3 cN + 2 d ≤ cs + 2 α, 3 cnh + en + 2 α ≥ 5 cs + 3 d,
  3 cN + 2 en ≤ cs + 2 α} are also required.----

{es = -1/2 (cN - 3 cs - 5 d + 2 α + en);, ts = -1/2 (cN - cs - d + en)};
FullSimplify[{cN ≥ 2 cs + es - α, cN ≤ -3 cnl + 2 cs - 2 es + 2 α,
  cN ≤ -3 cnh + 2 cs - 2 es + 2 α, cN ≥ 2 cs - en + 2 es - ts - α,
  cN ≤ -3 cnl + 2 cs - 4 en + 2 es - 4 ts + 2 α,
  cN ≤ -3 cnh + 2 cs - 4 en + 2 es - 4 ts + 2 α}]

{3 cN + en + 4 α ≥ 7 cs + 5 d, 3 cnl + cs + 5 d ≤ en + 4 α, 3 cnh + cs + 5 d ≤ en + 4 α,
 cN + en + 2 α ≥ 3 (cs + d), cnl + en ≤ cs + d, cnh + en ≤ cs + d}

----Since cnh > cN > cnl and cN = μ cnl + (1 - μ) cnh ;
{3 cnh + en + 4 α ≥ 7 cs + 5 d, 3 cN + cs + 5 d ≤ en + 4 α, cnh + en + 2 α ≥ 3 (cs + d),
  cN + en ≤ cs + d} are also required.----
```

```
----Optimal levels of emission taxes and import tariff under
  DC and IC are ≥ 0 iff----

FullSimplify[{1/2 (cs - cN + 2 d) ≥ 0, -1/2 (cN - 3 cs - 5 d + 2 α + en) ≥ 0,
  -1/2 (cN - cs - d + en) ≥ 0}]

{cs + 2 d ≥ cN, 3 cs + 5 d ≥ cN + en + 2 α, cs + d ≥ cN + en}

---Since cnh > cN > cnl and cN = μ cnl + (1 - μ) cnh;
{cs + 2 d ≥ cnl, 3 cs + 5 d ≥ cnl + en + 2 α, cs + d ≥ cnl + en} are also
 required----

----{α ≥ cs + d, cs ≥ 0, cnl ≥ 0, cnh ≥ 0, cnh > cnl, d ≥ 0, en ≥ 0, α ≥ 0}
 are also required----


----All the conditions found above together;
{3 cN + 2 α ≥ 5 cs + 2 d, 3 cnl + 2 d ≤ cs + 2 α, 3 cnh + 2 d ≤ cs + 2 α,
   3 cN + en + 2 α ≥ 5 cs + 3 d, 3 cnl + 2 en ≤ cs + 2 α, 3 cnh + 2 en ≤ cs + 2 α,
   3 cnh + 2 α ≥ 5 cs + 2 d, 3 cN + 2 d ≤ cs + 2 α, 3 cnh + en + 2 α ≥ 5 cs + 3 d,
   3 cN + 2 en ≤ cs + 2 α, 3 cN + en + 4 α ≥ 7 cs + 5 d, 3 cnl + cs + 5 d ≤ en + 4 α,
   3 cnh + cs + 5 d ≤ en + 4 α, cN + en + 2 α ≥ 3 (cs + d), cnl + en ≤ cs + d,
   cnh + en ≤ cs + d, 3 cnh + en + 4 α ≥ 7 cs + 5 d, 3 cN + cs + 5 d ≤ en + 4 α,
   cnh + en + 2 α ≥ 3 (cs + d), cN + en ≤ cs + d, cs + 2 d ≥ cN, 3 cs + 5 d ≥ cN + en + 2 α,
   cs + d ≥ cN + en, cs + 2 d ≥ cnl, 3 cs + 5 d ≥ cnl + en + 2 α, cs + d ≥ cnl + en,
   α ≥ cs + d, cs ≥ 0, cnl ≥ 0, cnh ≥ 0, cnh > cnl, d ≥ 0, en ≥ 0, α ≥ 0}----
```

WELFARE COMPARISON :

```
wdc[qs_, qnl_, qnh_, ps_, es_] =
  Expand[μ {((qs + qnl) ^2) / 2 + ps + (es - d) (qs + qnl)} +
    (1 - μ) {((qs + qnh) ^2) / 2 + ps + (es - d) (qs + qnh)}];


dqs = 1/3 (cnh - 2 cs - es + α - cnh μ + cnl μ);

dqnl = 1/6 (2 (cs - es + α) + cnh (-1 + μ) - cnl (3 + μ));

dqnh = 1/6 (2 cs - 2 es + 2 α + cnh (-4 + μ) - cnl μ);

dps = 1/9 (cnh - 2 cs - es + α - cnh μ + cnl μ)^2;

----where dqs, dqnl, dqnh are the optimal levels of outputs under
 DC and dps is the optimal profit level under DC----

WDC = FullSimplify[wdc[dqs, dqnl, dqnh, dps, es]];

wic[qs_, qnl_, qnh_, ps_, es_, ts_] =
  Expand[μ {((qs + qnl) ^2) / 2 + ps + (es - d) qs + ts qnl} +
    (1 - μ) {((qs + qnh) ^2) / 2 + ps + (es - d) qs + ts qnh}];
```

```
iqs = 1/3 (cnh - 2 cs + en - 2 es + ts + α - cnh μ + cnl μ);

iqnl = 1/6 (2 (cs - 2 en + es - 2 ts + α) + cnh (-1 + μ) - cnl (3 + μ));

iqnh = 1/6 (2 cs - 4 en + 2 es - 4 ts + 2 α + cnh (-4 + μ) - cnl μ);

IPS = 1/9 (cnh - 2 cs + en - 2 es + ts + α - cnh μ + cnl μ)^2;

----where iqs, iqnl, iqnh are the optimal levels of outputs under
 IC and IPS is the optimal profit level under IC----

WIC = FullSimplify[wic[iqs, iqnl, iqnh, IPS, es, ts]];

des = 1/2 (-cnh + cs + 2 d + cnh μ - cnl μ);

ies = -1/2 (cnh - 3 cs - 5 d + en + 2 α - cnh μ + cnl μ);

its = -1/2 (cnh - cs - d + en - cnh μ + cnl μ);

----where des and ies are the optimal levels of emission taxes under
 DC and IC, and its is the optimal level of import tariff under IC----

ses = FullSimplify[en + its]

1/2 (cs + d + en + cnh (-1 + μ) - cnl μ)

es = des; dWDC = FullSimplify[WDC]

{1/24 (2 (3 cnh^2 - 6 cnh cs + 7 cs^2 + 8 cs (d - α) + 4 (d - α)^2) -
    3 (cnh - cnl) (3 cnh + cnl - 4 cs) μ + 3 (cnh - cnl)^2 μ^2)}

es = ses; dsWDC = FullSimplify[WDC]

{1/24 (2 (3 cnh^2 - 6 cnh cs + 7 cs^2 + (3 d - en - 2 α) (d + en - 2 α) + 8 cs (d - α)) -
    3 (cnh - cnl) (3 cnh + cnl - 4 cs) μ + 3 (cnh - cnl)^2 μ^2)}

es = ies; ts = its; iWIC = FullSimplify[WIC]

{1/8 (2 (cnh^2 + 3 cs^2 + 6 cs d + 3 d^2 -
        2 cnh (cs + d - en) - 2 cs en - 2 d en + en^2 - 4 (cs + d) α + 2 α^2) -
    (cnh - cnl) (3 cnh + cnl - 4 (cs + d - en)) μ + (cnh - cnl)^2 μ^2)}

es = ses; ts = its; isWIC = FullSimplify[WIC]

{1/24 (2 (3 cnh^2 + 7 cs^2 - 6 cnh (cs + d - en) + 2 cs (5 d - en - 4 α) + (d + en - 2 α)^2) -
    3 (cnh - cnl) (3 cnh + cnl - 4 (cs + d - en)) μ + 3 (cnh - cnl)^2 μ^2)}
```

```
FullSimplify[dWDC - isWIC]

{1/12 (d - en) (-2 cs + 3 d + en - 4 α - 6 cnh (-1 + μ) + 6 cnl μ)}

F1 = 1/12 (d - en) (-2 cs + 3 d + en - 4 α + 6 cN);

FullSimplify[dsWDC - isWIC]

{1/6 (d - en) (-cs + d + en - 2 α - 3 cnh (-1 + μ) + 3 cnl μ)}

F2 = 1/6 (d - en) (-cs + d + en - 2 α + 3 cN);

FullSimplify[iWIC - dsWDC]

{1/6 (cs^2 + 3 d^2 - 4 d en + 2 en^2 + cs (5 d - 3 en - 2 α) -
    2 d α + α^2 + 3 cnh (d - en) (-1 + μ) - 3 cnl d μ + 3 cnl en μ)}

F3 = 1/6 (cs^2 + 3 d^2 - 4 d en + 2 en^2 - 2 d α + α^2 + cs (5 d - 3 en - 2 α) - 3 cN (d - en));

FullSimplify[F1 > 0, {3 cN + 2 α ≥ 5 cs + 2 d, 3 cnl + 2 d ≤ cs + 2 α,
   3 cnh + 2 d ≤ cs + 2 α, 3 cN + en + 2 α ≥ 5 cs + 3 d, 3 cnl + 2 en ≤ cs + 2 α,
   3 cnh + 2 en ≤ cs + 2 α, 3 cnh + 2 α ≥ 5 cs + 2 d, 3 cN + 2 d ≤ cs + 2 α,
   3 cnh + en + 2 α ≥ 5 cs + 3 d, 3 cN + 2 en ≤ cs + 2 α, 3 cN + en + 4 α ≥ 7 cs + 5 d,
   3 cnl + cs + 5 d ≤ en + 4 α, 3 cnh + cs + 5 d ≤ en + 4 α, cN + en + 2 α ≥ 3 (cs + d),
   cnl + en ≤ cs + d, cnh + en ≤ cs + d, 3 cnh + en + 4 α ≥ 7 cs + 5 d,
   3 cN + cs + 5 d ≤ en + 4 α, cnh + en + 2 α ≥ 3 (cs + d), cN + en ≤ cs + d,
   cs + 2 d ≥ cN, 3 cs + 5 d ≥ cN + en + 2 α, cs + d ≥ cN + en, cs + 2 d ≥ cnl,
   3 cs + 5 d ≥ cnl + en + 2 α, cs + d ≥ cnl + en, α ≥ cs + d, cs ≥ 0, cnl ≥ 0,
   cnh ≥ 0, cnh > cnl, d ≥ 0, en ≥ 0, α ≥ 0, d < en}]

True

FullSimplify[F2 < 0, {3 cN + 2 α ≥ 5 cs + 2 d, 3 cnl + 2 d ≤ cs + 2 α,
   3 cnh + 2 d ≤ cs + 2 α, 3 cN + en + 2 α ≥ 5 cs + 3 d, 3 cnl + 2 en ≤ cs + 2 α,
   3 cnh + 2 en ≤ cs + 2 α, 3 cnh + 2 α ≥ 5 cs + 2 d, 3 cN + 2 d ≤ cs + 2 α,
   3 cnh + en + 2 α ≥ 5 cs + 3 d, 3 cN + 2 en ≤ cs + 2 α, 3 cN + en + 4 α ≥ 7 cs + 5 d,
   3 cnl + cs + 5 d ≤ en + 4 α, 3 cnh + cs + 5 d ≤ en + 4 α, cN + en + 2 α ≥ 3 (cs + d),
   cnl + en ≤ cs + d, cnh + en ≤ cs + d, 3 cnh + en + 4 α ≥ 7 cs + 5 d,
   3 cN + cs + 5 d ≤ en + 4 α, cnh + en + 2 α ≥ 3 (cs + d), cN + en ≤ cs + d,
   cs + 2 d ≥ cN, 3 cs + 5 d ≥ cN + en + 2 α, cs + d ≥ cN + en, cs + 2 d ≥ cnl,
   3 cs + 5 d ≥ cnl + en + 2 α, cs + d ≥ cnl + en, α ≥ cs + d, cs ≥ 0, cnl ≥ 0,
   cnh ≥ 0, cnh > cnl, d ≥ 0, en ≥ 0, α ≥ 0, en < d < (en + α - cs) / 2}]

True
```

```
FullSimplify[F3 > 0, {3 cN + 2 α ≥ 5 cs + 2 d, 3 cnl + 2 d ≤ cs + 2 α,
  3 cnh + 2 d ≤ cs + 2 α, 3 cN + en + 2 α ≥ 5 cs + 3 d, 3 cnl + 2 en ≤ cs + 2 α,
  3 cnh + 2 en ≤ cs + 2 α, 3 cnh + 2 α ≥ 5 cs + 2 d, 3 cN + 2 d ≤ cs + 2 α,
  3 cnh + en + 2 α ≥ 5 cs + 3 d, 3 cN + 2 en ≤ cs + 2 α, 3 cN + en + 4 α ≥ 7 cs + 5 d,
  3 cnl + cs + 5 d ≤ en + 4 α, 3 cnh + cs + 5 d ≤ en + 4 α, cN + en + 2 α ≥ 3 (cs + d),
  cnl + en ≤ cs + d, cnh + en ≤ cs + d, 3 cnh + en + 4 α ≥ 7 cs + 5 d,
  3 cN + cs + 5 d ≤ en + 4 α, cnh + en + 2 α ≥ 3 (cs + d), cN + en ≤ cs + d,
  cs + 2 d ≥ cN, 3 cs + 5 d ≥ cN + en + 2 α, cs + d ≥ cN + en, cs + 2 d ≥ cnl,
  3 cs + 5 d ≥ cnl + en + 2 α, cs + d ≥ cnl + en, α ≥ cs + d, cs ≥ 0, cnl ≥ 0,
  cnh ≥ 0, cnh > cnl, d ≥ 0, en ≥ 0, α ≥ 0, (en + α - cs) / 2 < d}]

cs^2 + 5 cs d + 3 d^2 + 3 cN en + 2 en^2 + α^2 > 3 cN d + 3 cs en + 4 d en + 2 (cs + d) α
```

APPENDIX-C

NUMERICAL APPLICATIONS

In the case $(e_N + \alpha - c_S)/2 < d)$, the variables taking the values of $c_{NL} = 1;\ c_S = 9;\ d = 10;\ \alpha = 28$, generate following results for the changing values of c_{NH}. It is found that $W^{IC} - W^{DC} > 0$ everywhere.

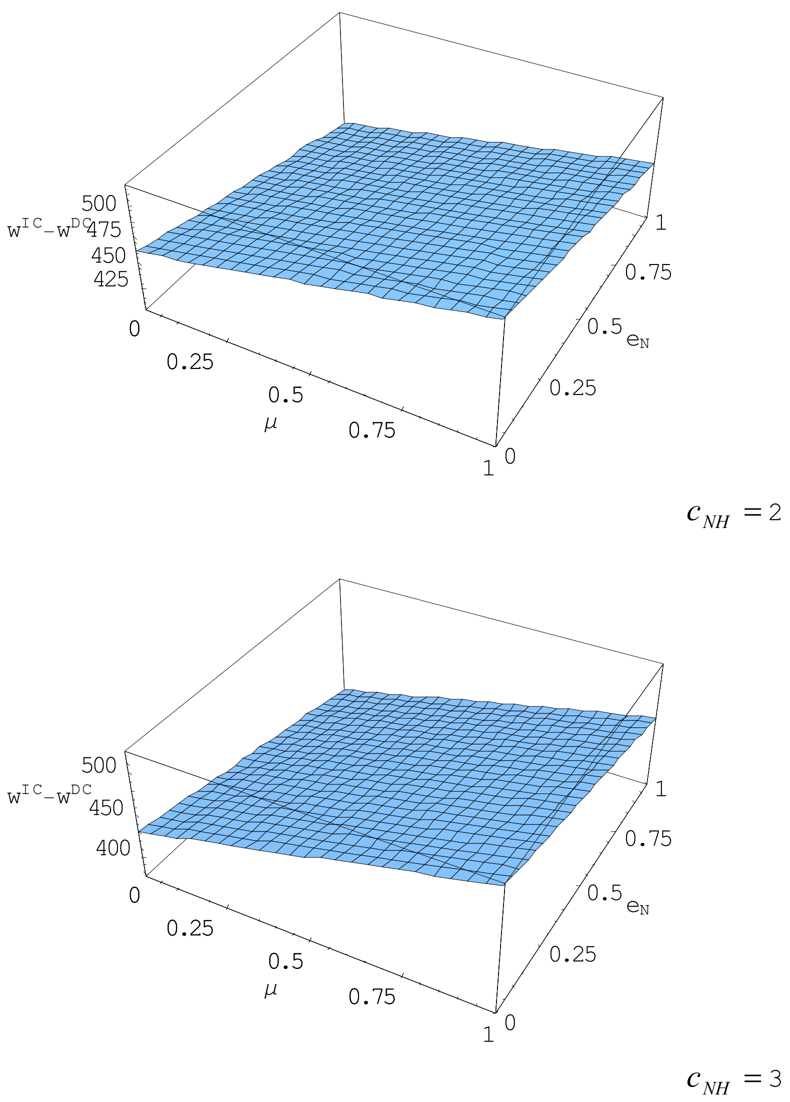

Figure C.1: Numerical Applications ($c_{NH} = 2, 3$)

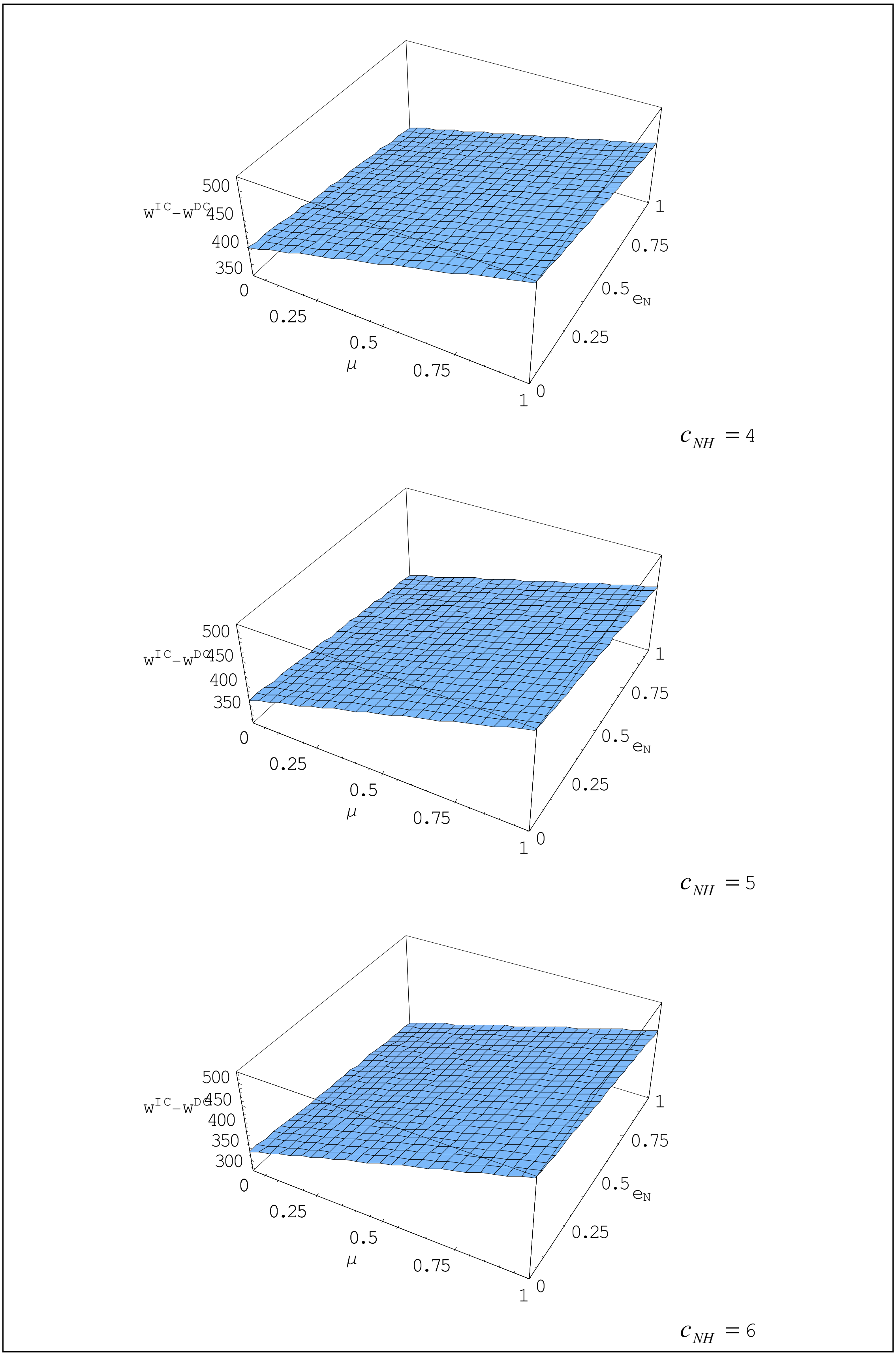

Figure C.2: Numerical Applications (c_{NH} = 4, 5, 6)

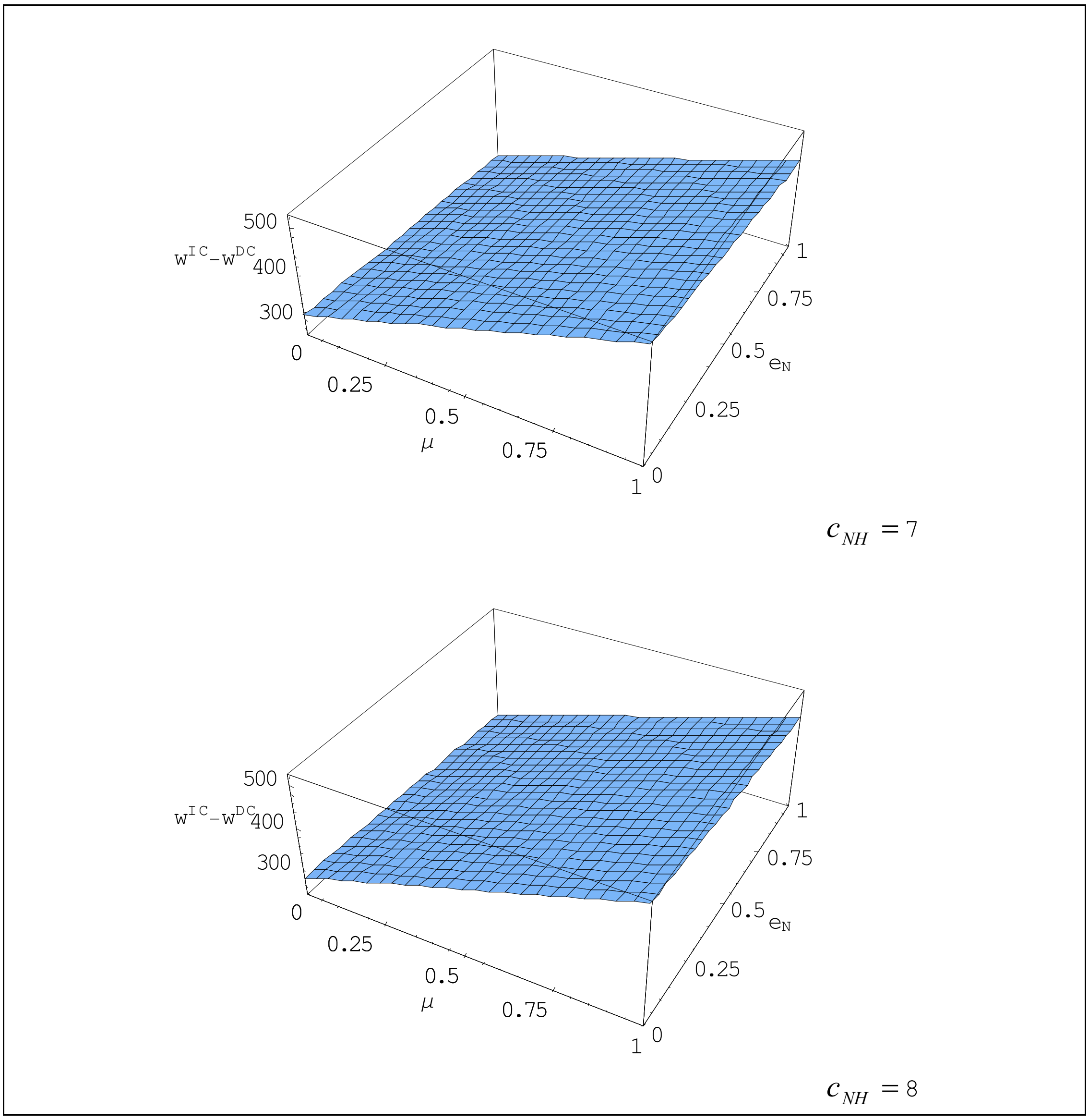

Figure C.3: Numerical Applications ($c_{NH} = 7, 8$)

APPENDIX-D

MATHEMATICA COMMANDS FOR THE COMPARISON OF POLLUTION LEVELS

```
des = 1/2 (-cnh + cs + 2 d + cnh μ - cnl μ);
ies = -1/2 (cnh - 3 cs - 5 d + en + 2 α - cnh μ + cnl μ);
its = -1/2 (cnh - cs - d + en - cnh μ + cnl μ);

ses = FullSimplify[en + its]
1/2 (cs + d + en + cnh (-1 + μ) - cnl μ)

{es = des}; DCqs = FullSimplify[dqs]
1/6 (-5 cs - 2 d + 2 α - 3 cnh (-1 + μ) + 3 cnl μ)

{es = des}; DCqnl = FullSimplify[dqnl]
1/6 (-3 cnl + cs - 2 d + 2 α)

{es = des}; DCqnh = FullSimplify[dqnh]
1/6 (-3 cnh + cs - 2 d + 2 α)

DCqN = FullSimplify[μ DCqnl + (1 - μ) DCqnh]
1/6 (cs - 2 d + 2 α + 3 cnh (-1 + μ) - 3 cnl μ)

DC = FullSimplify[DCqs + DCqN]
-2/3 (cs + d - α)

{es = ses, ts = its}; ICqs = FullSimplify[iqs]
1/6 (3 cnh - 5 cs - d - en + 2 α - 3 cnh μ + 3 cnl μ)
```

```
FullSimplify[DC - ICqs]

1/6 (cs - 3 d + en + 2 α + 3 cnh (-1 + μ) - 3 cnl μ)

qF1 = 1/6 (cs - 3 d + en + 2 α - 3 cN);

FullSimplify[qF1 > 0, {3 cN + 2 α ≥ 5 cs + 2 d, 3 cnl + 2 d ≤ cs + 2 α,
  3 cnh + 2 d ≤ cs + 2 α, 3 cN + en + 2 α ≥ 5 cs + 3 d, 3 cnl + 2 en ≤ cs + 2 α,
  3 cnh + 2 en ≤ cs + 2 α, 3 cnh + 2 α ≥ 5 cs + 2 d, 3 cN + 2 d ≤ cs + 2 α,
  3 cnh + en + 2 α ≥ 5 cs + 3 d, 3 cN + 2 en ≤ cs + 2 α, 3 cN + en + 4 α ≥ 7 cs + 5 d,
  3 cnl + cs + 5 d ≤ en + 4 α, 3 cnh + cs + 5 d ≤ en + 4 α, cN + en + 2 α ≥ 3 (cs + d),
  cnl + en ≤ cs + d, cnh + en ≤ cs + d, 3 cnh + en + 4 α ≥ 7 cs + 5 d,
  3 cN + cs + 5 d ≤ en + 4 α, cnh + en + 2 α ≥ 3 (cs + d), cN + en ≤ cs + d,
  cs + 2 d ≥ cN, 3 cs + 5 d ≥ cN + en + 2 α, cs + d ≥ cN + en, cs + 2 d ≥ cnl,
  3 cs + 5 d ≥ cnl + en + 2 α, cs + d ≥ cnl + en, α ≥ cs + d, cs ≥ 0, cnl ≥ 0,
  cnh ≥ 0, cnh > cnl, d ≥ 0, en ≥ 0, α ≥ 0, d < en}]

True

{es = ses}; DCqs = FullSimplify[dqs]

1/6 (3 cnh - 5 cs - d - en + 2 α - 3 cnh μ + 3 cnl μ)

{es = ses}; DCqnl = FullSimplify[dqnl]

1/6 (-3 cnl + cs - d - en + 2 α)

{es = ses}; DCqnh = FullSimplify[dqnh]

1/6 (-3 cnh + cs - d - en + 2 α)

DCqN = FullSimplify[μ DCqnl + (1 - μ) DCqnh]

1/6 (cs - d - en + 2 α + 3 cnh (-1 + μ) - 3 cnl μ)

DC = FullSimplify[DCqs + DCqN]

1/3 (-2 cs - d - en + 2 α)

{es = ses, ts = its}; ICqs = FullSimplify[iqs]

1/6 (3 cnh - 5 cs - d - en + 2 α - 3 cnh μ + 3 cnl μ)

FullSimplify[DC - ICqs]

1/6 (cs - d - en + 2 α + 3 cnh (-1 + μ) - 3 cnl μ)

qF2 = 1/6 (cs - d - en + 2 α - 3 cN);
```

```
FullSimplify[qF2 > 0, {3 cN + 2 α ≥ 5 cs + 2 d, 3 cnl + 2 d ≤ cs + 2 α,
  3 cnh + 2 d ≤ cs + 2 α, 3 cN + en + 2 α ≥ 5 cs + 3 d, 3 cnl + 2 en ≤ cs + 2 α,
  3 cnh + 2 en ≤ cs + 2 α, 3 cnh + 2 α ≥ 5 cs + 2 d, 3 cN + 2 d ≤ cs + 2 α,
  3 cnh + en + 2 α ≥ 5 cs + 3 d, 3 cN + 2 en ≤ cs + 2 α, 3 cN + en + 4 α ≥ 7 cs + 5 d,
  3 cnl + cs + 5 d ≤ en + 4 α, 3 cnh + cs + 5 d ≤ en + 4 α, cN + en + 2 α ≥ 3 (cs + d),
  cnl + en ≤ cs + d, cnh + en ≤ cs + d, 3 cnh + en + 4 α ≥ 7 cs + 5 d,
  3 cN + cs + 5 d ≤ en + 4 α, cnh + en + 2 α ≥ 3 (cs + d), cN + en ≤ cs + d,
  cs + 2 d ≥ cN, 3 cs + 5 d ≥ cN + en + 2 α, cs + d ≥ cN + en, cs + 2 d ≥ cnl,
  3 cs + 5 d ≥ cnl + en + 2 α, cs + d ≥ cnl + en, α ≥ cs + d, cs ≥ 0, cnl ≥ 0,
  cnh ≥ 0, cnh > cnl, d ≥ 0, en ≥ 0, α ≥ 0, en < d < (en + α - cs) / 2}]

True

{es = ies, ts = its}; ICqs = FullSimplify[iqs]
```

$$\frac{1}{2}\ (\text{cnh} - 3\ \text{cs} - 3\ \text{d} + \text{en} + 2\ \alpha - \text{cnh}\ \mu + \text{cnl}\ \mu)$$

```
FullSimplify[DC - ICqs]
```

$$\frac{1}{6}\ (5\ \text{cs} + 7\ \text{d} - 5\ \text{en} - 2\ \alpha + 3\ \text{cnh}\ (-1 + \mu) - 3\ \text{cnl}\ \mu)$$

$$\text{qF3} = \frac{1}{6}\ (5\ \text{cs} + 7\ \text{d} - 5\ \text{en} - 2\ \alpha - 3\ \text{cN});$$

```
FullSimplify[qF3 > 0, {3 cN + 2 α ≥ 5 cs + 2 d, 3 cnl + 2 d ≤ cs + 2 α,
  3 cnh + 2 d ≤ cs + 2 α, 3 cN + en + 2 α ≥ 5 cs + 3 d, 3 cnl + 2 en ≤ cs + 2 α,
  3 cnh + 2 en ≤ cs + 2 α, 3 cnh + 2 α ≥ 5 cs + 2 d, 3 cN + 2 d ≤ cs + 2 α,
  3 cnh + en + 2 α ≥ 5 cs + 3 d, 3 cN + 2 en ≤ cs + 2 α, 3 cN + en + 4 α ≥ 7 cs + 5 d,
  3 cnl + cs + 5 d ≤ en + 4 α, 3 cnh + cs + 5 d ≤ en + 4 α, cN + en + 2 α ≥ 3 (cs + d),
  cnl + en ≤ cs + d, cnh + en ≤ cs + d, 3 cnh + en + 4 α ≥ 7 cs + 5 d,
  3 cN + cs + 5 d ≤ en + 4 α, cnh + en + 2 α ≥ 3 (cs + d), cN + en ≤ cs + d,
  cs + 2 d ≥ cN, 3 cs + 5 d ≥ cN + en + 2 α, cs + d ≥ cN + en, cs + 2 d ≥ cnl,
  3 cs + 5 d ≥ cnl + en + 2 α, cs + d ≥ cnl + en, α ≥ cs + d, cs ≥ 0, cnl ≥ 0,
  cnh ≥ 0, cnh > cnl, d ≥ 0, en ≥ 0, α ≥ 0, (en + α - cs) / 2 < d}]

True
```

CURRICULUM VITAE

She was born in 1981 in Sivas, Turkey. She completed Sivas Selcuk Anatolian High School (with German as foreign language) in 1999. She graduated from the Department of Economics at Middle East Technical University with a B.Sc. degree in 2004. In the same year, she pursued her education with a M.Sc. degree program in Economics at Istanbul Technical University.