**İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SOCIAL SCIENCES**

# INTRA-INDUSTRY TRADE AND PRODUCTION BASED POLLUTION

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**Suphi ŞEN, B.A.**

**412061015**

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**Supervisor (Chairman): Assoc. Prof. Dr. Özgür KAYALICA**

**Members of the Examining Committee Prof.Dr. Benan ZEKİ ORBAY**

**Assoc.Prof.Dr. İlker TOPÇU**

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**YUKSEK LİSANS TEZİ**

**Mühendis Suphi ŞEN**
**412061015**

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**Tez Danışmanı :** **Doç.Dr. Özgür KAYALICA**
**Diğer Jüri Üyeleri** **Prof.Dr. Benan ZEKİ ORBAY**
**Doç.Dr. İlker TOPÇU**

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## LIST OF ABBREVIATIONS

**IIT** : Intra Industry Trade
**UNCTAD** : United Nations Conference on Trade and Development
**WTO** : World Trade Organization

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## SUMMARY

# PRODUCTION BASED POLLUTION EXTERNALITIES AND INTRA -INDUSTRY TRADE

**Suphi ŞEN**

**Environmental pollution is one of the major problems countries are facing in this century. Most of the countries are trying to protect themselves using various policies to prevent pollution. This paper is an attempt to determine optimal environmental policies under different circumstances. We construct a partial equilibrium model with two identical countries and two firms. Each firm is operating at its home country. Firms are producing homogeneous goods to be consumed in both countries. Each government's policy instruments are import tariff and quantity restriction on pollution. Every individual country is affected from the pollution generated during the production process of its own firm. The technology for abating the pollution is available to both firms. Agents play a three-stage game. At the first stage, governments determine the quantity restriction levels on pollution. At the second stage, governments determine the import tariffs. At the third stage, firms choose their output levels observing these policy instruments. Firstly, the model shows that efficiency in pollution abatement technology plays a crucial role on welfare maximizing behaviour of governments. A critical level of pollution abatement technology determines the preponderance of environmental misgivings in their welfare maximizing behavior. More efficient the firms in pollution abatement technology, governments' are inclined to be less strict in their policies to reduce negative environmental externalities. Secondly, our analysis compares optimal policies under non-cooperative and cooperative behaviour of governments for environmental policies. By cooperation, in environmental policies, environmental pollution can be reduced. Furthermore, we examine the effects of the liberalizing trade on environment. Free trade makes governments to be less strict in their policies about environment.**

**Keywords: Intra-industry Trade, Pollution Quota, Trade and Environment**

**JEL Codes: F1, H2**

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# ÖZET

## ÜRETİM KAYNAKLI KİRLİLİK VE ENDÜSTRİİÇİ TİCARET

**Suphi Şen**

**Son yüzyılın en büyük sorunlarindan biri çevre kirliliğidir. Ülkeler kirliliği önlemek için çeşitli politikalara başvurmaktadır. Bu çalışmada çeşitli durumlarda ülkelerin başvurduğu optimal çevre politikalari incelenmektedir. Bu amaçla iki ülkeli ve iki firmalı bir kısmi denge modeli oluşturduk. Her ülkede bir firma faaliyet etmektedir. Üretim hem yerli hem de yabancı pazar için yapılmaktadır. Hükümetlerin politika araçları ihracat tarifesi ve kirlilik kotasıdır. Ülkeler sadece yerel firmanın oluşturduğu kirlilikten etkilenmektedir. Kirliliği azaltma teknolojisi her firma için ulaşılabilirdir. Model üç aşamalı bir oyundan oluşmaktadır. Birinci aşamada hükümetler kirlilik kotasını belirler. İkinci aşamada yine hükümetler ihracat tarifelerini belirler. Son aşamada firmalar üretim miktarlarina karar verirler. Öncelikle hükümetlerin refah ençoklamasında, kirliliği azaltma teknolojisinin kritik bir önem taşıdığını gösterdik. Kirliliği önleme teknolojisin kritik bir seviyesi, hükümetlerin refah ençoklarken çevre hassasitinden ne kadar ödün vereceklerini belirlemektedir. Firmalar kirliliği önlemede etkinleştikçe hükümetler çevre politikalarında daha gevşek davranmaktadır. Ayrıca çevre politikalarında işbirliğinin kirlilik üzerine etkisi yine kirliliği önleme teknolojisinin etkinliğine bağlıdır. Son olarak serbest ticarete geçişin çevre politikalarina etkisi incelenmiştir.**

**Anahtar Kelimeler: Endüstriiçi Ticaret, Kirlilik Kotası, Ticaret ve Çevre**

**Bilim Dalı Sayısal Kodu: F1, H2**

# 1 INTRODUCTION

Debates over globalization have been going on for decades. However, recently a new dimension has come out. This is the relationship between international trade and environment. Globalization is associated with liberalization of international trade. It is argued that this is beneficial since the apparent increase in real world income has been attributed to the liberalization of international trade. Fruits of international trade have been put forward since the early economists. However, recently environmentalists argue against the trade liberalization by considering the environmental consequences of international trade. The debate between environmentalists and international trade lobbies is one of the most debated topics about globalization.

World Trade Organization (WTO) is the main institute which governs international trade. They set out some procedures for countries to be followed in their international trade relationships. The main purpose of WTO is liberalizing world trade. Among the rules of WTO there are also some regulations about environmental issue. Governments can put some restrictions in order to preserve natural life and resources. Thus, governments can apply interventions such as import tariffs, quotas and subsidies. When the matter is consumption based pollution, governments have the chance to apply environmental policies directly. On the other hand, if the matter is production based pollution governments may use international trade policies in order to preserve its environmental quality. One of the problems that are proposed by international trade policy community is that there is the possibility that governments may protect themselves against international competition as if they were making environmental protectionism.

Environmentalists argue that higher economic activity will be associated with a decrease in environmental quality. Moreover, less developed countries will adopt less tough environmental standards in order to gain an advantage in international trade. Therefore, they conclude that free trade is harmful to environment.

Copeland and Taylor (2003) summarize the debate over environment and international trade as follows. Firstly, international trade effects the environment through increasing economic activity. Since pollution occurs as a result of production and consumption which increases with economic activity, environmental consequences of international trade may outweigh its income generating advantages. Secondly, international trade changes the composition of trade pattern of a country. Pollution intensive production may shift to less developed countries and may create pollution heavens. Moreover, via transboundary pollution, whole world may suffer from the consequences of this effect.

Copeland and Taylor (2003) put forward two core questions to be analyzed in order to understand the relationship between international trade and environment.

Firstly, what is the relationship between environment and increasing economic activity due to international trade? Deep green environmentalists argue that increasing economic activity is absolutely harmful for the environment. Therefore, they conclude that international trade is harmful to environment. On the other hand, there is the income generating advantages of international trade. Supporters of free trade argue that as income gains increase, countries will be more willing to preserve environment. Moreover, the technical ability to apply environmental regulations will improve with the increasing income.

Secondly, Copeland and Taylor (2003) put forward the question, how the international trade relations of a country are effected from environmental regulations. The concern of the question is to analyze the situation in which pollution intensive industries migrate to less developed countries where environmental regulations are less tough. Therefore, environmental regulations may create a different specialization across the world in which poor countries specialize in the production of dirty goods and rich countries specialize in the production of clean goods. Therefore, the developing part of the world may become a pollution heaven. Furthermore, environmental regulation may be subject to the competitiveness of the developing world country and international agreements may become impossible.

As it is mentioned by Copeland and Taylor (2003), there is a strong relationship between environmental regulations and trade patterns of countries. When the concern is the inter-industry trade, mostly occurs between developed and developing countries, there might be specialization due to the pollution incentives of industries. On the other hand, today, most of the world trade occurs as intra industry trade in which similar products are traded between countries. In this case the countries are mostly at the same development level. This does not mean that the composition effect of international trade is worthless. Indeed, transfer of old technologies of an industry creates intra-industry trade between developed and less developed countries. However, it is clear that intra-industry trade has its own characteristics. Environmental pollution in an intra-industry trade case may be generated through consumption or production of goods. One of the main concerns of governments when making policy about international trade is the environmental damage arises during the production of goods which are subject to intra-industry trade. It is very common that there exists a two way trade of identical goods between countries in which the countries are subject to pollution generated during the production process of these goods. In order to analyze the interrelated relationship between trade policies, environmental regulations and their effects on welfare we construct a partial equilibrium model.

In this paper we study the production based generated pollution externalities. We developed a partial equilibrium model in which there are two countries and two firms. Each firm is operating at its home country. Firms are producing homogeneous goods to be consumed in both countries. Each government's policy instruments are import tariff and quantity restriction on pollution. Every individual country is affected from the pollution generated during the production process of its own firm. The technology for abating the pollution is available to both firms. Agents play a three-stage non-cooperative game. At the first stage, governments determine the quantity restriction levels on pollution given the firms output levels. At the second stage, governments determine the import tariffs. At the third stage, firms choose their output levels for any given level of policy instruments.

Firstly, we will show that efficiency in pollution abatement technology plays a crucial role on welfare maximizing behavior of governments. A critical level of pollution abatement technology determines the preponderance of environmental misgivings in their welfare maximizing behavior. Secondly, we will extend our analysis by examining the cooperation in environmental policy between countries and examining the effects of the liberalizing trade on environmental policies.

In the preceding part of the paper a literature survey is presented in the area of intra industry trade, environment and production based pollution externalities. Then, the model constructed will be presented. In the last part, the conclusions derived due to the model will be explained.

# 2 LITERATURE SURVEY

## 2.1 International Trade and Environment

Since Ricardo, international trade has been regarded as beneficial by mainstream economics. International trade induces specialization and leads to international division of labor. By producing the goods which they can most efficiently produce, each country uses its comparative advantage to increase global output and gains from international trade will accrue to all countries. This view has been challenged by many streams of economics. Most recently, environmentalists argue against the general view about the free trade.

### 2.1.1 Debates over International Trade and Environment

There is a multi-dimensional relationship between increased trade flows and environmental issues. Field and Field (2002) summarize this relationship as follows. Firstly, the mutual relationship between trade and environment arise the question of what are the causes and effects; How does increased trade effect environment and how does the environmental degradation effects international trade. Secondly, should countries use trade policies in order to reduce environmental damage? Finally, is collaboration needed in order to improve environmental quality on the world as a whole? These questions are explained by many opposed point of views such as environmentalists and international trade lobbies

Rauscher (1997) proposes four reasons for the environmentalists to regard international trade harmful to environment. Firstly, some countries may specialize in the production of dirty goods and the welfare loss caused by environmental degradation in these countries may outweigh the welfare gains through free trade. Besides, if this pollution has a transboundary effect, many countries can be subject to this effect. Secondly, mainstream economics predicts that international trade induces the world to produce and consume more which means more pollution. This may cause waste management problems. Thirdly, mobile factor movements due to environmental regulations may create pollution heavens. Some countries will adjust their environmental policies in order attract mobile factors of production. This may cause competition among countries which may have disastrous consequences. The fourth problem is the trade in hazardous wastes. It is clear that the exporters of these materials are more advance in storing or processing these materials than the importers. The sixth problem is that international trade requires transportation which is the most important polluting activities. As the sixth problem, it is argued that third world countries will never break their dependence on imports and they can never achieve a development level to apply sufficient environmental regulations.

There are also attempts of free trade lobbies against the environmental regulations. Rauscher (1997) states that free trade lobbies are against the polluter-pays principal which enforces the one who causes damage to pay the social cost of the activity. However, such a policy will lead pollution-intensive industries to move pollution heavens.

It is undeniable that free trade has important effects on environment. Regulations on international trade also have important effects on environmental quality. Besides environmental policies have sound effects on international trade. This mutual relationship between international trade and environment arise the question for an economist "Is free trade still good when environment is taken into consideration".

Environmental regulations sometimes cause distortions in international trade. For example in some cases governments uses environmental policies in order to discriminate between domestic goods and imported goods. So the borderline between true and pretended protectionism is not clear. Rauscher (1997) predicts that one of the main issues in the future will be, making international trade agreements and environmental arguments consistent.

### 2.1.2 International Trade and Environment: Theory

In the literature, many models have been set up in order to investigate the dimensions of the relationship between trade and environment.

Copeland and Taylor (1994-a) set up a north-south model in order to investigate the relationship between national income, pollution and international trade. In their model, two countries are producing goods which differ in pollution effect. They figure out that technologically developed country specializes in clean goods and its environmental policies are stricter. Besides they show that free trade increases pollution. Furthermore, an increase in North's production possibilities frontier increases pollution, while any improvement in South's production possibilities frontier reduces pollution.

Copeland and Taylor (1994-b) examines that how pollution is effected from national income levels and trade opportunities. Their findings show that higher the income inequality across countries, higher the level of global pollution due to free trade. Secondly, they show that if factor prices are equalized due to trade, than human capital abundant countries are more advantages. Thirdly, if pollution permits are subject to free trade, than pollution decreases. Finally, environmental policies are useless when they are used for trade objectives.

Copeland and Taylor (1996) predict that pollution intensive sectors tend to move to countries where environmental policies are lax. In their paper, they emphasize the distinction between consumption based pollution and production based pollution. They conclude that pollution heaven hypothesis holds for consumption based pollution as well as production based pollution.

Antweiler, Copeland and Taylor (2001) try to find out that if liberalization in goods market is good for environment. For this purpose, they construct a model to classify the impacts of trade on pollution into three groups: scale, technique and composition. If free trade changes composition of national income, it does not effect pollution. However, if the main effects are scale and technique effects, it reduces pollution. They find a surprising result: the net effect of trade on environment is positive.

To conclude, models in the literature are constructed to show different dimensions of the relationship between environment and trade. The effect of trade on environment is explained as positive or negative due to the dimensions considered in the model.

## 2.2 Intra Industry Trade

Intra industry trade is the two way trade of identical goods between countries. These goods can be differentiated in quality or brand. Due to these reasons, consumers may prefer the domestically produced goods or the imported goods. Today, largest part of the international trade occurs as intra industry trade. NAPES (National Asia Pacific Economic and Scientific Data Base) intra industry trade index shows that in the period from 1993 to 1995, 95 percent of international trade occurred as intra industry trade. Due to its large share in the international trade, intra-industry trade is very important in the interaction between trade policies and environmental policies.

### 2.2.1 Motivations of Intra-Industry Trade

International trade have two forms, inter-industry trade and intra-industry trade. It is called inter-industry trade if different commodities are traded. In intra-industry trade, similar commodities are exchanged. In the trade literature intra-industry trade had been a neglected form until a few decades. The reason is obvious, the great influence of Ricardian comparative advantage theory and Heckscher-Ohlin factor endowment theory. Both theories suggest that countries should specialize in producing specific goods. For example, in a Ricardian world countries can not import and export the same good. In the pre-World War II period, economists assumed countries specialize in production and trade. In the post World War II period, it is suggested that intra-industry trade is a post war phenomena. However, since specialization is a recommendation by David Ricardo, we can predict that two way-trade was an existing and unwanted form of trade even in early 1980's.

Balassa (1966) is one of the earliest economists who notice the importance of intra-industry trade. He noticed the intra industry trade occurs in the developed part of the world and its consequences for economic development. Since then, a large volume of literature has been developed on this subject. The most important question to be answered is existence, why do countries trade similar products? Explanations for the existence of intra-industry trade can be grouped into supply-side and demand-side explanations.

Demand side explanations focus on demand heterogeneity. Slightly differentiated goods, income inequalities or population growth creates different demand structures. Therefore, heterogeneity in demand may cause the country to import and export the same good.

Krugman (1979) states that demand diversity due to product differentiation is a strong motive for intra-industry trade. Slightly differentiated goods in quality, design or size may lead the consumers to prefer different brands. He argues that domestic goods can not satisfy the diversity in demand. Therefore, intra-industry trade occurs inherently.

Linder (1961) argues that income inequalities between and within countries can be motivation for intra-industry trade. In a low income country domestic firms will be oriented towards satisfying low income consumers. However, in the same country there must be high income consumers whose needs will be satisfied by the products which are produced by the firms of a foreign country which is oriented towards high income consumers since its country is a high income country. Therefore, Linder (1961) suggests an explanation for the intra-industry trade which occurs between developed part of the world and rest of the world.

Hamilton and Kniest (1991) state that intra-industry trade may be a result of population growth. As population grows, demand for slightly differentiated products will increase. The reason is that there would be a more heterogeneous demand in tastes.

Demand side explanations are necessary to explain existence of intra industry trade but not sufficient. Supply side explanations are valid to explain the existence of intra industry trade.

Supply side motivation of intra industry trade can be classified into two groups: Country specific explanations and industry specific explanations. Country specific explanations focus on the factor proportions in producing the similar products. Helpman (1981) having similar proportion in factor endowments leads countries to make more intra industry trade. Moreover it is argued that intra industry trade will occur in industries in which K/L ratio has a lower dispersion. Dispersion is simply the standard deviation of K/L ratio of firms within an industry. When the dispersion is lower, the goods produced are more likely to be substitutable. They also state that these industries will face higher competition with foreign firms, assuming that consumers prefer diversity in quality and variety.

Industry specific explanations are regarded with economies of scale and learning by doing. Krugman (1979, 1980) argue that scale economies in production is a main motivations of intra industry trade. In order to examine this issue, he constructs a two country – two firm model where similar goods are produced by the firms under increasing returns to scale. Due to trade, market extends, marginal costs decrease, volume of trade increases.

Brander and Krugman (1983) argue that reciprocal dumping, dumping of firm into the home country of rival firm, can occur in a natural way due to the oligopolistic competition between firms. Thus, they show that reciprocal dumping can occur without the motivations such as transportation costs and economies of scale. They also show that if transport costs are low opening trade increases welfare of countries. On the other hand, if transport costs dominate the positive effect of free trade on welfare, there occurs a decline in welfare of countries. Furthermore, they also show that in the case of free entry, opening trade certainly increases welfare.

One crucial concept in the model of Brander and Krugman (1983) is the segmented market concept proposed by Helpman (1982). The theory of oligopoly mostly focuses on single markets. However, there are many reasons for a multinational firm to exist in several markets. The basic reason is the transportation costs. Even the firms in different cities face different transportation costs. Therefore, these markets can be treated as different markets in theoretical models. Another reason for the segmentation is the taxes such as tariffs and export subsidies. To sum up, any reason which causes a cost differential among firms located in different places makes the firms to treat each market separately in their decisions.

Learning by doing is another factor that leads to intra industry trade. Firms can learn to imitate the products of its competitors and this will lead the products to be more substitutable. As a result intra industry trade occurs.

Also geographic localization of production may trigger intra industry trade. Geographic localization affects transportation costs which has an important effect on intra industry trade.

To conclude, in order to explain the existence of intra-industry trade, both supply side and demand side explanations are necessary.

### 2.2.2 Theory of Intra-Industry Trade

One of the earliest contributions to the theoretical framework of intra-industry trade is from Paul Krugman (1979). He constructs a model in which existence of intra industry trade is explained through economies of scale. In the model there are two countries and labor is the only production factor. Therefore firms have the same K/L ratios. Both the countries have identical production technologies, increasing returns to scale. He shows that intra industry trade occurs, in order to the firms to take the advantage of scale economies.

Krugman (1980) develops a model through which he examines effects of the economies of scale and product differentiation on intra industry trade. In the model, firms have some monopoly power but monopolistic competition drives profit to zero. Due to increasing returns to scale, intra industry trade occurs. Each slightly differentiated good is produced in one country. It is argued that gains from trade higher when intra industry trade occurs rather than each country offers the whole range of slightly differentiated products.

Using the same general equilibrium model Krugman (1981) reaches some conclusions on intra industry trade specialization. In the new version of his model, instead of two – two firm model, he used a two country- two industry model. In each country there are many firms each producing one good. On the demand side, goods are assumed to be imperfect substitutes. However, they are assumed to be perfect substitutes on the supply side. Free entry of firms drives profits to zero. He shows that structure of the trade between countries depends on the similarity of the factor endowments of countries. More similar the factor endowments, more likely the countries to make intra industry trade. Also, he shows that type of trade is the crucial point in analyzing the effect of trade liberalization. If intra industry trade is the dominant type of trade, then liberalizing trade is beneficial.

Brander (1981) emphasizes that Hechscher-Ohlin model and Ricardian model of international trade always assume that trade occurs in different goods. Every individual country specializes in the goods which they can produce most efficiently. However, by using a Cournot setting, it is possible to construct models which include intra industry trade. The crucial assumption of Cournot setting is that when firms are setting their output levels, they assume that other firms do not change their output level. Brander (1981) argues that Cournot strategy is a reasonable strategy for a firm to follow, since it does not require high information gathering costs and information processing costs. In order to analyze inter industry trade, Brander (1981) constructs a two country – two firm model in which there is a two way trade of similar goods between countries. In the model, pattern of trade is determined by increasing returns to scale, transportation costs and firms' imperfectly competitive behavior. Through this model Brander (1981) shows that identical products can be traded across countries despite efficiency loss due to transportation costs. As an example there is a two way trade between France and Germany in automotive sector.

Existence of two way trade due to product quality is examined in a theoretical framework by Falvey and Kierzowski (1987). They construct a two country-two firm model. Product differentiation is due to product quality. As a fact, the higher the quality, the higher the K/L ratio. They argue that when quality is determined by the immobile factor, capital, then specialization will occur between countries. It is clear that, the capital abundant country will specialize in high quality goods, whereas labor intense country will specialize in low quality products.

Davis (1995) develops a theoretical model in order to incorporate intra industry trade issue into the Ricardian trade model and Heckscher-Ohlin model. Three goods are produced, two to be traded in an intra industry type trade and one to be traded in an inter-industry type of trade. Model assumes that preferences are identical and homothetic, constant returns to scale and technological differentiation among countries. They show that both type of trade, inter-industry trade and intra-industry trade, occur at the equilibrium. Intra industry trade is a result of constant returns to scale and perfectly competitive markets.

Schmitt and Yu (2001) find a positive link between scale economies and the volume of intra industry trade and share of trade in total production. In their model there is a monopolistic competition with traded and non-traded goods.

To conclude, starting by 1970's, search for alternative theoretical framework to explain intra-industry trade gave results by 1980's. Monopolistic competition, increasing returns to scale and product differentiation in quality and variety is the crucial elements of this movement.

### 2.2.3 Intra-Industry Trade and Environment

Intra-industry trade and its effects on environment is a recent topic. Recently, there are many studies which focus on intra-industry trade and environment.

Kayalica and Kayalica (2005) develop a two country - two firm model in which identical goods are produced and traded. They also consider the effects of transboundry pollution. Governments maximize national welfares by using the policy instruments which are import tariffs and consumption taxes. They show that a higher consumption tax in one country associates with a lower tariff in that country. They also analyze the effects of revenue neutral reform and show that it increases consumption tax and reduces import tariffs. They find that changing tax structure is Pareto-improving. Therefore, non-cooperative Nash equilibrium is sub-optimal.

Kayalica and Yilmaz (2006) construct a partial equilibrium model in order to analyze consumption based pollution externalities in a reciprocal dumping type of trade. In their model, agents, governments and firms placed in two countries, play a two stage non-cooperative game. Firstly, governments decide on their policy instruments, consumption tax and export subsidy levels. Secondly, firms choose their output levels. They show that removing subsidies does not effect pollution. Thus, free trade does not effect environment in this specified context. They also show that uniform taxing increases the consumption based pollution.

Benarroch and Weder (2006) construct a two country model in order to investigate the relationship between intra-industry industry trade in intermediate products, pollution and increasing returns to scale. In their model, production occurs in two stages, intermediate and final good production. Monopolistic competition is the main characteristic of the intermediate good production and increasing returns to scale characterizes the final good production. There are polluting intermediate goods and pollution occurs if these goods are used in the final good production. Their goal is to show the effect of intermediate products on pollution. They figure out that international trade may cause lower pollution in the countries or may lead to lower pollution per unit of output at least in one country.

Fung and Maechler (2007) build a price-setting duopoly model of intra-industry trade in order to obtain the effects of trade liberalization on environment. Their findings show that trade liberalization effects environment due to two factors. Firstly, the nature of pollution plays a crucial role on the impact of trade liberalization on environment. If the pollution occurs as transboundary pollution, then trade liberalization absolutely effect the dirty country positively since the environmental effect is positive for the dirty country. However, if the pollution is local, then the effect of trade liberalization on environment is negative. Therefore, the overall welfare effect is ambiguous. Secondly, the type of the country which opens its economy is an important factor. If the pollution occurs as transboundary pollution, then trade liberalization absolutely effect the dirty country positively since the environmental effect is positive for the dirty country. However, if the pollution is local, then the effect of trade liberalization on environment is negative. Therefore, the overall welfare effect is ambiguous.

Another interesting dimension of the relationship between intra-industry trade and environment is the awareness of the society about environment. Aidt (2005) analyses the intra-industry trade and environment relation by considering the environmental awareness of society. In his two country model, he defines three group of citizens who differ in their preferences between consumption goods and environmental quality. In this way, he incorporates environmental awareness into his model. It is suggested that an environmental awareness has two dimensions. Firstly, the type of pollution is very important. Transboundary pollution and local pollution have different impacts across the societies. Secondly, societies may care about the pollution in other countries. It is showed that if pollution has a transboundary nature or the society is concerned with the pollution in a local context, the rise in environmentalism reduces pollution. On the other hand, if pollution is immobile and the society concerns with pollution in a global context, the rise in environmentalism may effect pollution positively or negatively.

# 3 CHAPTER 1: BEFORE TRADE LIBERALIZATION

Our model is an intra industry type, two country-two firm model. Each country hosts one firm which produces homogenous good to be consumed in both countries. It is assumed that each country have different production technologies. The countries' markets are segmented and firms face different demand conditions in each market. We assume linear inverse demand functions as follows.

$$p_h = \alpha - (x_h + y_h)$$
$$p_f = \alpha - (x_f + y_f)$$

Countries are labeled with h (home) and f (foreign). Supply of home country's firm is x. It produces $x_h$ for its domestic demand and $x_f$ for the foreign country's demand. Supply of foreign country' firm is y. It produces $y_h$ for home country's demand and $y_f$ for its domestic demand. Firms face with different prices in each country distinguished with $p_h$ and $p_f$. Since the markets are segmented, each firm takes other firm's output decision for each market constant when deciding its own output. Total output of each firm is given with the following equation.

$$D_i = x_i + y_i, \quad i = h, f$$

Therefore we have the following profit functions for each firm.

$$\pi_h = (p_h - k_h)\, x_h + (p_f - k_h - \tau_f)\, x_f$$

$$\pi_f = (p_f - k_f)\, y_f + (p_h - k_f - \tau_h)\, y_h$$

Profits of firm h and firm f are $\pi_h$ and $\pi_f$. $\tau_i$ (i = h,f) is the import tariff levied on per unit of import. Marginal cost is $k_i$ (i = h,f) for each firm. Marginal cost structure of firms is given as follows.

$$k_h = c_h + \mu\,(\theta - z_h)$$

$$k_f = c_f + \mu\ (\theta - z_f)$$

Marginal cost structure is composed of two parts. First part ($c_i$) is the production cost and second part ($\mu\ (\theta - z_i)$) is the pollution abatement cost. Each government determines a quantity restriction per unit of output ($z_i$, i = h, f) on the pollutants emitted. Therefore, firms have to abate the pollution in the amount of $\theta - z_i$ where i= h, f .$\theta$ is the gross pollution per unit of output. Thus, firms are subject to an abatement cost of $\mu(\theta - z_h)$ where $\mu$ is the abatement cost for per unit of output.

The welfare of each country is composed of four parts, consumer surplus (CS), producer surplus (PS), import tariff revenue (ITR) and disutility of pollution (DP). Welfare of each country is given with the following equations.

$$W_h = CS_h + PS_h + ITR_h - DP_h$$

$$W_f = CS_f + PS_f + ITR_f - DP_f$$

### 3.1 Non – Cooperation in Environmental Policy

In this section, the non-cooperative solution of our model is examined. There is a three stage game between countries. At the first stage of our model, governments determine the pollution quota given the reaction functions of later stages. At the second stage, governments again determine the import tariffs given the reaction functions of later stage and the pollution quota determined. At the final stage, firms determine their output level given the results of earlier stages. The problem is solved with backwards induction method. There is an oligopolistic competition between firms and they wish to maximize their profits. Welfare maximization is the motivation of governments in this non-cooperative strategic game.

#### 3.1.1 Stage 3: Firms determine the output levels

At the third stage of the game, each firm determines their output level taking reaction function of other firm as given. Firms give their decisions in a Cournot-Nash fashion. Since the markets are segmented, firms determine their output levels separately for each market.

From the first order conditions we obtain the optimal output levels of the firms as follows:

$$x_h=1/3(c_f-2c_h+\alpha-z_f\mu+2z_h\mu-\theta\mu+\tau_h) \quad (3.1)$$

$$x_f=1/3(c_f-2c_h+\alpha-z_f\mu+2z_h\mu-\theta\mu-2\tau_f) \quad (3.2)$$

$$y_h=1/3(-2c_f+c_h+\alpha+2z_f\mu-z_h\mu-\theta\mu-2\tau_h) \quad (3.2)$$

$$y_f=1/3(-2c_f+c_h+\alpha+2z_f\mu-z_h\mu-\theta\mu+\tau_f) \quad (3.4)$$

second order conditions are directly satisfied.

Comparative static analysis on the outcomes of stage 3 shows that due to any improvement in the foreign country's production technologies which associates with a decrease in the marginal cost of firm f, firm h decreases the output level for both domestic and foreign market and firm f increases the output level for both domestic and foreign market. Any increase in demand associates with a higher output level for both firms. If foreign government increases the pollution quota, firm h decreases its output levels for both home and foreign market and firm f increases its output level for both home and foreign market. When the foreign government increases the import tariff, firm h decreases its output level for foreign market and firm f increases its output level for its own domestic market. However, the rise in import tariff of foreign government does not effect the output decisions of both firms for the home market. Due to any increase in the gross pollution occurs during the production of the good, both firms decrease their supply to both markets. These are the clear results that can be obtained by making comparative statics. However, the effect of any change in the unit cost of abating the pollution on the output decisions of firms is ambiguous and depends on the magnitude of the pollution quotas and gross pollution as it can be seen from equations below.

$$\partial x_h/\partial\mu=1/3(-z_f+2z_h-\theta)$$

$$\partial x_f/\partial\mu=1/3(-z_f+2z_h-\theta)$$

$$\partial y_h/\partial\mu=1/3(2z_f-z_h-\theta)$$

$$\partial y_f/\partial\mu=1/3(2z_f-z_h-\theta)$$

### 3.1.2 Stage 2: Governments determine the import tariffs

At the second stage, governments determine the import tariffs in order to protect its domestic firm from international competition. Optimal level of import tariffs will be determined by the welfare maximizing behavior of governments.

As mentioned before, welfare functions of countries are composed of four parts. These are consumer surplus (CS), producer surplus (PS), import tariff revenues (ITR) and disutility from pollution (DP).

$$W_i = CS_i + PS_i + ITR_i - DP_i \quad ( i = h, f )$$

It is well known that differentiation of consumer surplus is as follows

$$dCS_i = -D_i \, dp_i, \; i = h, f$$

In order to analyze the optimal import tariff policies, equations (3.1) to (3.2) are substituted in the welfare functions and by totally differentiating we obtain the below results.

$$3\, dW_h = A1 \; d\tau_h + A2 \; d\tau_f$$

$$3\, dWf = A2 \; d\tau_f + A1 \; d\tau_h$$

where

$$A1 = (-c_f - z_h + \alpha + z_f\mu - \theta\mu - 3\tau_h)$$

$$A2 = (-c_h - z_f + \alpha + z_h\mu - \theta\mu - 3\tau_f)$$

Since the system is symmetric between home and foreign country, all equilibrium values can be obtained through using the results of just one country. Results of other country are just the symmetric of our results.

In order solve this system, we just equate A1 and A2 to zero and solve for the equilibrium values of $\tau_h$ and $\tau_f$.

$$\tau_h = 1/3(-c_f - z_h + \alpha + z_f\mu - \theta\mu)$$

$$\tau_f = 1/3(-c_h - z_f + \alpha + z_h\mu - \theta\mu)$$

Second order conditions and stability conditions of this stage directly holds. In accord with the expectations, results of comparative statics analysis are as follows. Due to any improvement in the production technologies of foreign country, home country increases the import tariff. Higher the pollution quota level of home country, lower the import tariff level of home country. Higher the demand, higher the import tariff levels. If gross pollution occurs during the production process increases, import tariff levels decreases. All these explanations are valid for foreign country, since the system is symmetric. In addition to these results, we have an ambiguous relationship between import tariff levels and pollution abatement technology.

### 3.1.3 Stage 1: Governments determine the pollution quotas

At the first stage, governments determine the pollution quotas in order to maximize their welfare. Firstly, we substitute the equilibrium values of stage two and three, which are the output decisions of firms and import tariff levels determined by the governments, into the welfare functions of countries. Secondly, totally differentiating the welfare function we obtain the following equations.

$$3\ dW_h = A3\ dz_h + A4\ dz_f$$

$$3\ dWf = A4\ dz_f + A3\ dz_h$$

where

$$A3=1/81(c_h(90-113\mu)+c_f(-45+51\mu)+(-45+62\mu)(\alpha-\theta\mu)+z_f(-18+(61-51\mu)\mu)+z_h(9+\mu(-180+113\mu)))$$

$$A4=1/81(c_f(90-113\mu)+c_h(-45+51\mu)+(-45+62\mu)(\alpha-\theta\mu)+z_h(-18+(61-51\mu)\mu)+z_f(9+\mu(-180+113\mu)))$$

In order to find the optimal values of the pollution quotas determined by the welfare maximizing governments, we equate A3 and A4 to zero and solve for $z_h$ and $z_f$. Results are as follows.

$$Z_h=(c_f(-1215-1035\mu+2782\mu^2)+\alpha(1215-12519\mu+22322\mu^2-10168\mu^3)+\mu(2c_h(6777-12552\mu+5084\mu^2)+\theta(-1215+12519\mu-22322\mu^2+10168\mu^3)))/(-243-1044\mu+28877\mu^2-34458\mu^3+10168\mu^4)$$

$$Zf=(c_h(-1215-1035\mu+2782\mu^2)+\alpha(1215-12519\mu+22322\mu^2-10168\mu^3)+\mu(2c_f(6777-12552\mu+5084\mu^2)+\theta(-1215+12519\mu-22322\mu^2+10168\mu^3)))/(-243-1044\mu+28877\mu^2-34458\mu^3+10168\mu^4)$$

Now, by substituting the equilibrium values of $z_h$ and $z_f$ into the expressions obtained previously we have our final results. Thus, the formal framework of our analysis is completed.

When we check the second order conditions and stability conditions of stage 1, our findings do not hold for every values of unit cost of pollution abatement, μ. Instead, our findings are valid for an interval which is a function of μ. Not for every case but for the non-cooperative case, stability conditions are not binding. The solution interval is determined by second order conditions. Thus, our model is valid between an upper and lower limit of μ schematized in the below identity.

$$\mu_1 < \mu < \mu_2$$

Above, $\mu_1$ is the lower limit and $\mu_2$ is the upper limit of μ. Our finding from second order conditions plays a crucial role in our comparative statics analysis.

### 3.1.4 Comparative Statics

*Effect of gross pollution on the policy arguments*

As mentioned before gross pollution is the maximum amount of pollution that occurs during the production of goods. First degree derivatives of policy arguments with respect to gross pollution show the effect of changes in gross pollution on policy arguments of governments. Results are as follows.

$$\partial z_i/\partial\theta=(\mu(-1215+12519\mu-22322\mu^2+10168\mu^3))/(-243-1044\mu+28877\mu^2-34458\mu^3+10168\mu^4)$$

Derivative of $z_i$, with respect to θ is a function of μ, unit cost of abating the pollution. When we analyze the sign of this expression in the interval where second order conditions hold, we find that this expression changes sign at a critical value of μ. From second order conditions the higher limit and lower limit of μ has been obtained and we have labeled the lower limit with $\mu_1$ and higher limit with $\mu_2$. Let's label the critical level of μ with $\mu_c$.

Holding the second order conditions, when $\mu$ is smaller than $\mu_c$, $\partial z_i/\partial\theta$ is positive and when $\mu$ is higher than $\mu_c$, $\partial z_i/\partial\theta$ is negative. The reason can be explained by examining the components of welfare functions. Holding everything else constant, when gross pollution increases, firms have to incur higher costs since they have to abate more pollution. Therefore, producer surplus will be affected negatively from an increase in gross pollution. Secondly, amount of the goods consumed will decrease due to the decrease in supply. Thus, consumer surplus will be affected negatively, too. Thirdly, import tariff revenue decreases since the amount of production for import will also decrease. However, disutility of pollution decreases due to the decrease in output levels. Thus, an increase in gross pollution has both negative and positive effects on welfare. It can be said that when the unit cost of abating the pollution is sufficiently low, that is firms are efficient in abating the pollution, governments prefer to choose higher level of pollution quota due to an increase in gross pollution. The reason is that, in this case the gains from consumer surplus, production surplus and import tariff revenue surpass the loss from increase in pollution. The crucial points are those firms are efficient in abating the pollution and gross pollution has contrasting effects on the components of welfare function.

The effect of an increase in gross pollution on the pollution quota determined by governments when unit cost of abatement is above the critical level can also be explained in the same way. In this case firms are inefficient in abating the pollution. Thus, any increase in pollution quota has severe effects on the welfare through the disutility of pollution quota. Therefore, governments respond to an increase in gross pollution by lowering the pollution quotas. That is the welfare gains from abating the pollution surpass the gains from consumer surplus, production surplus and import tariff revenue, if the firms are inefficient in abatement technology.

In order to analyze the effects of changes in gross pollution on import tariffs, we take the derivative of import tariff with respect to gross pollution. It is a function of unit cost of abatement as it can be seen in the equation below.

$$\partial\tau_i/\partial\theta = (2\mu(9+2\mu))/(-9+\mu(-119+62\mu))$$

Inside the interval determined by second order conditions, $\partial\tau_i/\partial\theta$ is strictly positive. Holding the second order conditions, due to any increase in gross pollution, governments determine higher import tariff levels. That is, it is beneficial for the governments to increase the import tariffs due to an increase in gross pollution, since welfare gains from abating the pollution surpass the gains from consumer surplus, producer surplus and import tariffs.

*The effect of changes in demand on policy arguments*

First degree derivatives of policy arguments with respect to demand parameter, $\alpha$, inform what the direction of the change in the policy arguments is due to infinitely small change in demand. The derivative of pollution quota with respect to demand is as follows.

$$\partial z_i/\partial\alpha = (1215-12519\mu+22322\mu^2-10168\mu^3)/(-243-1044\mu+28877\mu^2-34458\mu^3+10168\mu^4)$$

Derivative of $z_i$, pollution quota, with respect to $\alpha$, demand, is a function of $\mu$, unit cost of abating the pollution. Again, there is a critical level of $\mu$ where this expression changes sign. We have labeled the critical level of $\mu$ with $\mu_c$. $\mu_c$, where $\partial z_i/\partial\alpha$ changes sign is exactly the same with $\mu c$ where $\partial z_i/\partial\theta$ changes sign.

Holding the second order conditions, $\partial z_i/\partial\alpha$ is positive if $\mu$ is higher than $\mu_c$ and $\partial z_i/\partial\alpha$ is negative if $\mu$ is lower than $\mu_c$. Holding everything else constant, when demand increases, firms will supply more goods. Therefore, producer surplus will be affected positively from an increase in demand. Secondly, it is clear that consumer surplus will be affected positively. Thirdly, import tariff revenue increases since the amount of production for import will also increase. However, disutility of pollution increases due to the increase in output levels. Thus, an increase in demand has both negative and positive effects on pollution. It can be said that when the unit cost of abating the pollution is sufficiently low, that is firms are efficient in abating the pollution, governments prefer to choose lower level of pollution quota due to an increase in demand. The reason is that, in this case the gains from consumer surplus, production surplus and import tariff revenue can not surpass the loss from increase in pollution. The crucial points are those firms are efficient in abating the pollution and demand has contrasting effects on the components of welfare function.

The effect of an increase in demand on the pollution quota determined by governments when unit cost of abatement is above the critical level can also be explained in the same way. In this case firms are inefficient in abating the pollution. Thus, any increase in demand has severe effects on the welfare through the disutility of pollution quota. Therefore, governments respond to an increase in gross pollution by lowering the pollution quotas. That is the welfare gains from abating the pollution surpass the gains from consumer surplus, production surplus and import tariff revenue, if the firms are in efficient in abatement technology.

In order to analyze the effects of changes in demand on import tariffs, we take the derivative of import tariff with respect to gross pollution. As it can be seen from the equation below, it is a function of unit cost of abatement.

$$\partial\tau_i/\partial\alpha = -(2(9+2\mu))/(-9+\mu(-119+62\mu))$$

Inside the interval determined by second-order conditions, the sign $\partial\tau_i/\partial\alpha$ is strictly positive. Holding the second order conditions, due to any increase in demand, governments determine higher import tariff levels. That is, it is beneficial for the governments to increase the import tariffs due to an increase in demand, since welfare gains from abating the pollution surpass the gains from consumer surplus, producer surplus in import tariff revenue.

## 3.2 Cooperative Solution

In this section, the cooperative solution of our model is examined. It is a three stage game between countries. Different from the previous section, governments determine a unique pollution quota cooperatively at the first stage of the game. The rest of the game is the same with the previous section. Since the problem is solved with backwards induction method, solutions to the third and second stages are exactly the same. Therefore, only the first stage of the game will be examined.

### 3.2.1 Stage 1: Governments determine a unique pollution quota cooperation

At second stage governments determine the import tariffs in order to maximize their individual welfare. At the first stage, governments determine a unique pollution quota in order to maximize the total welfare which is the sum of their individual welfare. Firstly, we substitute the equilibrium values of stage two and three, which are the output decisions of firms and import tariff levels determined by the governments, into the welfare functions of countries. Then we add the sum of these welfare functions. By totally differentiating the total welfare function we obtain the following results.

$$dW_T = 1/81(c_f(41-65\mu)+c_h(41-65\mu)+2(z(1+5\mu)(-19+13\mu)+(-41+65\mu)(\alpha-\theta\mu)))dz$$

In order to find the optimal values of the pollution quota determined, we equate coefficient of z to zero and solve for z. Results are as follows.

$$z=((-41+65\mu)(c_f+c_h-2\alpha+2\theta\mu))/(2(-19-82\mu+65\mu^2))$$

Now by substituting the equilibrium values of z into total welfare function, we have our final results.

When we check the second order conditions and stability conditions of stage 1, our findings does not hold for every values of unit cost of pollution abatement, $\mu$. The solution interval is determined by second order conditions. Thus, our model is valid between an upper and lower limit of $\mu$ schematized as below identity.

$$\mu 1 < \mu < \mu 2$$

Our finding from second order conditions plays a crucial role in our comparative statics analysis. Differently from the non-cooperative case, cooperative solution allows us to make comparative statics analysis for other parameters of the model.

### 3.2.2 Comparative Statics

Since the explanation of our findings from the comparative statics analysis is the same with the non-cooperative case, we will only present our findings.

**Table 3.1. Results of Comparative Statics for Cooperation Case**

| | z | | τh | | τf | |
|---|---|---|---|---|---|---|
| | μ < μc | μ > μc | μ < μc | μ > μc | μ < μc | μ >μc |
| **ch** | + | - | | | - | - |
| **cf** | + | - | - | - | | |
| **α** | - | + | + | + | + | + |
| **θ** | + | - | - | - | - | - |

The comparative statics analysis results of the cooperative case are presented in table 1. Each cell shows the sign of derivative of an exogenous variable in the columns with respect to the parameters in the rows for unit cost of abatement both below and above a critical level. The comparative statics analysis of the policy parameters with respect to demand and gross pollution has been done in the non-cooperative case. Since there is no difference in their interpretations, it will not be examined again in depth. Similar to the non-cooperative case, the pollution quota determined cooperatively changes in the same direction with the gross pollution due to a change in the gross pollution for small values of unit cost of abatement. However, it changes in the opposite direction with gross pollution due to a change in gross pollution for large values of unit cost of abatement. Different from the non-cooperative case, due to a change in gross pollution, import tariffs changes strictly in the opposite direction. Effect of the change in the demand or gross pollution on the components of the welfare is the reason of this fact. When gross pollution or demand changes, the components of welfare change in different direction. In the interval determined by second order conditions, the outcome of the negative and positive effects on welfare determines the direction of the change in policy arguments due to the change in parameters of the model.

In the cooperative case, we obtain some results from the comparative statics analysis of policy arguments due to a change in production technology.

*Effect of production Technology on Policy arguments*

First degree derivatives of policy arguments with respect to marginal costs of firms, $c_h$ and $c_f$, show the effect of infinitely small changes in production technology on policy arguments of governments. Results are as follows.

$$\partial z/\partial c_i=(-41+65\ \mu)/(2\ (-19-82\ \mu+65\ \mu^2))$$

Derivative of z, pollution quota determined by governments cooperatively, with respect to $c_i$, marginal cost of production, is a function of μ, unit cost of abating the pollution. When we analyze the sign of this expression in the interval where second order conditions hold, we find that this expression changes sign at $\mu_c$.

Holding the second order conditions, when μ is smaller than μc, $\partial z/\partial c_i$ is positive and when μ is higher than μc, $\partial z/\partial c_i$ is negative. The reason can be explained as follows. Holding everything else constant, due to an improvement in production technology, firms supply more. Therefore, producer surplus will be affected positively from an improvement in production technology. That is producer surplus will increase due a decrease in marginal cost of production. Secondly, amount of the goods consumed will increase due to the decrease in supply. Thus, consumer surplus will increase, too. Thirdly, import tariff revenue increases since the amount of production for import will also increase. However, disutility of pollution increases due to the increase in output levels. Thus, an improvement in production technology has both negative and positive effects on pollution. It can be said that when the unit cost of abating the pollution is sufficiently low, that is firms are efficient in abating the pollution, governments prefer to choose lower level of pollution quota due to an improvement in production technology. The reason is that, in this case the gains from consumer surplus, production surplus and import tariff revenue can not surpass the loss from increase in pollution. The crucial points are those firms are efficient in abating the pollution and gross pollution has contrasting effects on the components of welfare function.

The effect of an improvement in production technology on the pollution quota determined by governments cooperatively, when unit cost of abatement is above the critical level can also be explained in the same way. In this case firms are inefficient in abating the pollution

### 3.3 Comparison Between Non-Cooperation and Cooperation

Until now, in the cooperation and non-cooperation case, we have got the values of policy arguments; pollution quotas and import tariffs. In this stage we will compare these results.

Values of policy arguments are a function of demand, production technologies of firms, pollution abatement technology and gross pollution as it is illustrated below.

$$\tau_h^{nc} = f(\alpha, ch, cf, \mu, \theta)$$

$$\tau_f^{nc} = f(\alpha, ch, cf, \mu, \theta)$$

$$Z_h^{nc} = f(\alpha, ch, cf, \mu, \theta)$$

$$Z_f^{nc} = f(\alpha, ch, cf, \mu, \theta)$$

$$\tau_h^{c} = f(\alpha, ch, cf, \mu, \theta)$$

$$\tau_f^{c} = f(\alpha, ch, cf, \mu, \theta)$$

$$Z^{c} = f(\alpha, ch, cf, \mu, \theta)$$

In order to indicate the non-cooperative case, values of policy arguments are labeled with nc. For the cooperative case, values of policy arguments are labeled with c.

Firstly, pollution quotas will be compared. In order to compare the pollution quotas determined by governments in the non-cooperative and cooperative case, we obtain the difference of these values. The differences are equal to individual pollution quotas minus the unique pollution quota determined cooperatvely. As it is illustrated below, the difference is a function of demand, production technologies of firms, pollution abatement technology and gross pollution.

$$\Delta z_h = f(\alpha, ch, cf, \mu, \theta)$$

$$\Delta z_f = f(\alpha, ch, cf, \mu, \theta)$$

Thus, in order to investigate the relationship between $\Delta z$, $\mu$, cf and ch; we will give values to $\alpha$ and $\theta$. While attending values to $\alpha$ and $\theta$, we know that $\mu$ changes in an interval determined by second order conditions. Also the values we attend must provide the positive output conditions. It is safe to attend 100 to α. By considering the positive output conditions, we can choose 70 for θ. It can be showed that our results will not be affected from the values attended to α and θ. Finally, we will construct two scenarios making assumptions about the production technologies of firms to investigate how $\Delta z$ changes with μ. In the first scenario, it will be assumed that firms have the same production technology. That is ch is equal to cf and both are 1.

In the scenario, ch and cf is taken as 1. In the graph below, it can be seen that $\Delta z_h$ and $\Delta z_f$ are negative when pollution abatement technology is efficient. That is the unique pollution quota determined cooperatively by both governments is higher than the pollution quotas determined individually by the governmnets. As abatemment technology became more inefficient, $\Delta z_h$ and $\Delta z_f$ get smaller since the unique pollution quota determined cooperatively became smaller. After a critical value of μ, $\Delta z_h$ and $\Delta z_f$ are positive where pollution abatement technology is inefficient. That is the unique pollution quota determined cooperatively by both governments is lower than the pollution quotas determined individually by the governmnets.

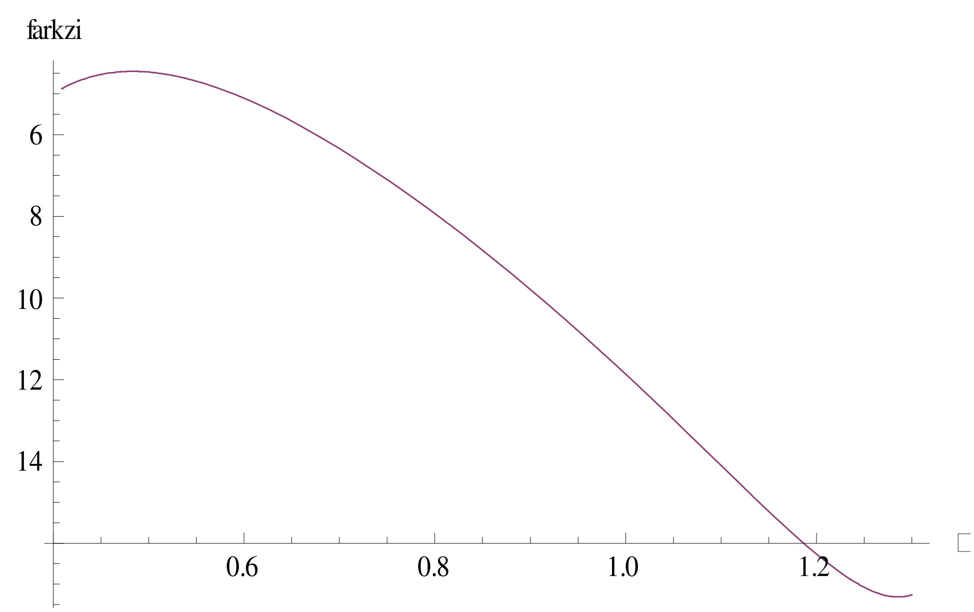


**Figure 3.1.** Change of Difference of Pollution Quotas with Unit Cost of Abatement – Scenario 1

The reason can be explained as follows. As it was discussed in previous sections, the welfare function of countries is composed of production surplus, consumer surplus, import tariffs and disutility of pollution. Welfare increases through the first three elements when production increases. However, welfare decreases through the distutility of pollution when production increases. Thus, there are two opposite effect of changing the production level. In our scenarios there are two crucial variables; abatement technology and production technology. More efficient the firms in production technology, more willingness the governments to increase their welfare through production surplus, consumer surplus and import tariffs by increasing production. The second crucial variable is abatement technology. More efficient the firms in abatement technology, more willingness the governments to increase welfare through decreasing disutility of pollution by decreasing production level. In this respect, it is advantageous for firms to increase welfare through disutility of pollution by decreasing production level when pollution abatement technology is inefficient.. Thus, when pollution abatement technology is inefficient, governments prefer to increase pollution quota by cooperation.

Secondly, if firms are efficient in abatement technology, governments behave in the opposite way. In this case, firms are efficient in abatement technology. Efficiency in abatement technology let the governments to increase production level.

In the second scenario, it will be assumed that domestic firm is efficient relative to foreign firm. In this scenario ch will stay 1 and cf will be taken 2. In the graph below, it can be seen that $\Delta z_h$ and $\Delta z_f$ are negative. That is the unique pollution quota determined cooperatively by both governments is higher than the pollution quotas determined individually by the governmnets. Only there is a small interval of $\mu$ where $\Delta z_f$ is positive.

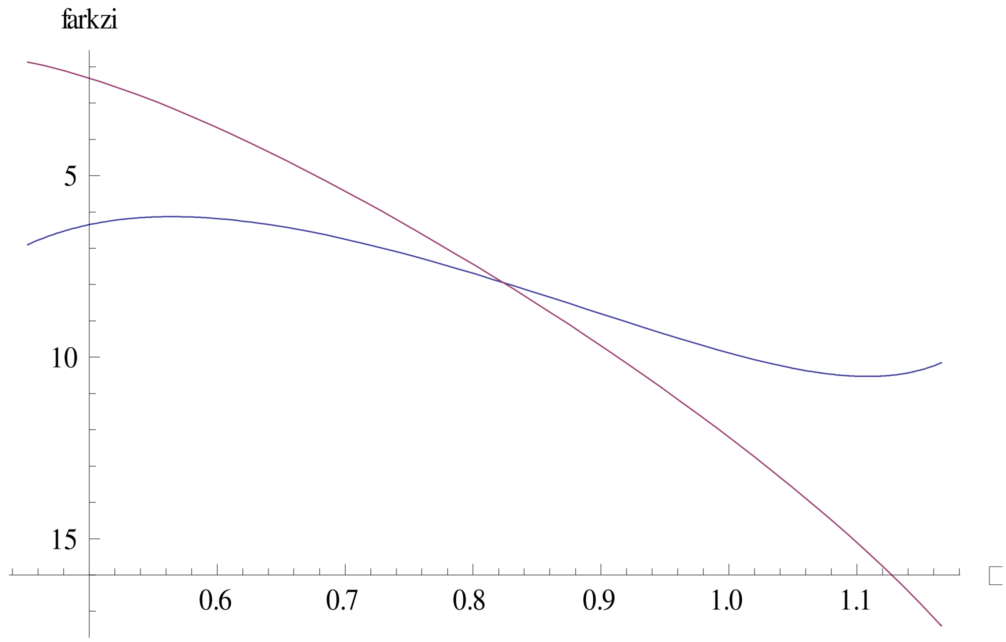


**Figure 3.2.** Change of Difference of Pollution Quotas with Unit Cost of Abatement – Scenario 2

When we analyze the graph above, it can be realized that how level of production technology effects the environmental policies of governments. When production technology is efficient governments have an incentive to increase pollution quotas to increase welfare through producer surplus, consumer surplus and import tariff revenues. On the other hand, when production technology is relatively inefficient firm has an incentive to increase welfare by decreasing disutility of pollution. In the graph, it can be seen that when pollution abatement technology is efficint firms prefers to increase pollution quota by cooperation in order to increase their welfare through disutility of pollution. As pollution abatement technology became inefficient they prefer to determine lower pollution quotas by cooperation. In addition, relative efficiency in production technology of domestic firm let the home government to determine a higher pollution quota in the non-cooperation case to take the advantage of its relative efficiency in production technology. That is in an interval of $\mu$ where pollution abatement technology is efficient, domestic firm determine a higher pollution quota non-cooperatively. However, $\Delta z_f$ responds more strongly than $\Delta z_h$ to the changes in $\mu$. The reason can be explained as follows. We have showed that improvement in abatement technology let the governments to have higher pollution quotas. Also, higher efficiency in production technology lets the governments to determine higher pollution quotas. Therefore, for ecery valid value of $\mu$, domestic government has an higher incentive to have higher pollution quota with respect to foreign government. Thus, improvement in abatement technology effects the domestic firm incentive to increase pollution quota less than the foreign government. So, as $\mu$ increase domestic government's pollution quota determined non-cooperatively doesn't grow as much as the foreign government's pollution quota. Thus, as it can be see in the graph, after a critical value of $\mu$, $\Delta z_h$ is higher than $\Delta z_f$. That is in this region home government determines a lower pollution quota than foreign government.

# 4 CHAPTER 2: FREE TRADE

In this chapter, effects of trade liberalization on the policy arguments of governments will be examined. With trade liberalization, governments give up the import tariffs levied on the imports. In order to extend the model to free trade case, import tariffs are taken zero and all the terms including import tariffs drop off the relevant expressions. In preceding sections, free trade case will be examined for both non-cooperative and cooperative case. Then, they will be compared. Secondly, results of main model and free trade case will be compared. Differently from previous section, profit functions of firms do not include import tariff term. Therefore we have the following profit functions for each firm.

$$\pi_h = (p_h - k_h)\, x_h + (p_f - k_h)\, x_f \tag{4}$$

$$\pi_f = (p_f - k_f)\, y_f + (p_h - k_f)\, y_h \tag{5}$$

Also, welfare functions do not include import tariff term. The welfare of each country is composed of three parts; consumer surplus (CS), producer surplus (PS) and disutility of pollution (DP). Welfare of each country are given with the following equations.

$$W_h = CS_h + PS_h - DP_h \tag{8}$$

$$W_f = CS_f + PS_f - DP_f \tag{9}$$

## 4.1 Non – Cooperation in Environmental Policy

In this section, non-cooperative solution of free trade extension of our model is examined. Since import tariffs are abandoned, the model is consist of two stage game. At the first stage, governments determine the pollution quota given the reaction functions of later stages. At the second stage, firms determine their output level given the results of earlier stages.

### 4.1.1 Stage 2: Firms determines the output levels

At the second stage of the game, each firm determines their output level taking reaction function of other firm as given. The first order conditions obtain the optimal output levels of the firms.

$$x_h = 1/3(c_f - 2c_h + \alpha - z_f\mu + 2z_h\mu - \theta\mu) \qquad (4.1)$$

$$x_f = 1/3(c_f - 2c_h + \alpha - z_f\mu + 2z_h\mu - \theta\mu) \qquad (4.2)$$

$$y_h = 1/3(-2c_f + c_h + \alpha + 2z_f\mu - z_h\mu - \theta\mu) \qquad (4.3)$$

$$y_f = 1/3(-2c_f + c_h + \alpha + 2z_f\mu - z_h\mu - \theta\mu) \qquad (4.4)$$

Thus, there is a two way trade between these countries. In the problem, second order conditions are directly satisfied.

Since comparative static analysis on the outcomes of stage 2 is parallel with the stage 3 of the main model, they won't be examined again.

### 4.1.2 Stage 1: Governments determine the pollution quotas

At the first stage, governments determine the pollution quotas in order to maximize their welfare. Firstly, we substitute the equilibrium values of stage one, which are the output decisions of firms into the welfare functions of countries. Secondly, first degree derivative of $W_h$ with respect to $z_h$ and $W_f$ with respect to $z_f$ are equated to zero. Expressions obtained are as follows:

$$1/9(-6(c_f-2c_h+\alpha)+(7c_f-17c_h+6z_f-24z_h+10\alpha+6\theta)\mu+(-7z_f+17z_h-10\theta)\mu 2)= 0$$

$$1/9(-6(c_h+\alpha)+c_f(12-17\mu)+\mu(7ch+6z_h+10\alpha+6\theta-7z_h\mu-10\theta\mu+z_f(-24+17\mu)))= 0$$

In order to find the optimal values of the pollution quotas determined by the welfare maximizing governments, above equations are solved for $z_h$ and $z_f$ simultaneously. Values obtained are as follows:

$$Z_h=(c_f(-6+7\mu)+c_h(21-44\mu+20\mu^2)-(\alpha-\theta\mu)(15-37\mu+20\mu^2))/(\mu(45-61\mu+20\mu^2))$$

$$Z_f=(c_h(-6+7\mu)+c_f(21-44\mu+20\mu^2)-(\alpha-\theta\mu)(15-37\mu+20\mu^2))/(\mu(45-61\mu+20\mu^2))$$

Now by substituting the equilibrium values of $z_h$ and $z_f$ into the expressions obtained, we have our final results. Thus, the formal framework of our analysis is completed.

Again our solutions are valid for an interval of pollution abatement technology determined by second order conditions.

### 4.1.3 Comparative Statics

Our findings from comparative statics analysis are presented in the below table. Explanation of our findings is not different from previous sections, so we are yetinmek with presenting our results.

**Table 4.1. Results of Comparative Statics for Non-cooperation Case After-liberalization**

| | zh | |
|---|---|---|
| | μ < μc | μ > μc |
| **ch** | + | - |
| **cf** | - | + |
| **α** | - | + |
| **θ** | + | - |

Each cell shows the sign of derivative of zh in the columns with respect to the parameters in the rows for unit cost of abatement both below and above a critical level. If pollution abatement technology is efficient, pollution quota of home country increases due to any improvement in production technology of home firm and decreases due to any improvement in the production technology of foreign firm. If pollution abatement technology is not efficient, pollution quota of home country decreases due to any improvement in production technology of home firm and increases due to any improvement in the production technology of foreign firm The pollution quota changes in the same direction with the gross pollution due to a change in the gross pollution for small values of unit cost of abatement. However, it changes in the opposite direction with gross pollution due to a change in gross pollution for large values of unit cost of abatement. Secondly, for low values of unit cost of pollution abatement, pollution quota decreases as demand increases, however for high values of unit cost of pollution abatement, pollution quota increases as demand increases. Effect of the change in the demand or gross pollution on the components of the welfare is the reason of this fact. When gross pollution or demand changes, the components of welfare change in different direction. In the interval determined by second order conditions, the outcome of the negative and positive effects on welfare determines the direction of the change in policy arguments due to the change in parameters of the model.

## 4.2 Cooperation in Environmental Policy

In this section, the cooperative solution of our extended model is examined. There is a two stage game between countries. Differently from the previous section, now, governments determine a unique pollution quota cooperatively at the first stage of the game. The rest of the game is the same with the previous section. Since the problem is solved with backwards induction method, solution to the second stages are exactly the same. Therefore, only the first stage of the game will be examined.

### 4.2.1 Stage 1: Governments determine a unique pollution quota

At the first stage, governments determine a unique pollution quota in order to maximize the total welfare which is the sum of their individual welfare. Firstly, we substitute the equilibrium values of stage two, which is the output decisions of firms into the welfare functions of countries. Then we add the sum of these welfare functions. By totally differentiating the total welfare function we obtain the following results.

$$dW_T = 1/9(6(c_f+c_h-2\alpha)-4(2(c_f+c_h+3z-2\alpha)-3\theta)\mu+16(z-\theta)\mu^2)dz$$

In order to find the optimal values of the pollution quota determined, we equate coefficient of dz to zero and solve for z. Results are as follows.

$$z=((-3+4\mu)(c_f+c_h-2\alpha+2\theta\mu))/(4\mu(-3+2\mu))$$

Now by substituting the equilibrium values of z into total welfare function, we have our final results.

When we check the second order conditions and stability conditions of stage 1, our findings does not hold for every values of unit cost of pollution abatement, μ. The solution interval is determined by second order conditions. Thus, our model is valid between an upper and lower limit of μ.

### 4.2.2 Comparative Statics

Since the explanation of our findings from the comparative statics analysis is the same with the non-cooperative case, we will only present our findings.

**Table 4.2. Results of Comparative Statics for Cooperation Case After-liberalization**

| | z | |
|---|---|---|
| | μ < μc | μ > μc |
| **ch** | + | - |
| **cf** | + | - |
| **α** | - | + |
| **θ** | + | - |

Each cell shows the sign of derivative of $z_h$ in the columns with respect to the parameters in the rows for unit cost of abatement both below and above a critical level. If pollution abatement technology is efficient, pollution quota of home country increases due to any improvement in production technology of home firm and foreign firm. If pollution abatement technology is not efficient, pollution quota of home country decreases due to any improvement in production technology of home firm and foreign firm the pollution quota changes in the same direction with the gross pollution due to a change in the gross pollution for small values of unit cost of abatement. However, it changes in the opposite direction with gross pollution due to a change in gross pollution for large values of unit cost of abatement. Secondly, for low values of unit cost of pollution abatement, pollution quota decreases as demand increases, however for high values of unit cost of pollution abatement, pollution quota increases as demand increases. Effect of the change in the demand or gross pollution on the components of the welfare is the reason of this fact. When gross pollution or demand changes, the components of welfare change in different direction. In the interval determined by second order conditions, the outcome of the negative and positive effects on welfare determines the direction of the change in policy arguments due to the change in parameters of the model.

### 4.3 Comparison Between Non-Cooperation and Cooperation

Up to now, in the cooperation and non-cooperation case, we have got the values of policy arguments; pollution quotas and import tariffs. In this stage we will compare these results.

Values of policy arguments are a function of demand, production technologies of firms, pollution abatement technology and gross pollution as it is illustrated below.

$$Z_h^{nc} = f(\alpha, ch, cf, \mu, \theta)$$

$$Z_f^{nc} = f(\alpha, ch, cf, \mu, \theta)$$

$$Z^{c} = f(\alpha, ch, cf, \mu, \theta)$$

In order to indicate the non-cooperative case, values of policy arguments are labeled with nc. For the cooperative case, values of policy arguments are labeled with c.

In order to compare the pollution quotas determined by governments in the non-cooperative and cooperative case, we obtain the difference of these values. As it is illustrated below, the difference is a function of demand, production technologies of firms, pollution abatement technology and gross pollution.

$$\Delta z_h = f(\alpha, ch, cf, \mu, \theta)$$

$$\Delta z_f = f(\alpha, ch, cf, \mu, \theta)$$

Thus, in order to investigate the relationship between $\Delta z$, $\mu$, cf and ch; we will give values to $\alpha$ and $\theta$. While attending values to $\alpha$ and $\theta$, we know that $\mu$ changes in an interval determined by second order conditions. Also the values we attend must provide the positive output conditions. It is safe to attend 100 to $\alpha$. By considering the positive output conditions, we can choose 70 for $\theta$. It can be showed that our results will not be affected from the values attended to $\alpha$ and $\theta$. Finally, we will construct two scenarios making assumptions about the production technologies of firms to investigate how $\Delta z$ changes with $\mu$. In the first scenario, it will be assumed that firms have the same production technology. That is ch is equal to cf and both are 1.

In the scenario, ch and cf is taken as 1. In the graph below, it can be seen that $\Delta z_h$ and $\Delta z_f$ are negative. That is the unique pollution quota determined cooperatively by both governments is higher than the pollution quotas determined individually by the governmnets.

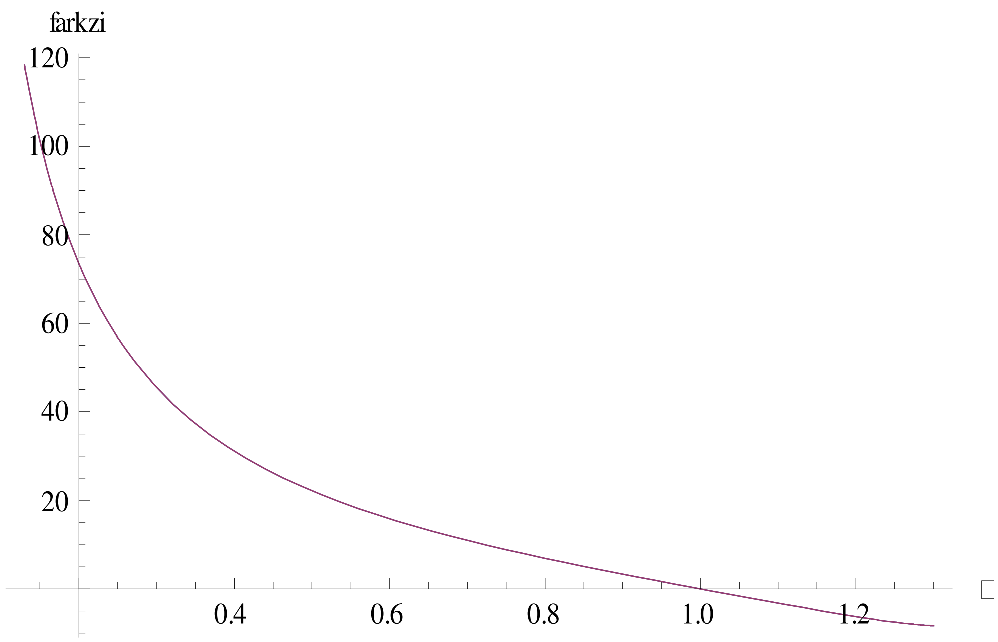


**Figure 4.1.** Change of Differences of Polllution Quotas with Unit Cost of Abatement – Scenario1

The reason can be explained as follows. As it was discussed in previous sections, the welfare function of countries is composed of production surplus, consumer surplus, import tariffs and disutility of pollution. Welfare increases through the first three elements when production increases. However, welfare decreases through the distutility of pollution when production increases. Thus, there are two opposite effect of changing the production level. In our scenarios there are two crucial variables; abatement technology and production technology. More efficient the firms in production technology, more willingness the governments to increase their welfare through production surplus, consumer surplus and import tariffs by increasing production. The second crucial variable is abatement technology. More efficient the firms in abatement technology, more willingness the governments to increase welfare through decreasing disutility of pollution by decreasing production level. In this respect, it is advantageous for firms to increase welfare through disutility of pollution by decreasing production level when pollution abatement technology is inefficient.. Thus, when pollution abatement technology is inefficient, governments prefer to increase pollution quota by cooperation.

Secondly, if firms are efficient in abatement technology, governments behave in the opposite way. In this case, firms are efficient in abatement technology. Efficiency in abatement technology let the governments to increase production level.

In the second scenario, it will be assumed that domestic firm is efficient relative to foreign firm. In this scenario ch will stay 1 and cf will be taken 2. In the graph below, it can be seen that $\Delta z_h$ and $\Delta z_f$ are negative. That is the unique pollution quota determined cooperatively by both governments is higher than the pollution quotas determined individually by the governmnets. Only there is a small interval of $\mu$ where $\Delta z_f$ is positive.

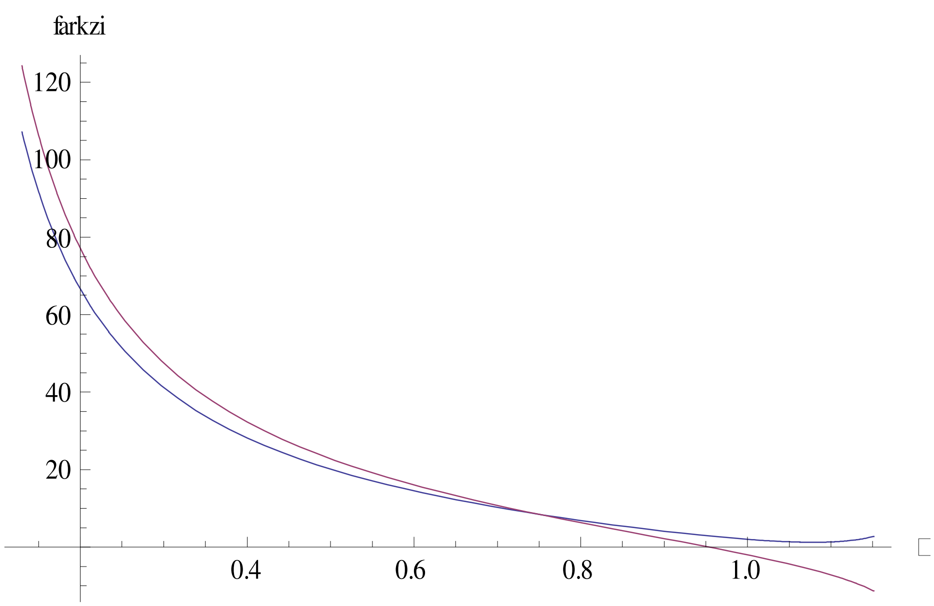


**Figure 4.2.** Change of Differences of Polllution Quotas with Unit Cost of Abatement – Scenario2

When we analyze the graph above, it can be realized that how level of production technology effects the environmental policies of governments. When production technology is efficient governments have an incentive to increase pollution quotas to increase welfare through producer surplus, consumer surplus and import tariff revenues. On the other hand, when production technology is relatively inefficient firm has an incentive to increase welfare by decreasing disutility of pollution. In the graph, it can be seen that when pollution abatement technology is efficint firms prefers to increase pollution quota by cooperation in order to increase their welfare through disutility of pollution. As pollution abatement technology became inefficient they prefer to determine lower pollution quotas by cooperation. In addition, relative efficiency in production technology of domestic firm let the home government to determine a higher pollution quota in the non-cooperation case to take the advantage of its relative efficiency in production technology. That is in an interval of μ where pollution abatement technology is efficient, domestic firm determine a higher pollution quota non-cooperatively. However, $\Delta z_f$ responds more strongly than $\Delta z_h$ to the changes in μ. The reason can be explained as follows. We have showed that improvement in abatement technology let the governments to have higher pollution quotas. Also, higher efficiency in production technology lets the governments to determine higher pollution quotas. Therefore, for ecery valid value of μ, domestic government has an higher incentive to have higher pollution quota with respect to foreign government. Thus, improvement in abatement technology effects the domestic firm incentive to increase pollution quota less than the foreign government. So, as μ increase domestic government's pollution quota determined non-cooperatively doesn't grow as much as the foreign government's pollution quota. Thus, as it can be see in the graph, after a critical value of μ, $\Delta z_h$ is higher than $\Delta z_f$. That is in this region home government determines a lower pollution quota than foreign government.

### 4.4 Comparison Between Before and After Trade Liberalization

In this section we will examine how trade liberalization effects the values pollution quotas. Analysis is done for both cases, non-cooperative and cooperative case. We use the scenarios used in the previous sections.

We will use the same scenarios used in previous sections. α is taken 100 and θ is 70. The interval of μ is cross section of the intervals in the non-cooperative cases of after liberalization and before liberalization cases. We take the differences for both home and foreign countries pollution quotas determined non-cooperatively before and after liberalization. These operations are summarized as below.

$$\Delta z_h^{nc} = z_h^{nc\text{-}b} - z_h^{nc\text{-}a}$$

$$\Delta z_f^{nc} = z_f^{nc\text{-}b} - z_f^{nc\text{-}a}$$

Above, nc indicates that all values are belong to non-cooperative cases. In order to indicate the before and after liberalization cases, b and a are used. $\Delta z_h^{nc}$ is the difference between the pollution quotas of home country determined non-cooperatively before and after liberalization. $\Delta z_f^{nc}$ is the difference between the pollution quotas of home country determined non-cooperatively before and after liberalization. Below graph shows how these differences change between the lower and upper limit of $\mu$.

In the first scenario home firm and foreign firm have the smae efficiency in production technology and the marginal cost of production is taken 1.

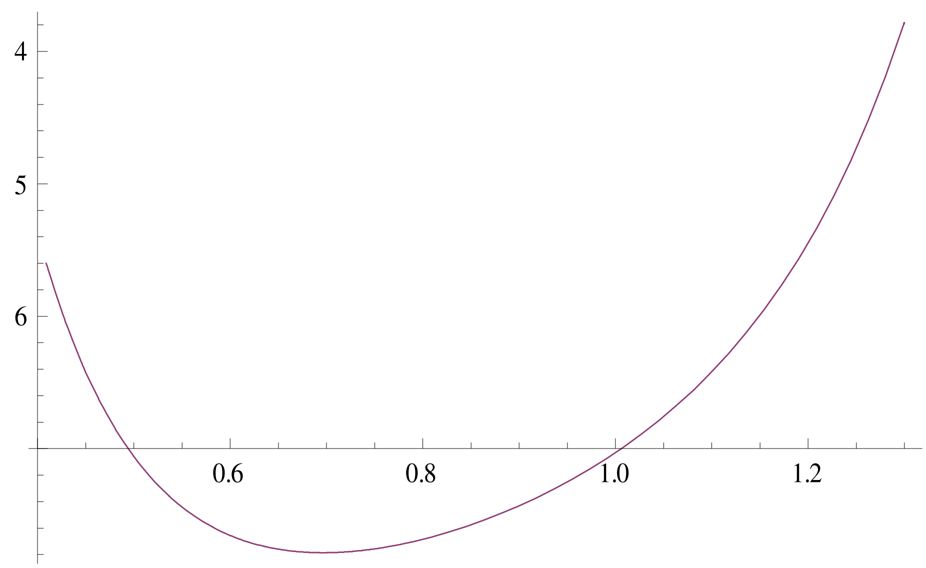


**Figure 4.3.** Change of Differences of Pollution Quotas with Unit Cost of Abatement Before and After Liberalizing Trade in Non-cooperation Case-Scenario 1

As it can be seen from the graph $\Delta z_h^{nc}$ and $\Delta z_f^{nc}$ is always negative. Thus trade liberalization let the firms to increase their pollution quota. The reason is that liberalizing trade increases volume of trade. Thus, firms produce mor for both domestic and foreign market. Therefore, governments prefer to increase their welfare through increasing producer surplus, concumer surplus and import tarif revenues.

In the second scenario home firm is efficient in production technology and its marginal cost of production is taken 1. Foreign firm is inefficient in production technology and its marginal cost of production is taken 5.

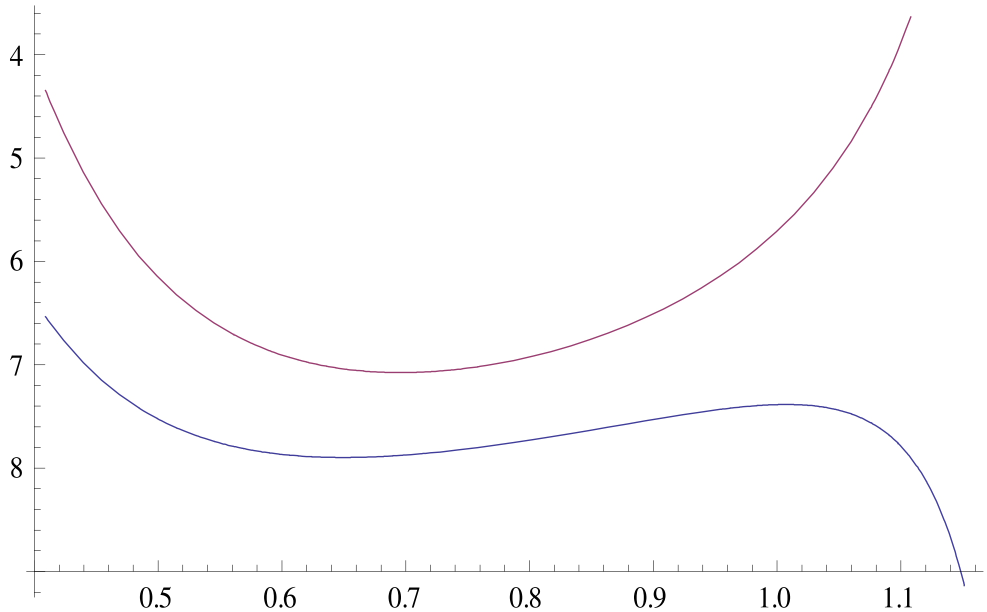


**Figure 4.4.** Change of Differences of Pollution Quotas with Unit Cost of Abatement Before and After Liberalizing Trade in Non-cooperation Case-Scenario 2

As it can be seen from the graph $\Delta z_h^{nc}$ and $\Delta z_f^{nc}$ is always negative. Thus trade liberalization let the firms to increase their pollution quota. The reason is that liberalizing trade increases volume of trade. Thus, firms produce mor for both domestic and foreign market. Therefore, governments prefer to increase their welfare through increasing producer surplus, concumer surplus and import tarif revenues. Secondly, it is seen that $\Delta z_h^{nc}$ higher than is always higher than $\Delta z_f^{nc}$. The reason is obvious. Import tariff is a way to protect domestic firms from international competition. When trade is liberalized, foreign firm worse of in terms of international competition, since it is inefficient in production technology. Thus, foreign government can not be as willingness as the domestic government to increase pollution quota. That is, foreign government is always more inclined to keep pollution at a lower level. On the other hand domestic government increases pollution in order to benefit from the domestic firm's competitive advantage in production technologies.

Secondly, we will analyze the difference of pollution quotas determined cooperatively before and after liberalization.

$$\Delta z^c = z^{c\text{-}b} - z^{c\text{-}a}$$

$z^{c\text{-}b}$ is the pollution quota determined cooperatively before liberalization and $z^{c\text{-}a}$ is the pollution quota determined cooperatively after liberalization. The difference is denoted with $\Delta z^c$. Below the graph shows how $\Delta z^c$ changes in the valid interval of $\mu$. In the first scenario home firm and foreign firm have the smae efficiency in production technology and the marginal cost of production is taken 1.

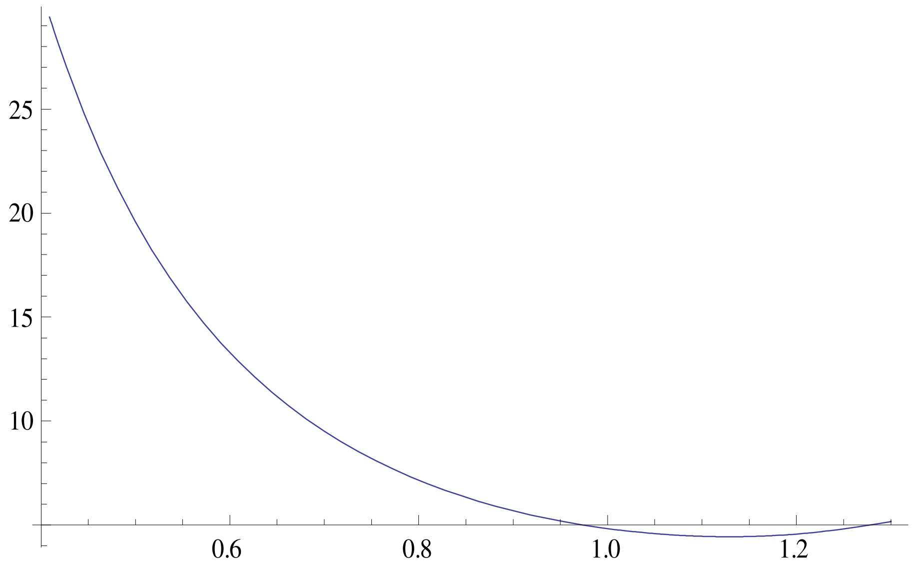


**Figure 4.5.** Change of Differences of Pollution Quotas with Unit Cost of Abatement Before and After Liberalizing Trade in Cooperation Case – Scenario 1

As it can be seen in the graph above pollution quota determined cooperatively decreases with trade liberalization for all values of unit cost of abatement.

In the second scenario home firm is efficient in production technology and its marginal cost of production is taken 1. Foreign firm is inefficient in production technology and its marginal cost of production is taken 5.

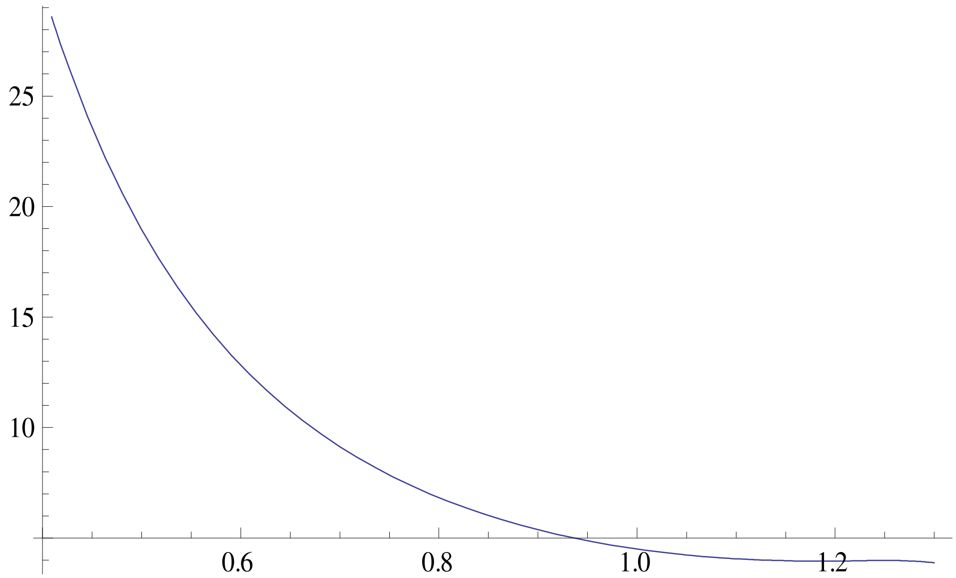


**Figure 4.5.** Change of Differences of Pollution Quotas with Unit Cost of Abatement Before and After Liberalizing Trade in Cooperation Case – Scenario 2

As it can be seen in the graph above, again, pollution quota determined cooperatively decreases with trade liberalization for all values of unit cost of abatement.

## 5 CONCLUSION

In this paper, our main objective was to study how governments form their environmental policies if intra-industry trade is their main type of trade. In order to study the effects of pollution abatement technology on environmental policies, we incorporate a marginal cost structure consisting of two parts. While, first part is related with production technology, second part is related with pollution abatement technology. This marginal cost structure allowed us to examine how environmental policies are related to pollution abatement technology.

In order to investigate this relationship we constructed an intra-industry type two country-two firm partial equilibrium model. In the model, agents maximize their objective functions through a three-stage game. At the firs stage, governments make their environmental policies by putting pollution quotas on production, in order to maximize national welfare. Secondly, again governments make their international trade policies by levying import tariffs in order to maximize national welfare. At the third stage, firms determine output levels for both domestic and foreign market. In the free trade extension of our model, the game consists of two stages, since import tariffs are excluded.

We solved the before-liberalization case for two scenarios, non-cooperation and cooperation environmental policy. When governments are determining pollution quotas non-cooperatively, each government maximizes its own welfare. When they cooperate, they determine a unique pollution quota by maximizing total welfare which is the sum of individual welfares of countries. Comparative statics analysis for both non-cooperation and cooperation cases revealed the importance of pollution abatement technology on policy making. When governments are changing the environmental and international trade policies due to a structural change such as change in production costs, demand and gross pollution, they have to consider the opposite effects on welfare. While welfare is affected positively from producer surplus, consumer surplus and import tariffs if production level rises, it is affected positively from disutility of pollution if production level decreases. Pollution abatement technology plays its key role at this point. If pollution abatement technology is efficient, governments prefers to increase output level by making policies in respond to structural changes. The reason is that effective pollution abatement technology allows governments to increase pollution quota without causing severe environmental damage. This means they prefer to increase welfare via production surplus, consumer surplus and import tariffs. On the other hand, if pollution abatement technology is not efficient, governments prefer to decrease production level in order avoid severe environmental problems. That is while maximizing the welfare; they prefer to decrease pollution rather than increasing the production surplus, consumer surplus and import tariffs. We have reached the same results while analyzing the cooperation case.

In the before-liberalization case, we have also compared the pollution quotas determined cooperatively and non-cooperatively. In order to examine this, we gave numerical values to some variables under an assumption. We assumed that domestic firm is significantly inefficient in production technology relative to foreign firm. Our analysis revealed that when marginal cost of domestic firm is very high with respect to foreign firm and abatement technology is efficient, cooperation in environmental policy let the home government to determine a lower pollution quota and let the foreign government to determine a higher pollution quota. However, when the abatement technology is not efficient, cooperation in environmental policy let the home government to determine a higher pollution quota and let the foreign government to determine a higher pollution quota. it is advantageous for firm h to increase welfare through disutility of pollution by decreasing production level. So, home government always has an incentive to decrease production level. When pollution abatement technology is inefficient, home government has one more motivation to decrease disutility of pollution. Thus, when pollution abatement technology is inefficient, home government prefers to increase pollution quota by cooperation. On the other hand, foreign firm is efficient in production technology relative to home firm which is an incentive to increase production level. But it is inefficient in abatement technology which is an incentive to decrease production level. Foreign government prefers to decrease pollution quota by cooperation, because its efficiency in production technology is a stronger incentive than its inefficiency in abatement technology.

All our findings in the free trade case supported the results of the before-liberalization case. In the last section, we firstly compared the pollution quotas determined non-cooperatively before and after liberalization. Secondly we compared the pollution quotas determined cooperatively before and after trade liberalization. In the non-cooperative case, trade liberalization let the firm that is inefficient in production technology to reduce its pollution quota. On the other hand the firm that is efficient in production technology increases its pollution quota with trade liberalization. The reason is obvious. Import tariff is a way to protect domestic firms from international competition. When trade is liberalized, domestic firm is worse of in terms of international competition; since it is inefficient in production technology. Thus, home government prefers to increase its welfare by at least eliminating pollution with lower pollution quotas. On the other hand foreign government increases pollution in order to benefit from the foreign firm's competitive advantage in production technologies.

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**APPENDIX: MODELLING IN MATHEMATICA**

**BEFORE LIBERALIZATION: NON-COOPERATION IN ENVIRONMENTAL POLICY**

**MODEL**

for i=h,f

h:home

f:foreign

xi=output of home country consumed in country i

yi=ouput of foreign country consumed in country i

ki=marginal cost of country i

ki=ci+$\mu$ ($\theta$-zi)

ci=constant marginal cost

$\mu$=cost of abatement per unit of output

$\theta$=gross pollution per unit of output

z=abatement per unit of output

pi=$\alpha$-$\beta$ (xi+yi)

$\beta$=1

**STAGE 3:**

pri=profit function of country i

ph=$\alpha$-$\beta$ (xh+yh)

pf=$\alpha$-$\beta$ (xf+yf)

kh=ch+$\mu$($\theta$-zh)

kf=cf+μ(θ-zf)

prh=(α-β (xh+yh)-kh) xh+(α-β (xf+yf)-kh-τf) xf

xh (-ch-xh-yh+α-(-zh+θ) μ)+xf (-ch-xf-yf+α-(-zh+θ) μ-τf)

First Order Conditions:

derpr1=D[prh,xh]

-ch-2 xh-yh+α-(-zh+θ) μ

derpr2=D[prh,xf]

-ch-2 xf-yf+α-(-zh+θ) μ-τf

prf=yf (-kf+α-(xf+yf) β)+yh (-kf+α-(xh+yh) β-τh)

yf (-cf-xf-yf+α-(-zf+θ) μ)+yh (-cf-xh-yh+α-(-zf+θ) μ-τh)

derpr3=D[prf,yh]

-cf-xh-2 yh+α-(-zf+θ) μ-τh

derpr4=D[prf,yf]

-cf-xf-2 yf+α-(-zf+θ) μ

Simplify[Solve[{derpr1  0,derpr2  0,derpr3  0,derpr4==0},{xh,xf,yh,yf}]]

{{xh→1/3 (cf-2 ch+α-zf μ+2 zh μ-θ μ+τh),xf→1/3 (cf-2 ch+α-zf μ+2 zh μ-θ μ-2 τf),yh→1/3 (-2 cf+ch+α+2 zf μ-zh μ-θ μ-2 τh),yf→1/3 (-2 cf+ch+α+2 zf μ-zh μ-θ μ+τf)}}

d: equilibrium value

dyf=1/3 (-2 cf+ch+α+2 zf μ-zh μ-θ μ+τf)

1/3 (-2 cf+ch+α+2 zf μ-zh μ-θ μ+τf)

dxf=1/3 (cf-2 ch+α-zf μ+2 zh μ-θ μ-2 τf)

1/3 (cf-2 ch+α-zf μ+2 zh μ-θ μ-2 τf)

dxh=1/3 (cf-2 ch+α-zf μ+2 zh μ-θ μ+τh)

$1/3\ (cf-2\ ch+\alpha-zf\ \mu+2\ zh\ \mu-\theta\ \mu+\tau h)$

$dyh=1/3\ (-2\ cf+ch+\alpha+2\ zf\ \mu-zh\ \mu-\theta\ \mu-2\ \tau h)$

$1/3\ (-2\ cf+ch+\alpha+2\ zf\ \mu-zh\ \mu-\theta\ \mu-2\ \tau h)$

dprh=FullSimplify[prh/.{xh→dxh,xf→dxf,yh→dyh,yf→dyf}]

$1/9\ (2\ (cf-2\ ch+\alpha-(zf-2\ zh+\theta)\ \mu)^2-4\ (cf-2\ ch+\alpha-(zf-2\ zh+\theta)\ \mu)\ \tau f+4\ \tau f^2+2\ (cf-2\ ch+\alpha-(zf-2\ zh+\theta)\ \mu)\ \tau h+\tau h^2)$

dprf=FullSimplify[prf/.{xh→dxh,xf→dxf,yh→dyh,yf→dyf}]

$1/9\ (8\ cf^2+2\ ch^2+2\ \alpha 2+8\ zf^2\ \mu 2+2\ zh^2\ \mu 2+4\ zh\ \theta\ \mu 2+2\ \theta 2\ \mu 2-2\ zh\ \mu\ \tau f-2\ \theta\ \mu\ \tau f+\tau f^2+4\ zf\ \mu\ (-2\ (zh+\theta)\ \mu+\tau f-2\ \tau h)+2\ \alpha\ (4\ zf\ \mu-2\ (zh+\theta)\ \mu+\tau f-2\ \tau h)+2\ ch\ (2\ \alpha+4\ zf\ \mu-2\ (zh+\theta)\ \mu+\tau f-2\ \tau h)-4\ cf\ (2\ ch+2\ \alpha+4\ zf\ \mu-2\ (zh+\theta)\ \mu+\tau f-2\ \tau h)+4\ zh\ \mu\ \tau h+4\ \theta\ \mu\ \tau h+4\ \tau h^2)$

**STAGE 2**

$Wh=\beta\ (dxh+dyh)$^2/2+dprh+$\tau h$*dyh-zh (dxh+dxf)

$1/3\ (-2\ cf+ch+\alpha+2\ zf\ \mu-zh\ \mu-\theta\ \mu-2\ \tau h)\ \tau h+1/9\ (2\ (cf-2\ ch+\alpha-(zf-2\ zh+\theta)\ \mu)^2-4\ (cf-2\ ch+\alpha-(zf-2\ zh+\theta)\ \mu)\ \tau f+4\ \tau f^2+2\ (cf-2\ ch+\alpha-(zf-2\ zh+\theta)\ \mu)\ \tau h+\tau h^2)-zh\ (1/3\ (cf-2\ ch+\alpha-zf\ \mu+2\ zh\ \mu-\theta\ \mu-2\ \tau f)+1/3\ (cf-2\ ch+\alpha-zf\ \mu+2\ zh\ \mu-\theta\ \mu+\tau h))+1/2\ (1/3\ (-2\ cf+ch+\alpha+2\ zf\ \mu-zh\ \mu-\theta\ \mu-2\ \tau h)+1/3\ (cf-2\ ch+\alpha-zf\ \mu+2\ zh\ \mu-\theta\ \mu+\tau h))^2$

derW2=FullSimplify[D[Wh,$\tau h$]]

$1/3\ (-cf-zh+\alpha+zf\ \mu-\theta\ \mu-3\ \tau h)$

$Wf=\beta\ (dxf+dyf)$^2/2+dprf+$\tau f$*dxf-(zf (dyf+dyh))

$1/3\ (cf-2\ ch+\alpha-zf\ \mu+2\ zh\ \mu-\theta\ \mu-2\ \tau f)\ \tau f+1/2\ (1/3\ (cf-2\ ch+\alpha-zf\ \mu+2\ zh\ \mu-\theta\ \mu-2\ \tau f)+1/3\ (-2\ cf+ch+\alpha+2\ zf\ \mu-zh\ \mu-\theta\ \mu+\tau f))^2-zf\ (1/3\ (-2\ cf+ch+\alpha+2\ zf\ \mu-zh\ \mu-\theta\ \mu+\tau f)+1/3\ (-2\ cf+ch+\alpha+2\ zf\ \mu-zh\ \mu-\theta\ \mu-2\ \tau h))+1/9\ (8\ cf^2+2\ ch^2+2\ \alpha 2+8\ zf^2\ \mu 2+2\ zh^2\ \mu 2+4\ zh\ \theta\ \mu 2+2\ \theta 2\ \mu 2-2\ zh\ \mu\ \tau f-2\ \theta\ \mu\ \tau f+\tau f^2+4\ zf\ \mu\ (-2\ (zh+\theta)\ \mu+\tau f-2\ \tau h)+2\ \alpha\ (4\ zf\ \mu-2\ (zh+\theta)\ \mu+\tau f-2\ \tau h)+2\ ch\ (2\ \alpha+4\ zf\ \mu-2\ (zh+\theta)\ \mu+\tau f-2\ \tau h)-4\ cf\ (2\ ch+2\ \alpha+4\ zf\ \mu-2\ (zh+\theta)\ \mu+\tau f-2\ \tau h)+4\ zh\ \mu\ \tau h+4\ \theta\ \mu\ \tau h+4\ \tau h^2)$

derW4=FullSimplify[D[Wf,$\tau f$]]

$1/3\ (-ch-zf+\alpha+zh\ \mu-\theta\ \mu-3\ \tau f)$

Simplify[Solve[{derW2  0,derW4  0},{$\tau h$,$\tau f$}]]

```
{{τh→1/3 (-cf-zh+α+zf μ-θ μ),τf→1/3 (-ch-zf+α+zh μ-θ μ)}}

dτh=1/3 (-cf-zh+α+zf μ-θ μ)
1/3 (-cf-zh+α+zf μ-θ μ)
dτf=1/3 (-ch-zf+α+zh μ-θ μ)
1/3 (-ch-zf+α+zh μ-θ μ)
```

substitution

```
ddxh=FullSimplify[dxh/.{τh→dτh,τf→dτf}]
1/9 (2 cf-6 ch+4 α-2 (zf+2 θ) μ+zh (-1+6 μ))
ddxf=FullSimplify[dxf/.{τh→dτh,τf→dτf}]
1/9 (3 cf-4 ch+2 zf+α-(3 zf-4 zh+θ) μ)
ddyh=FullSimplify[dyh/.{τh→dτh,τf→dτf}]
1/9 (-4 cf+3 ch+2 zh+α-(-4 zf+3 zh+θ) μ)
ddyf=FullSimplify[dyf/.{τh→dτh,τf→dτf}]
1/9 (-6 cf+2 ch+4 α-2 (zh+2 θ) μ+zf (-1+6 μ))

ddprh=FullSimplify[dprh/.{τh→dτh,τf→dτf}]
1/81 ((cf+zh-α-zf μ+θ μ)^2+4 (ch+zf-α-zh μ+θ μ)^2+6 (-cf-zh+α+(zf-θ) μ) (cf-2 ch+α-(zf-2 zh+θ) μ)+12 (ch+zf-α-zh μ+θ μ) (cf-2 ch+α-(zf-2 zh+θ) μ)+18 (cf-2 ch+α-(zf-2 zh+θ) μ)^2)

ddprf=FullSimplify[dprf/.{τh→dτh,τf→dτf}]
1/81 (52 cf^2+13 ch^2-4 cf (12 ch-3 zf+4 zh+14 α+2 (13 zf-6 zh-7 θ) μ)+17 (α-θ μ)^2+2 zh (-2+11 μ) (-α+θ μ)+zh^2 (4+μ (-12+13 μ))+zf^2 (1+4 μ (-3+13 μ))+2 ch (zh (6-13 μ)+zf (-2+24 μ)+11 (α-θ μ))+4 zf (2 α (-1+7 μ)+μ (5 zh+2 θ-2 (6 zh+7 θ) μ)))

dWh=FullSimplify[Wh/.{τh→dτh,τf→dτf}]
1/162 (54 cf^2+113 ch^2+2 zh (-45+62 μ) (α-θ μ)+65 (α-θ μ)^2+zf^2 (8+6 μ (-4+9 μ))-6 cf (17 ch+15 zh+α-(17 zh+θ) μ+2 zf (-2+9 μ))+2 ch (90 zh-62 α-113 zh μ+62 θ μ+zf (-16+51 μ))+zh^2 (9+μ (-180+113 μ))-2 zf ((4+3 μ) (-α+θ μ)+zh (18+μ (-61+51 μ))))

dWf=FullSimplify[Wf/.{τh→dτh,τf→dτf}]
```

1/162 (113 cf$^2$+54 ch$^2$+2 zh (4+3 μ) (α-θ μ)+65 (α-θ μ)$^2$-6 ch (15 zf-4 zh+α-(17 zf-18 zh+θ) μ)+zh$^2$ (8+6 μ (-4+9 μ))+zf$^2$ (9+μ (-180+113 μ))-2 cf (51 ch+zh (16-51 μ)+zf (-90+113 μ)+62 (α-θ μ))-2 zf ((-45+62 μ) (-α+θ μ)+zh (18+μ (-61+51 μ))))

**STAGE 1**

derW1=FullSimplify[D[dWh,zh]]

1/81 (ch (90-113 μ)+cf (-45+51 μ)+(-45+62 μ) (α-θ μ)+zf (-18+(61-51 μ) μ)+zh (9+μ (-

180+113 μ)))

derW3=FullSimplify[D[dWf,zf]]

1/81 (cf (90-113 μ)+ch (-45+51 μ)+(-45+62 μ) (α-θ μ)+zh (-18+(61-51 μ) μ)+zf (9+μ (-180+113 μ)))

Simplify[Solve[{derW1  0,derW3  0},{zh,zf}]]

{{zh→(cf (-1215-1035 μ+2782 μ2)+α (1215-12519 μ+22322 μ2-10168 μ3)+μ (2 ch (6777-12552 μ+5084 μ2)+θ (-1215+12519 μ-22322 μ2+10168 μ3)))/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4),zf→(ch (-1215-1035 μ+2782 μ2)+α (1215-12519 μ+22322 μ2-10168 μ3)+μ (2 cf (6777-12552 μ+5084 μ2)+θ (-1215+12519 μ-22322 μ2+10168 μ3)))/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4)}}

dzh=(cf (-1215-1035 μ+2782 μ2)+α (1215-12519 μ+22322 μ2-10168 μ3)+μ (2 ch (6777-12552 μ+5084 μ2)+θ (-1215+12519 μ-22322 μ2+10168 μ3)))/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4)

(cf (-1215-1035 μ+2782 μ2)+α (1215-12519 μ+22322 μ2-10168 μ3)+μ (2 ch (6777-12552 μ+5084 μ2)+θ (-1215+12519 μ-22322 μ2+10168 μ3)))/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4)

dzf=(ch (-1215-1035 μ+2782 μ2)+α (1215-12519 μ+22322 μ2-10168 μ3)+μ (2 cf (6777-12552 μ+5084 μ2)+θ (-1215+12519 μ-22322 μ2+10168 μ3)))/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4)

(ch (-1215-1035 μ+2782 μ2)+α (1215-12519 μ+22322 μ2-10168 μ3)+μ (2 cf (6777-12552 μ+5084 μ2)+θ (-1215+12519 μ-22322 μ2+10168 μ3)))/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4)

**SUBSTITUTION:**

dddxh=FullSimplify[ddxh/.{zh→dzh,zf→dzf}]

((9+26 μ) (-α+θ μ) (27+μ (-241+164 μ))+cf (81+μ (-927+2406 μ-224 μ2))+2 ch (81+2 μ (-135+μ (-1799+1122 μ))))/((-9+μ (-119+62 μ)) (27+μ (-241+164 μ)))

dddxf=FullSimplify[ddxf/.{zh→dzh,zf→dzf}]

((-9+22 μ) (-α+θ μ) (27+μ (-241+164 μ))+cf (-81+μ (2124+7 μ (-133+54 μ)))+ch (-162+μ (639+μ (-5847+3230 μ))))/((-9+μ (-119+62 μ)) (27+μ (-241+164 μ)))

dddyh=FullSimplify[ddyh/.{zh→dzh,zf→dzf}]

((-9+22 μ) (-α+θ μ) (27+μ (-241+164 μ))+ch (-81+μ (2124+7 μ (-133+54 μ)))+cf (-162+μ (639+μ (-5847+3230 μ))))/((-9+μ (-119+62 μ)) (27+μ (-241+164 μ)))

dddyf=FullSimplify[ddyf/.{zh→dzh,zf→dzf}]

((9+26 μ) (-α+θ μ) (27+μ (-241+164 μ))+ch (81+μ (-927+2406 μ-224 μ2))+2 cf (81+2 μ (-135+μ (-1799+1122 μ))))/((-9+μ (-119+62 μ)) (27+μ (-241+164 μ)))

dddprh=FullSimplify[ddprh/.{zh→dzh,zf→dzf}]

(2 (α-θ μ)$^{2}$ (81+4 μ (9+145 μ)) (27+μ (-241+164 μ))$^{2}$-2 ch (α-θ μ) (27+μ (-241+164 μ)) (2916+μ (-9963+μ (-12123+4 μ (-76102+46937 μ))))+cf$^{2}$ (13122+μ (-494262+μ (5911299+μ (-8513136+μ (8676637+28 μ (-63633+6895 μ))))))+ch$^{2}$ (52488+μ (-381996+μ (262845+μ (706806+μ (85250725+68 μ (-1505337+449633 μ))))))+2 cf (-(α-θ μ) (27+μ (-241+164 μ)) (1458+μ (-27135+μ (52659+4 μ (9164+623 μ))))+ch (26244+μ (-589761+μ (2289141+μ (-7638111+μ (-8807373+4 μ (1798184+53907 μ))))))))/((9+(119-62 μ) μ)$^{2}$ (27+μ (-241+164 μ))$^{2}$)

dddprf=FullSimplify[ddprf/.{zh→dzh,zf→dzf}]

(2 (α-θ μ)$^{2}$ (81+4 μ (9+145 μ)) (27+μ (-241+164 μ))$^{2}$-2 ch (α-θ μ) (27+μ (-241+164 μ)) (1458+μ (-27135+μ (52659+4 μ (9164+623 μ))))+ch$^{2}$ (13122+μ (-494262+μ (5911299+μ (-8513136+μ (8676637+28 μ (-63633+6895 μ))))))+cf$^{2}$ (52488+μ (-381996+μ (262845+μ (706806+μ (85250725+68 μ (-1505337+449633 μ))))))+2 cf (-(α-θ μ) (27+μ (-241+164 μ)) (2916+μ (-9963+μ (-12123+4 μ (-76102+46937 μ))))+ch (26244+μ (-589761+μ (2289141+μ (-7638111+μ (-8807373+4 μ (1798184+53907 μ))))))))/((9+(119-62 μ) μ)$^{2}$ (27+μ (-241+164 μ))$^{2}$)

ddτh=FullSimplify[dτh/.{zh→dzh,zf→dzf}]

((cf+ch-2 α) (9+2 μ))/(-9+μ (-119+62 μ))+(2 θ μ (9+2 μ))/(-9+μ (-119+62 μ))+(9 (cf-ch) (-3+5 μ))/(27+μ (-241+164 μ))

ddτf=FullSimplify[dτf/.{zh→dzh,zf→dzf}]

((cf+ch-2 α) (9+2 μ))/(-9+μ (-119+62 μ))+(2 θ μ (9+2 μ))/(-9+μ (-119+62 μ))-(9 (cf-ch) (-3+5 μ))/(27+μ (-241+164 μ))

ddWh=FullSimplify[dWh/.{zh→dzh,zf→dzf}]

(-576 μ (-9+2 μ) (α-θ μ)$^2$ (27+μ (-241+164 μ))$^2$+4 ch (α-θ μ) (27+μ (-241+164 μ)) (-2187+μ (-35316+μ (690327+4 μ (-195475+51271 μ))))+ch$^2$ (111537+μ (290142+μ (-23178150+μ (378642978+μ (-643249875+4 (94894907-18496619 μ) μ)))))+cf$^2$ (-124659+μ (2363418+μ (15682734+μ (-32451210+μ (98609053+4 μ (-25138897+7391109 μ))))))+2 cf (-2 (α-θ μ) (27+μ (-241+164 μ)) (-2187+μ (34668+μ (50103+4 μ (-54499+27655 μ))))+ch (6561+μ (562788+μ (-30404484+μ (7900884+μ (28872283+4 μ (-6066485+1679731 μ))))))))/(2 (9+(119-62 μ) μ)$^2$ (27+μ (-241+164 μ))$^2$)

ddWf=FullSimplify[dWf/.{zh→dzh,zf→dzf}]

(-576 μ (-9+2 μ) (α-θ μ)$^2$ (27+μ (-241+164 μ))$^2$-4 ch (α-θ μ) (27+μ (-241+164 μ)) (-2187+μ (34668+μ (50103+4 μ (-54499+27655 μ))))+cf$^2$ (111537+μ (290142+μ (-23178150+μ (378642978+μ (-643249875+4 (94894907-18496619 μ) μ)))))+ch$^2$ (-124659+μ (2363418+μ (15682734+μ (-32451210+μ (98609053+4 μ (-25138897+7391109 μ))))))+2 cf (2 (α-θ μ) (27+μ (-241+164 μ)) (-2187+μ (-35316+μ (690327+4 μ (-195475+51271 μ))))+ch (6561+μ (562788+μ (-30404484+μ (7900884+μ (28872283+4 μ (-6066485+1679731 μ))))))))/(2 (9+(119-62 μ) μ)$^2$ (27+μ (-241+164 μ))$^2$)

**SECOND ORDER CONDITIONS AND STABILITY CONDITIONS**

**STAGE 1**

SOC of Stage 1

D[derW1,zh]

1/81 (9+μ (-180+113 μ))

D[derW3,zf]

1/81 (9+μ (-180+113 μ))

SOC of Stage 2

D[derW2,τh]

-1

D[derW4,τf]

-1

SOC of Stage 3

H2={{D[derpr1,xh],D[derpr1,xf]},{D[derpr2,xh],D[derpr2,xf]}}

{{-2,0},{0,-2}}

H1={{D[derpr1,xh]}}

{{-2}}

Reduce[Det[H1]<0&&Det[H2]>0]

True

SOC Condition

Reduce[1/81 (9+μ (-180+113 μ))<0&&μ>0]

3/113 (30-$\sqrt{787}$ )<μ<3/113 (30+$\sqrt{787}$ )

Stability Conditions

S1={{D[derW1,zh],D[derW1,zf]},{D[derW3,zh],D[derW3,zf]}}

{{1/81 (9+μ (-180+113 μ)),1/81 (-18+(61-51 μ) μ)},{1/81 (-18+(61-51 μ) μ),1/81 (9+μ (-180+113 μ))}}

Reduce[Det[S1]>0]

μ<1/124 (119-13 $\sqrt{97}$ )||1/328 (241-$\sqrt{40369}$ )<μ<1/328 (241+$\sqrt{40369}$ )||μ>1/124 (119+13 $\sqrt{97}$ )

S2={{D[derW2,τh],D[derW2,τf]},{D[derW4,τh],D[derW4,τf]}}

{{-1,0},{0,-1}}

Reduce[Det[S2]>0]

True

SOLUTION INTERVAL

Reduce[3/113 (30-$\sqrt{787}$ )<μ<3/113 (30+$\sqrt{787}$ )&&Det[S1]>0]

1/328 (241-$\sqrt{40369}$ )<μ<1/328 (241+$\sqrt{40369}$ )

COMPARATIVE STATICS

"Comparative statics of Stage 1"

D[dzh,ch]

(2 μ (6777-12552 μ+5084 μ2))/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4)

$\text{Reduce}[(2\ \mu\ (6777-12552\ \mu+5084\ \mu 2))/(-243-1044\ \mu+28877\ \mu 2-34458\ \mu 3+10168\ \mu 4)>0\ \&\&\ 1/113\ (90-3\sqrt{787})<\mu<1/113\ (90+3\sqrt{787})]$

$1/328\ (241-\sqrt{40369})<\mu<(3138-21\sqrt{2797})/2542 \,||\, 1/328\ (241+\sqrt{40369})<\mu<1/113\ (90+3\sqrt{787})$

$\text{Reduce}[(2\ \mu\ (6777-12552\ \mu+5084\ \mu 2))/(-243-1044\ \mu+28877\ \mu 2-34458\ \mu 3+10168\ \mu 4)\leq 0\ \&\&\ 1/113\ (90-3\sqrt{787})<\mu<1/113\ (90+3\sqrt{787})]$

$1/113\ (90-3\sqrt{787})<\mu<1/328\ (241-\sqrt{40369}) \,||\, (3138-21\sqrt{2797})/2542\leq\mu<1/328\ (241+\sqrt{40369})$

$\text{D}[dzh,cf]$

$(-1215-1035\ \mu+2782\ \mu 2)/(-243-1044\ \mu+28877\ \mu 2-34458\ \mu 3+10168\ \mu 4)$

$\text{Reduce}[(-1215-1035\ \mu+2782\ \mu 2)/(-243-1044\ \mu+28877\ \mu 2-34458\ \mu 3+10168\ \mu 4)\leq 0\ \&\&\ 1/113\ (90-3\sqrt{787})<\mu<1/113\ (90+3\sqrt{787})]$

$1/328\ (241-\sqrt{40369})<\mu\leq(1035+9\sqrt{180145})/5564 \,||\, 1/328\ (241+\sqrt{40369})<\mu<1/113\ (90+3\sqrt{787})$

$\text{Reduce}[(-1215-1035\ \mu+2782\ \mu 2)/(-243-1044\ \mu+28877\ \mu 2-34458\ \mu 3+10168\ \mu 4)>0\ \&\&\ 1/113\ (90-3\sqrt{787})<\mu<1/113\ (90+3\sqrt{787})]$

$1/113\ (90-3\sqrt{787})<\mu<1/328\ (241-\sqrt{40369}) \,||\, (1035+9\sqrt{180145})/5564<\mu<1/328\ (241+\sqrt{40369})$

$\text{D}[dzh, \theta\ ]$

$(\mu\ (-1215+12519\ \mu-22322\ \mu 2+10168\ \mu 3))/(-243-1044\ \mu+28877\ \mu 2-34458\ \mu 3+10168\ \mu 4)$

$\text{Reduce}[(\mu\ (-1215+12519\ \mu-22322\ \mu 2+10168\ \mu 3))/(-243-1044\ \mu+28877\ \mu 2-34458\ \mu 3+10168\ \mu 4)\leq 0\ \&\&\ 1/113\ (90-3\sqrt{787})<\mu<1/113\ (90+3\sqrt{787})\ \&\&\ 0<\mu]$

$45/62\leq\mu<1/113\ (90+3\sqrt{787})$

$\text{Reduce}[(\mu\ (-1215+12519\ \mu-22322\ \mu 2+10168\ \mu 3))/(-243-1044\ \mu+28877\ \mu 2-34458\ \mu 3+10168\ \mu 4)>0\ \&\&\ 1/113\ (90-3\sqrt{787})<\mu<1/113\ (90+3\sqrt{787})\ \&\&\ 0<\mu]$

$1/113\ (90-3\sqrt{787})<\mu<45/62$

D[dzh, α]

(1215-12519 μ+22322 μ2-10168 μ3)/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4)

Reduce[(1215-12519 μ+22322 μ2-10168 μ3)/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4)≥0&&1/113 (90-3 $\sqrt{787}$ )<μ<1/113 (90+3 $\sqrt{787}$ )&&0<μ]

45/62≤μ<1/113 (90+3 $\sqrt{787}$ )

Reduce[(1215-12519 μ+22322 μ2-10168 μ3)/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4)≤0&&1/113 (90-3 $\sqrt{787}$ )<μ<1/113 (90+3 $\sqrt{787}$ )&&0<μ]

1/113 (90-3 $\sqrt{787}$ )<μ≤45/62

D[ddτh,ch]

(9+2 μ)/(-9+μ (-119+62 μ))-(9 (-3+5 μ))/(27+μ (-241+164 μ))

Reduce[(9+2 μ)/(-9+μ (-119+62 μ))-(9 (-3+5 μ))/(27+μ (-241+164 μ))≤0&&1/113 (90-3 $\sqrt{787}$ )<μ<1/113 (90+3 $\sqrt{787}$ )&&0<μ]

1/328 (241-$\sqrt{40369}$ )<μ≤(8023-5 $\sqrt{635473}$ )/4924||1/328 (241+$\sqrt{40369}$ )<μ<1/113 (90+3 $\sqrt{787}$ )

Reduce[(9+2 μ)/(-9+μ (-119+62 μ))-(9 (-3+5 μ))/(27+μ (-241+164 μ))ρ0&&1/113 (90-3 $\sqrt{787}$ )<μ<1/113 (90+3 $\sqrt{787}$ )&&0<μ]

1/113 (90-3 $\sqrt{787}$ )<μ<1/328 (241-$\sqrt{40369}$ )||(8023-5 $\sqrt{635473}$ )/4924≤μ<1/328 (241+$\sqrt{40369}$ )

D[ddτh,cf]

(9+2 μ)/(-9+μ (-119+62 μ))+(9 (-3+5 μ))/(27+μ (-241+164 μ))

Reduce[(9+2 μ)/(-9+μ (-119+62 μ))+(9 (-3+5 μ))/(27+μ (-241+164 μ))≤0&&1/113 (90-3 $\sqrt{787}$ )<μ<1/113 (90+3 $\sqrt{787}$ )&&0<μ]

1/113 (90-3 $\sqrt{787}$ )<μ<1/328 (241-$\sqrt{40369}$ )||Root[486+693 #1-6035 $\#1^2$+3118 $\#1^3$&,2]≤μ<1/328 (241+$\sqrt{40369}$ )

Reduce[(9+2 μ)/(-9+μ (-119+62 μ))+(9 (-3+5 μ))/(27+μ (-241+164 μ))ρ0&&1/113 (90-3 $\sqrt{787}$ )<μ<1/113 (90+3 $\sqrt{787}$ )&&0<μ]

1/328 (241-$\sqrt{40369}$ )<μ≤Root[486+693 #1-6035 #1$^2$+3118 #1$^3$&,2]ǁ1/328 (241+$\sqrt{40369}$ )<μ<1/113 (90+3 $\sqrt{787}$ )

D[ddτh, θ ]

(2 μ (9+2 μ))/(-9+μ (-119+62 μ))

Reduce[(2 μ (9+2 μ))/(-9+μ (-119+62 μ))==0&&1/113 (90-3 $\sqrt{787}$ )<μ<1/113 (90+3 $\sqrt{787}$ )&&0<μ]

False

Reduce[(2 μ (9+2 μ))/(-9+μ (-119+62 μ))ρ0&&1/113 (90-3 $\sqrt{787}$ )<μ<1/113 (90+3 $\sqrt{787}$ )&&0<μ]

False

Reduce[(2 μ (9+2 μ))/(-9+μ (-119+62 μ))≤0&&1/113 (90-3 $\sqrt{787}$ )<μ<1/113 (90+3 $\sqrt{787}$ )&&0<μ]

1/113 (90-3 $\sqrt{787}$ )<μ<1/113 (90+3 $\sqrt{787}$ )

τh is non-increasing in θ

D[ddτh, α]

-(2 (9+2 μ))/(-9+μ (-119+62 μ))

Reduce[ -(2 (9+2 μ))/(-9+μ (-119+62 μ))≤0&&1/113 (90-3 $\sqrt{787}$ )<μ<1/113 (90+3 $\sqrt{787}$ )&&0<μ]

False

Reduce[ -(2 (9+2 μ))/(-9+μ (-119+62 μ))==0&&1/113 (90-3 $\sqrt{787}$ )<μ<1/113 (90+3 $\sqrt{787}$ )&&0<μ]

False

Reduce[-(2 (9+2 μ))/(-9+μ (-119+62 μ))≥0&&1/113 (90-3 $\sqrt{787}$ )<μ<1/113 (90+3 $\sqrt{787}$ )&&0<μ]

1/113 (90-3 $\sqrt{787}$ )<μ<1/113 (90+3 $\sqrt{787}$ )

**BEFORE-LIBERALIZATION: COOPERATION POLLUTION POLICY**

"Z=ZH=ZF"

**STAGE 3:**

ph=α-β (xh+yh)

```
pf=α-β (xf+yf)

kh=ch+μ(θ-z)
kf=cf+μ(θ-z)

pri=profit function of country i

prh=(α-β (xh+yh)-kh) xh+(α-β (xf+yf)-kh-τf) xf
xh (-ch-xh-yh+α-(-z+θ) μ)+xf (-ch-xf-yf+α-(-z+θ) μ-τf)

derpr1=D[prh,xh]
-ch-2 xh-yh+α-(-z+θ) μ
derpr2=D[prh,xf]
-ch-2 xf-yf+α-(-z+θ) μ-τf


prf=yf (-kf+α-(xf+yf) β)+yh (-kf+α-(xh+yh) β-τh)
yf (-cf-xf-yf+α-(-z+θ) μ)+yh (-cf-xh-yh+α-(-z+θ) μ-τh)


derpr3=D[prf,yh]
-cf-xh-2 yh+α-(-z+θ) μ-τh
derpr4=D[prf,yf]
-cf-xf-2 yf+α-(-z+θ) μ

Simplify[Solve[{derpr1  0,derpr2  0,derpr3  0,derpr4==0},{xh,xf,yh,yf}]]

{{xh→1/3 (cf-2 ch+α+z μ-θ μ+τh),xf→1/3 (cf-2 ch+α+z μ-θ μ-2 τf),yh→1/3 (-2
cf+ch+α+z μ-θ μ-2 τh),yf→1/3 (-2 cf+ch+α+z μ-θ μ+τf)}}

dyf=1/3 (-2 cf+ch+α+z μ-θ μ+τf)
1/3 (-2 cf+ch+α+z μ-θ μ+τf)
dxf=1/3 (cf-2 ch+α+z μ-θ μ-2 τf)
1/3 (cf-2 ch+α+z μ-θ μ-2 τf)
dxh=1/3 (cf-2 ch+α+z μ-θ μ+τh)
```

```
1/3 (cf-2 ch+α+z μ-θ μ+τh)
dyh=1/3 (-2 cf+ch+α+z μ-θ μ-2 τh)
1/3 (-2 cf+ch+α+z μ-θ μ-2 τh)

dprh=FullSimplify[prh/.{xh→dxh,xf→dxf,yh→dyh,yf→dyf}]
1/9 (2 (cf-2 ch+α+(z-θ) μ)^2-4 (cf-2 ch+α+(z-θ) μ) τf+4 τf^2+2 (cf-2 ch+α+(z-θ) μ) τh+τh^2)
dprf=FullSimplify[prf/.{xh→dxh,xf→dxf,yh→dyh,yf→dyf}]
1/9 (8 cf^2+2 ch^2+2 α2+2 z^2 μ2+2 θ2 μ2-2 θ μ τf+τf^2+2 z μ (-2 θ μ+τf-2 τh)+2 α (2 z μ-2 θ μ+τf-2 τh)+2 ch (2 α+2 z μ-2 θ μ+τf-2 τh)-4 cf (2 ch+2 α+2 z μ-2 θ μ+τf-2 τh)+4 θ μ τh+4 τh^2)
```

STAGE 2

```
Wh=β (dxh+dyh)^2/2+dprh+τh*dyh-z (dxh+dxf)
1/3 (-2 cf+ch+α+z μ-θ μ-2 τh) τh+1/9 (2 (cf-2 ch+α+(z-θ) μ)^2-4 (cf-2 ch+α+(z-θ) μ) τf+4 τf^2+2 (cf-2 ch+α+(z-θ) μ) τh+τh^2)-z (1/3 (cf-2 ch+α+z μ-θ μ-2 τf)+1/3 (cf-2 ch+α+z μ-θ μ+τh))+1/2 (1/3 (-2 cf+ch+α+z μ-θ μ-2 τh)+1/3 (cf-2 ch+α+z μ-θ μ+τh))^2

derW1=FullSimplify[D[Wh,τh]]
1/3 (-cf-z+α+z μ-θ μ-3 τh)

Wf=β (dxf+dyf)^2/2+dprf+τf*dxf-(z (dyf+dyh))
1/3 (cf-2 ch+α+z μ-θ μ-2 τf) τf+1/2 (1/3 (cf-2 ch+α+z μ-θ μ-2 τf)+1/3 (-2 cf+ch+α+z μ-θ μ+τf))^2-z (1/3 (-2 cf+ch+α+z μ-θ μ+τf)+1/3 (-2 cf+ch+α+z μ-θ μ-2 τh))+1/9 (8 cf^2+2 ch^2+2 α2+2 z^2 μ2+2 θ2 μ2-2 θ μ τf+τf^2+2 z μ (-2 θ μ+τf-2 τh)+2 α (2 z μ-2 θ μ+τf-2 τh)+2 ch (2 α+2 z μ-2 θ μ+τf-2 τh)-4 cf (2 ch+2 α+2 z μ-2 θ μ+τf-2 τh)+4 θ μ τh+4 τh^2)

derW2=FullSimplify[D[Wf,τf]]
1/3 (-ch-z+α+z μ-θ μ-3 τf)

Simplify[Solve[{derW1  0,derW2  0},{τh,τf}]]
{{τh→1/3 (-cf+α+z (-1+μ)-θ μ),τf→1/3 (-ch+α+z (-1+μ)-θ μ)}}
```

dτh=1/3 (-cf+α+z (-1+μ)-θ μ)

1/3 (-cf+α+z (-1+μ)-θ μ)

dτf=1/3 (-ch+α+z (-1+μ)-θ μ)

1/3 (-ch+α+z (-1+μ)-θ μ)

substitution

ddxh=FullSimplify[dxh/.{τh→dτh,τf→dτf}]

1/9 (2 cf-6 ch-z+4 α+4 z μ-4 θ μ)

ddxf=FullSimplify[dxf/.{τh→dτh,τf→dτf}]

1/9 (3 cf-4 ch+α-θ μ+z (2+μ))

ddyh=FullSimplify[dyh/.{τh→dτh,τf→dτf}]

1/9 (-4 cf+3 ch+α-θ μ+z (2+μ))

ddyf=FullSimplify[dyf/.{τh→dτh,τf→dτf}]

1/9 (-6 cf+2 ch-z+4 α+4 z μ-4 θ μ)

ddprh=FullSimplify[dprh/.{τh→dτh,τf→dτf}]

1/81 (13 $cf^2$-48 cf ch+52 $ch^2$+8 cf z-4 ch z+5 $z^2$+22 cf α-56 ch α-4 z α+17 α2+2 (11 cf-28 ch-2 z+17 α) (z-θ) μ+17 $(z-θ)^2$ μ2)

ddprf=FullSimplify[dprf/.{τh→dτh,τf→dτf}]

1/81 (52 $cf^2$-48 cf ch+13 $ch^2$-4 cf z+8 ch z+5 $z^2$-56 cf α+22 ch α-4 z α+17 α2-2 (28 cf-11 ch+2 z-17 α) (z-θ) μ+17 $(z-θ)^2$ μ2)

dWh=FullSimplify[Wh/.{τh→dτh,τf→dτf}]

1/162 (54 $cf^2$+113 $ch^2$-4 ch (-37 z+31 α+31 (z-θ) μ)+(-19 z+13 α+13 (z-θ) μ) (z+5 α+5 z μ-5 θ μ)-6 cf (17 ch+α-θ μ+z (11+μ)))

dWf=FullSimplify[Wf/.{τh→dτh,τf→dτf}]

1/162 (113 $cf^2$+54 $ch^2$-2 cf (51 ch-74 z+62 α+62 (z-θ) μ)+(-19 z+13 α+13 (z-θ) μ) (z+5 α+5 z μ-5 θ μ)-6 ch (α-θ μ+z (11+μ)))

**STAGE 1**

WT=dWh+dWf

1/162 (113 $cf^2$+54 $ch^2$-2 cf (51 ch-74 z+62 α+62 (z-θ) μ)+(-19 z+13 α+13 (z-θ) μ) (z+5 α+5 z μ-5 θ μ)-6 ch (α-θ μ+z (11+μ)))+1/162 (54 $cf^2$+113 $ch^2$-4 ch (-37 z+31 α+31 (z-θ) μ)+(-19 z+13 α+13 (z-θ) μ) (z+5 α+5 z μ-5 θ μ)-6 cf (17 ch+α-θ μ+z (11+μ)))

derW3=FullSimplify[D[WT,z]]

1/81 (cf (41-65 μ)+ch (41-65 μ)+2 (z (1+5 μ) (-19+13 μ)+(-41+65 μ) (α-θ μ)))

Simplify[Solve[{derW3  0},{z}]]

{{z→((-41+65 μ) (cf+ch-2 α+2 θ μ))/(2 (-19-82 μ+65 μ2))}}

dz=((-41+65 μ) (cf+ch-2 α+2 θ μ))/(2 (-19-82 μ+65 μ2))

((-41+65 μ) (cf+ch-2 α+2 θ μ))/(2 (-19-82 μ+65 μ2))

SUBSTITUTION:

ddτh=FullSimplify[dτh/.{z→dz}]

1/3 (-cf+α-θ μ+((-1+μ) (-41+65 μ) (cf+ch-2 α+2 θ μ))/(2 (-19-82 μ+65 μ2)))

ddτf=FullSimplify[dτf/.{z→dz}]

1/3 (-ch+α-θ μ+((-1+μ) (-41+65 μ) (cf+ch-2 α+2 θ μ))/(2 (-19-82 μ+65 μ2)))

dddxh=FullSimplify[ddxh/.{z→dz}]

(18 (13+11 μ) (-α+θ μ)+ch (269+755 μ-520 μ2)+cf (-35+μ (-557+520 μ)))/(18 (1+5 μ) (-19+13 μ))

dddxf=FullSimplify[ddxf/.{z→dz}]

1/9 (3 cf-4 ch+α-θ μ+((2+μ) (-41+65 μ) (cf+ch-2 α+2 θ μ))/(2 (-19-82 μ+65 μ2)))

dddyh=FullSimplify[ddyh/.{z→dz}]

1/9 (-4 cf+3 ch+α-θ μ+((2+μ) (-41+65 μ) (cf+ch-2 α+2 θ μ))/(2 (-19-82 μ+65 μ2)))

dddyf=FullSimplify[ddyf/.{z→dz}]

(18 (13+11 μ) (-α+θ μ)+cf (269+755 μ-520 μ2)+ch (-35+μ (-557+520 μ)))/(18 (1+5 μ) (-19+13 μ))

dddprh=FullSimplify[ddprh/.{z→dz}]

1/(324 (19+(82-65 μ) μ)$^2$) (648 (α-θ μ)$^2$ (109+μ (10+241 μ))+36 ch (α-θ μ) (-3007+μ (-8889+5 μ (-3777+2873 μ)))+ch$^2$ (77261+5 μ (102098+μ (156318+65 μ (-4502+1469 μ))))+cf$^2$ (39641+μ (196966+μ (257898+65 μ (-14554+7345 μ))))-2 cf (18 (α-θ μ) (917+μ (-8529+μ (-10209+14365 μ)))+ch (23135+μ (350488+5 μ (88332+1469 μ (-164+65 μ)))))) dddprf=FullSimplify[ddprf/.{z→dz}]

1/(324 (19+(82-65 μ) μ)$^2$) (648 (α-θ μ)$^2$ (109+μ (10+241 μ))-36 ch (α-θ μ) (917+μ (-8529+μ (-10209+14365 μ)))+cf$^2$ (77261+5 μ (102098+μ (156318+65 μ (-4502+1469 μ))))+ch$^2$ (39641+μ (196966+μ (257898+65 μ (-14554+7345 μ))))-2 cf (-18 (α-θ μ) (-3007+μ (-8889+5 μ (-3777+2873 μ)))+ch (23135+μ (350488+5 μ (88332+1469 μ (-164+65 μ))))))

ddWh=FullSimplify[dWh/.{z→dz}]

(-11664 (α-θ μ)$^2$+2592 ch (-13+7 μ) (-α+θ μ)+cf$^2$ (2989+5 μ (-6226+3497 μ))+ch$^2$ (-19043+μ (-12986+17485 μ))+2 cf (1296 (-4+7 μ) (α-θ μ)+ch (2195-269 μ (-82+65 μ))))/(648 (1+5 μ) (-19+13 μ))

ddWf=FullSimplify[dWf/.{z→dz}]

(2592 ch (-4+7 μ) (α-θ μ)-11664 (α-θ μ)$^2$+ch$^2$ (2989+5 μ (-6226+3497 μ))+cf$^2$ (-19043+μ (-12986+17485 μ))+cf (2592 (-13+7 μ) (-α+θ μ)+ch (4390-538 μ (-82+65 μ))))/(648 (1+5 μ) (-19+13 μ))

dWT=FullSimplify[WT/.{z→dz}]

(11664 ch (α-θ μ)-11664 (α-θ μ)$^2$+cf$^2$ (-8027+269 μ (-82+65 μ))+ch$^2$ (-8027+269 μ (-82+65 μ))+2 cf (5832 (α-θ μ)+ch (2195-269 μ (-82+65 μ))))/(324 (1+5 μ) (-19+13 μ))

**SECOND ORDER CONDITIONS AND STABILITY CONDITIONS**

**STAGE 1**

SOC of Stage 1

D[derW3,z]

2/81 (1+5 μ) (-19+13 μ)

SOC of Stage 2

D[derW1,τh]

-1

SOC of stage 1

H2={{D[derpr1,xh],D[derpr1,xf]},{D[derpr2,xh],D[derpr2,xf]}}

{{-2,0},{0,-2}}

H1={{D[derpr1,xh]}}

{{-2}}

Reduce[Det[H1]<0&&Det[H2]>0]

True

SOC Condition

Reduce[2/81 (1+5 μ) (-19+13 μ)<0&&μ>0]

0<μ<19/13

"stability condition of stage 2 holds"

J={{D[derW1,τh],D[derW1,τf]},{D[derW2,τh],D[derW2,τf]}}

{{-1,0},{0,-1}}

Simplify[Det[J]]

1

**COMPARATIVE STATICS**

"Comparative statics of Stage 1"

"Comparative Statics on Policy Arguments:"

"dzh=(cf (-135-105 μ+412 μ2)+α (135-1533 μ+2918 μ2-1408 μ3)+μ (2 ch (819-1665 μ+704 μ2)+θ (-135+1533 μ-2918 μ2+1408 μ3)))/(-27-120 μ+3833 μ2-4710 μ3+1408 μ4)"

D[dz,ch]

(-41+65 μ)/(2 (-19-82 μ+65 μ2))

0<μ<19/13

Reduce[(-41+65 μ)/(2 (-19-82 μ+65 μ2))≥0&&0<μ<19/13]

0<μ≤41/65

Reduce[(-41+65 μ)/(2 (-19-82 μ+65 μ2))≤0&&0<μ<19/13]

41/65≤μ<19/13

D[dz,cf]

(-41+65 μ)/(2 (-19-82 μ+65 μ2))

Reduce[(-41+65 μ)/(2 (-19-82 μ+65 μ2))≥0&&0<μ<19/13]

0<μ≤41/65

Reduce[(-41+65 μ)/(2 (-19-82 μ+65 μ2))≤0&&0<μ<19/13]

41/65≤μ<19/13

D[dz,μ]

-((-41+65 μ) (-82+130 μ) (cf+ch-2 α+2 θ μ))/(2 (-19-82 μ+65 μ^2)^2)+(θ (-41+65 μ))/(-19-82 μ+65 μ2)+(65 (cf+ch-2 α+2 θ μ))/(2 (-19-82 μ+65 μ2))

D[dz, θ ]

(μ (-41+65 μ))/(-19-82 μ+65 μ2)

```
Reduce[(μ (-41+65 μ))/(-19-82 μ+65 μ2)≥0&&0<μ<19/13]
0<μ≤41/65
Reduce[(μ (-41+65 μ))/(-19-82 μ+65 μ2)≤0&&0<μ<19/13]
41/65≤μ<19/13
D[dz, α]
-(-41+65 μ)/(-19-82 μ+65 μ2)
Reduce[-(-41+65 μ)/(-19-82 μ+65 μ2)≥0&&0<μ<19/13]
41/65≤μ<19/13
Reduce[-(-41+65 μ)/(-19-82 μ+65 μ2)≤0&&0<μ<19/13]
0<μ≤41/65
D[ddτh,ch]
((-1+μ) (-41+65 μ))/(6 (-19-82 μ+65 μ2))
Reduce[((-1+μ) (-41+65 μ))/(6 (-19-82 μ+65 μ2))≤0&&0<μ<19/13]
0<μ≤41/65||1≤μ<19/13
Reduce[((-1+μ) (-41+65 μ))/(6 (-19-82 μ+65 μ2))ρ0&&0<μ<19/13]
41/65≤μ≤1
D[ddτh,cf]
1/3 (-1+((-1+μ) (-41+65 μ))/(2 (-19-82 μ+65 μ2)))
Reduce[1/3 (-1+((-1+μ) (-41+65 μ))/(2 (-19-82 μ+65 μ2)))≤0&&0<μ<19/13]
0<μ<19/13
Reduce[1/3 (-1+((-1+μ) (-41+65 μ))/(2 (-19-82 μ+65 μ2)))ρ0&&0<μ<19/13]
False
Simplify[D[ddτh,μ]]
(4 (-448 α-95 θ+650 α μ+76 θ μ-130 α μ2-161 θ μ2+cf (224-325 μ+65 μ2)+ch
(224-325 μ+65 μ2)))/(19+82 μ-65 μ^2)^2
D[ddτh, θ ]
1/3 (-μ+((-1+μ) μ (-41+65 μ))/(-19-82 μ+65 μ2))
Reduce[1/3 (-μ+((-1+μ) μ (-41+65 μ))/(-19-82 μ+65 μ2))>0&&0<μ<19/13]
False
Reduce[1/3 (-μ+((-1+μ) μ (-41+65 μ))/(-19-82 μ+65 μ2))≤0&&0<μ<19/13]
0<μ<19/13
τh is non-decreasing in θ
D[ddτh, α]
1/3 (1-((-1+μ) (-41+65 μ))/(-19-82 μ+65 μ2))
```

Reduce[1/3 (1-((-1+μ) (-41+65 μ))/(-19-82 μ+65 μ2))>0&&0<μ<19/13]

0<μ<19/13

Reduce[1/3 (1-((-1+μ) (-41+65 μ))/(-19-82 μ+65 μ2))≤0&&0<μ<19/13]

False

τh is non-decreasing in α

**COMPARISON:Non-cooperative and cooperation in z**

"13/100<μ<130/100"

α=100

100

θ=50

50

ch=1000

1000

cf=1

1

zh20=(cf (-1215-1035 μ+2782 μ2)+α (1215-12519 μ+22322 μ2-10168 μ3)+μ (2 ch (6777-12552 μ+5084 μ2)+θ (-1215+12519 μ-22322 μ2+10168 μ3)))/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4)

(-1215-1035 μ+2782 μ2+100 (1215-12519 μ+22322 μ2-10168 μ3)+μ (2000 (6777-12552 μ+5084 μ2)+50 (-1215+12519 μ-22322 μ2+10168 μ3)))/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4)

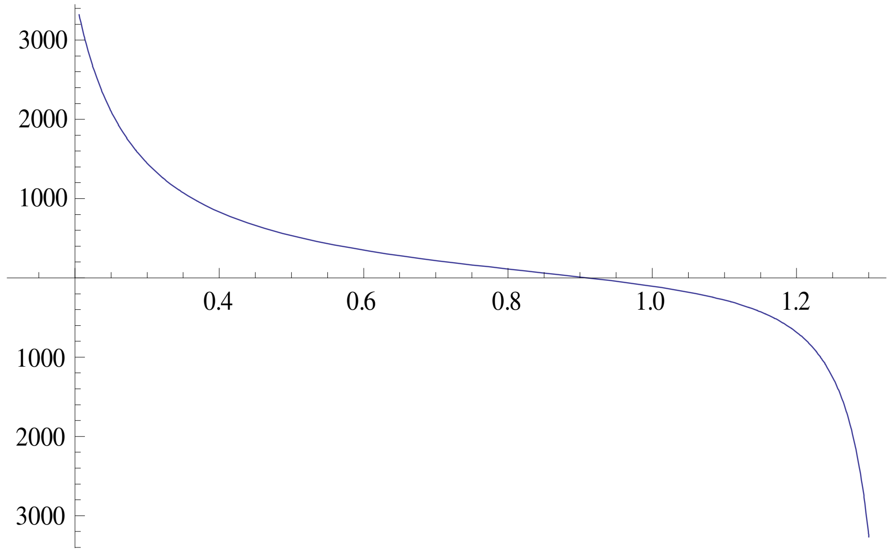
z21=((-41+65 μ) (cf+ch-2 α+2 θ μ))/(2 (-19-82 μ+65 μ2))

((-41+65 μ) (801+100 μ))/(2 (-19-82 μ+65 μ2))

FullSimplify[farkzh=zh20-z21]

1/4 (12313/(19-13 μ)-3905/(1+5 μ)+(70290-114124 μ)/(9+(119-62 μ) μ)+(1998 (-135+164 μ))/(27+μ (-241+164 μ)))

Plot[farkzh,{μ,13/100,130/100}]



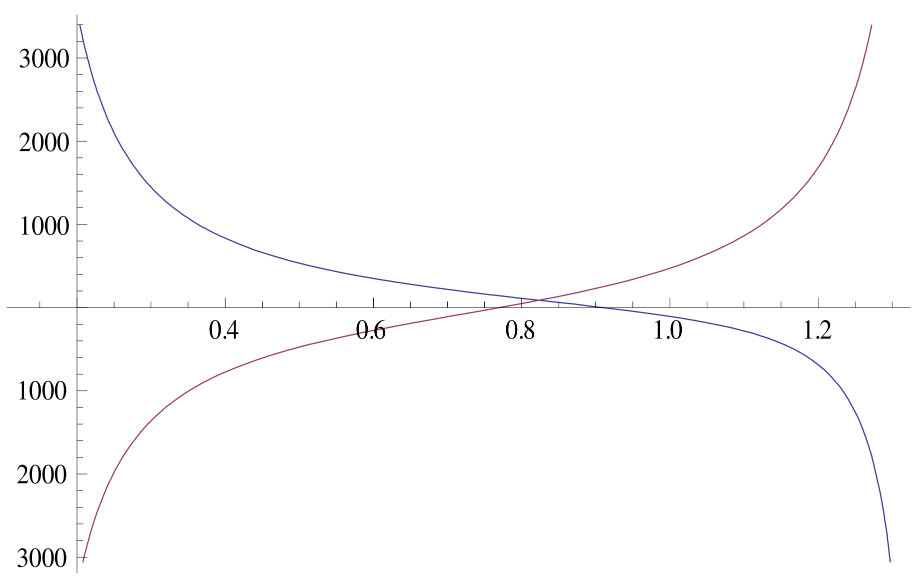

zf20=(ch (-1215-1035 μ+2782 μ2)+α (1215-12519 μ+22322 μ2-10168 μ3)+μ (2 cf (6777-12552 μ+5084 μ2)+θ (-1215+12519 μ-22322 μ2+10168 μ3)))/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4)

(1000 (-1215-1035 μ+2782 μ2)+100 (1215-12519 μ+22322 μ2-10168 μ3)+μ (2 (6777-12552 μ+5084 μ2)+50 (-1215+12519 μ-22322 μ2+10168 μ3)))/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4)

FullSimplify[farkzf=zf20-z21]

1/4 (12313/(19-13 μ)-3905/(1+5 μ)+(70290-114124 μ)/(9+(119-62 μ) μ)+(1998 (135-164 μ))/(27+μ (-241+164 μ)))

Plot[{farkzh,farkzf},{μ,13/100,130/100}]



**TRADE LIBERALIZATION:NON-COOPERATIVE SOLUTION**

**STAGE 2:**

ph=α-β (xh+yh)

pf=α-β (xf+yf)

kh=ch+μ(θ-zh)

kf=cf+μ(θ-zf)

pri=profit function of country i

prh=(α-β (xh+yh)-kh) xh+(α-β (xf+yf)-kh) xf

xf (-ch-xf-yf+α-(-zh+θ) μ)+xh (-ch-xh-yh+α-(-zh+θ) μ)

derpr1=D[prh,xh]

-ch-2 xh-yh+α-(-zh+θ) μ

derpr2=D[prh,xf]

-ch-2 xf-yf+α-(-zh+θ) μ

prf=yf (-kf+α-(xf+yf) β)+yh (-kf+α-(xh+yh) β)

yf (-cf-xf-yf+α-(-zf+θ) μ)+yh (-cf-xh-yh+α-(-zf+θ) μ)

derpr3=D[prf,yh]

-cf-xh-2 yh+α-(-zf+θ) μ

derpr4=D[prf,yf]

-cf-xf-2 yf+α-(-zf+θ) μ

Simplify[Solve[{derpr1  0,derpr2  0,derpr3  0,derpr4==0},{xh,xf,yh,yf}]]

{{xh→1/3 (cf-2 ch+α-zf μ+2 zh μ-θ μ),xf→1/3 (cf-2 ch+α-zf μ+2 zh μ-θ μ),yh→1/3 (-2 cf+ch+α+2 zf μ-zh μ-θ μ),yf→1/3 (-2 cf+ch+α+2 zf μ-zh μ-θ μ)}}

dyf=1/3 (-2 cf+ch+α+2 zf μ-zh μ-θ μ)

1/3 (-2 cf+ch+α+2 zf μ-zh μ-θ μ)

dxf=1/3 (cf-2 ch+α-zf μ+2 zh μ-θ μ)

1/3 (cf-2 ch+α-zf μ+2 zh μ-θ μ)

```
dxh=1/3 (cf-2 ch+α-zf μ+2 zh μ-θ μ)
1/3 (cf-2 ch+α-zf μ+2 zh μ-θ μ)
dyh=1/3 (-2 cf+ch+α+2 zf μ-zh μ-θ μ)
1/3 (-2 cf+ch+α+2 zf μ-zh μ-θ μ)

dprh=FullSimplify[prh/.{xh→dxh,xf→dxf,yh→dyh,yf→dyf}]
2/9 (cf-2 ch+α-(zf-2 zh+θ) μ)^2
dprf=FullSimplify[prf/.{xh→dxh,xf→dxf,yh→dyh,yf→dyf}]
2/9 (-2 cf+ch+α+(2 zf-zh-θ) μ)^2
```

**STAGE 1**

```
Wh=β (dxh+dyh)^2/2+dprh-zh (dxh+dxf)
-2/3 zh (cf-2 ch+α-zf μ+2 zh μ-θ μ)+2/9 (cf-2 ch+α-(zf-2 zh+θ) μ)^2+1/2 (1/3 (-2 cf+ch+α+2 zf μ-zh μ-θ μ)+1/3 (cf-2 ch+α-zf μ+2 zh μ-θ μ))^2
derW1=FullSimplify[D[Wh,zh]]
1/9 (-6 (cf-2 ch+α)+(7 cf-17 ch+6 zf-24 zh+10 α+6 θ) μ+(-7 zf+17 zh-10 θ) μ2)


Wf=β (dxf+dyf)^2/2+dprf-(zf (dyf+dyh))
2/9 (-2 cf+ch+α+(2 zf-zh-θ) μ)^2-2/3 zf (-2 cf+ch+α+2 zf μ-zh μ-θ μ)+1/2 (1/3 (-2 cf+ch+α+2 zf μ-zh μ-θ μ)+1/3 (cf-2 ch+α-zf μ+2 zh μ-θ μ))^2
derW2=FullSimplify[D[Wf,zf]]
1/9 (-6 (ch+α)+cf (12-17 μ)+μ (7 ch+6 zh+10 α+6 θ-7 zh μ-10 θ μ+zf (-24+17 μ)))

Simplify[Solve[{derW1  0,derW2  0},{zh,zf}]]
{{zh→(cf (-6+7 μ)+ch (21-44 μ+20 μ2)-(α-θ μ) (15-37 μ+20 μ2))/(μ (45-61 μ+20 μ2)),zf→(ch (-6+7 μ)+cf (21-44 μ+20 μ2)-(α-θ μ) (15-37 μ+20 μ2))/(μ (45-61 μ+20 μ2))}}
dzh=(cf (-6+7 μ)+ch (21-44 μ+20 μ2)-(α-θ μ) (15-37 μ+20 μ2))/(μ (45-61 μ+20 μ2))
(cf (-6+7 μ)+ch (21-44 μ+20 μ2)-(α-θ μ) (15-37 μ+20 μ2))/(μ (45-61 μ+20 μ2))
dzf=(ch (-6+7 μ)+cf (21-44 μ+20 μ2)-(α-θ μ) (15-37 μ+20 μ2))/(μ (45-61 μ+20 μ2))
(ch (-6+7 μ)+cf (21-44 μ+20 μ2)-(α-θ μ) (15-37 μ+20 μ2))/(μ (45-61 μ+20 μ2))
```

substitution

ddxh=FullSimplify[dxh/.{zh→dzh,zf→dzf}]

(cf-ch)/(5-4 μ)+(cf+ch-2 α)/(-9+5 μ)+(2 θ μ)/(-9+5 μ)

ddxf=FullSimplify[dxf/.{zh→dzh,zf→dzf}]

(cf-ch)/(5-4 μ)+(cf+ch-2 α)/(-9+5 μ)+(2 θ μ)/(-9+5 μ)

ddyh=FullSimplify[dyh/.{zh→dzh,zf→dzf}]

(cf-ch)/(-5+4 μ)+(cf+ch-2 α)/(-9+5 μ)+(2 θ μ)/(-9+5 μ)

ddyf=FullSimplify[dyf/.{zh→dzh,zf→dzf}]

(cf-ch)/(-5+4 μ)+(cf+ch-2 α)/(-9+5 μ)+(2 θ μ)/(-9+5 μ)

ddprh=FullSimplify[dprh/.{zh→dzh,zf→dzf}]

(2 (ch (14-9 μ)+cf (-4+μ)+2 (-5+4 μ) (α-θ μ))$^2$)/(45-61 μ+20 μ^2)$^2$

ddprf=FullSimplify[dprf/.{zh→dzh,zf→dzf}]

(2 (-ch (-4+μ)+cf (-14+9 μ)+2 (-5+4 μ) (-α+θ μ))$^2$)/(45-61 μ+20 μ^2)$^2$

dWh=FullSimplify[Wh/.{zh→dzh,zf→dzf}]

1/((9-5 μ)$^2$ (5-4 μ)$^2$ μ) 2 (-2 (5-4 μ)$^2$ (-3+μ) (α-θ μ)$^2$+ch (-5+4 μ) (α-θ μ) (84+μ (-109+33 μ))+ch$^2$ (294+μ (-584+(384-83 μ) μ))+cf (-24+17 μ) (ch (7+μ (-7+2 μ))-(α-θ μ) (5+μ (-9+4 μ)))+cf$^2$ (24+μ (7+μ (-41+17 μ))))

dWf=FullSimplify[Wf/.{zh→dzh,zf→dzf}]

-1/((9-5 μ)$^2$ (5-4 μ)$^2$ μ) 2 (ch (-1+μ) (-5+4 μ) (-24+17 μ) (α-θ μ)+2 (5-4 μ)$^2$ (-3+μ) (α-θ μ)$^2$-ch$^2$ (24+μ (7+μ (-41+17 μ)))+cf (-ch (-24+17 μ) (7+μ (-7+2 μ))+(-5+4 μ) (-α+θ μ) (84+μ (-109+33 μ)))+cf$^2$ (-294+μ (584+μ (-384+83 μ))))

**SECOND OREDER CONDITIONS AND STABILITY CONDITIONS**

**STAGE 1**

SOC of Stage 1

D[derW1,zh]

1/9 (-24 μ+17 μ2)

D[derW2,zf]

1/9 μ (-24+17 μ)

SOC of Stage 2

H2={{D[derpr1,xh],D[derpr1,xf]},{D[derpr2,xh],D[derpr2,xf]}}

{{-2,0},{0,-2}}

```
H1={{D[derpr1,xh]}}
{{-2}}
Reduce[Det[H1]<0&&Det[H2]>0]
True
```

SOC Condition

```
Reduce[1/9 (-24 μ+17 μ2)<0&&μ>0]
0<μ<24/17
```

Stability Conditions

```
S1={{D[derW1,zh],D[derW1,zf]},{D[derW2,zh],D[derW2,zf]}}
{{1/9 (-24 μ+17 μ2),1/9 (6 μ-7 μ2)},{1/9 (6-7 μ) μ,1/9 μ (-24+17 μ)}}
Reduce[Det[S1]>0&&μ>0]
0<μ<5/4||μ>9/5
```

SOLUTION INTERVAL

```
Reduce[0<μ<24/17&&Det[S1]>0]
0<μ<5/4
```

**COMPARATIVE STATICS**

```
"Comparative statics of Stage 1"
D[dzh,ch]
(21-44 μ+20 μ2)/(μ (45-61 μ+20 μ2))
Reduce[(21-44 μ+20 μ2)/(μ (45-61 μ+20 μ2))>0&&0<μ<5/4]
0<μ<7/10
Reduce[(21-44 μ+20 μ2)/(μ (45-61 μ+20 μ2))≤0&&0<μ<5/4]
7/10≤μ<5/4
D[dzh,cf]
(-6+7 μ)/(μ (45-61 μ+20 μ2))
Reduce[(-6+7 μ)/(μ (45-61 μ+20 μ2))≤0&&0<μ<5/4]
0<μ≤6/7
Reduce[(-6+7 μ)/(μ (45-61 μ+20 μ2))>0&&0<μ<5/4]
6/7<μ<5/4
Simplify[D[dzh,μ]]
(cf (270-732 μ+787 μ2-280 μ3)+ch (-945+2562 μ-3044 μ2+1760 μ3-400 μ4)+(5-4 μ)^2 (-30 θ μ2+α (27-30 μ+25 μ2)))/(μ2 (45-61 μ+20 μ^2)^2)
D[dzh, θ ]
```

```
(15-37 μ+20 μ2)/(45-61 μ+20 μ2)
Reduce[(15-37 μ+20 μ2)/(45-61 μ+20 μ2)≤0&&0<μ<5/4]
3/5≤μ<5/4
Reduce[(15-37 μ+20 μ2)/(45-61 μ+20 μ2)>0&&0<μ<5/4]
0<μ<3/5
D[dzh, α]
(-15+37 μ-20 μ2)/(μ (45-61 μ+20 μ2))
Reduce[(-15+37 μ-20 μ2)/(μ (45-61 μ+20 μ2))≥0&&0<μ<5/4]
3/5≤μ<5/4
Reduce[(-15+37 μ-20 μ2)/(μ (45-61 μ+20 μ2))≤0&&0<μ<5/4]
0<μ≤3/5
```

**TRADE LIBERALIZATION:COOPERATION POLLUTION POLICY "Z=ZH=ZF"**

**STAGE 3:**

```
ph=α-β (xh+yh)
-xh-yh+α
pf=α-β (xf+yf)
-xf-yf+α
kh=ch+μ(θ-z)
ch+(-z+θ) μ
kf=cf+μ(θ-z)
cf+(-z+θ) μ
```

pri=profit function of country i

```
prh=(α-β (xh+yh)-kh) xh+(α-β (xf+yf)-kh) xf
xf (-ch-xf-yf+α-(-z+θ) μ)+xh (-ch-xh-yh+α-(-z+θ) μ)

derpr1=D[prh,xh]
-ch-2 xh-yh+α-(-z+θ) μ
derpr2=D[prh,xf]
```

```
-ch-2 xf-yf+α-(-z+θ) μ
```

```
prf=yf (-kf+α-(xf+yf) β)+yh (-kf+α-(xh+yh) β)
yf (-cf-xf-yf+α-(-z+θ) μ)+yh (-cf-xh-yh+α-(-z+θ) μ)
```

```
derpr3=D[prf,yh]
-cf-xh-2 yh+α-(-z+θ) μ
derpr4=D[prf,yf]
-cf-xf-2 yf+α-(-z+θ) μ
```

```
Simplify[Solve[{derpr1  0,derpr2  0,derpr3  0,derpr4==0},{xh,xf,yh,yf}]]
```

```
{{xh→1/3 (cf-2 ch+α+z μ-θ μ),xf→1/3 (cf-2 ch+α+z μ-θ μ),yh→1/3 (-2 cf+ch+α+z μ-θ μ),yf→1/3 (-2 cf+ch+α+z μ-θ μ)}}
dyf=1/3 (-2 cf+ch+α+z μ-θ μ)
1/3 (-2 cf+ch+α+z μ-θ μ)
dxf=1/3 (cf-2 ch+α+z μ-θ μ)
1/3 (cf-2 ch+α+z μ-θ μ)
dxh=1/3 (cf-2 ch+α+z μ-θ μ)
1/3 (cf-2 ch+α+z μ-θ μ)
dyh=1/3 (-2 cf+ch+α+z μ-θ μ)
1/3 (-2 cf+ch+α+z μ-θ μ)
dprh=FullSimplify[prh/.{xh→dxh,xf→dxf,yh→dyh,yf→dyf}]
2/9 (cf-2 ch+α+(z-θ) μ)^2
dprf=FullSimplify[prf/.{xh→dxh,xf→dxf,yh→dyh,yf→dyf}]
2/9 (-2 cf+ch+α+(z-θ) μ)^2
```

**STAGE 2**

```
Wh=β (dxh+dyh)^2/2+dprh-z (dxh+dxf)
2/9 (cf-2 ch+α+(z-θ) μ)^2-2/3 z (cf-2 ch+α+z μ-θ μ)+1/2 (1/3 (cf-2 ch+α+z μ-θ μ)+1/3 (-2 cf+ch+α+z μ-θ μ))^2
```

Wf=β (dxf+dyf)^2/2+dprf-(z (dyf+dyh))

2/9 (-2 cf+ch+α+(z-θ) μ)$^{2}$-2/3 z (-2 cf+ch+α+z μ-θ μ)+1/2 (1/3 (cf-2 ch+α+z μ-θ μ)+1/3 (-2 cf+ch+α+z μ-θ μ))$^{2}$

FullSimplify[WT=Wh+Wf]

1/9 (11 cf$^{2}$+11 ch$^{2}$-2 cf (7 ch-3 z+4 α+4 z μ-4 θ μ)+4 (α+(z-θ) μ) (-3 z+2 α+2 z μ-2 θ μ)+ch (-8 α+z (6-8 μ)+8 θ μ))

derW=FullSimplify[D[WT,z]]

1/9 (6 (cf+ch-2 α)-4 (2 (cf+ch+3 z-2 α)-3 θ) μ+16 (z-θ) μ2)

Simplify[Solve[{derW  0},{z}]]

{{z→((-3+4 μ) (cf+ch-2 α+2 θ μ))/(4 μ (-3+2 μ))}}

dz=((-3+4 μ) (cf+ch-2 α+2 θ μ))/(4 μ (-3+2 μ))

((-3+4 μ) (cf+ch-2 α+2 θ μ))/(4 μ (-3+2 μ))

SUBSTITUTION:

ddxh=FullSimplify[dxh/.{z→dz}]

(-5 cf+7 ch-2 α+2 (2 cf-2 ch+θ) μ)/(-12+8 μ)

ddxf=FullSimplify[dxf/.{z→dz}]

(-5 cf+7 ch-2 α+2 (2 cf-2 ch+θ) μ)/(-12+8 μ)

ddyh=FullSimplify[dyh/.{z→dz}]

(-2 α+cf (7-4 μ)+2 θ μ+ch (-5+4 μ))/(-12+8 μ)

ddyf=FullSimplify[dyf/.{z→dz}]

(-2 α+cf (7-4 μ)+2 θ μ+ch (-5+4 μ))/(-12+8 μ)

ddprh=FullSimplify[dprh/.{z→dz}]

(5 cf-7 ch+2 α-2 (2 cf-2 ch+θ) μ)$^{2}$/(8 (3-2 μ)$^{2}$)

ddprf=FullSimplify[dprf/.{z→dz}]

(7 cf-5 ch-2 α-4 cf μ+4 ch μ+2 θ μ)$^{2}$/(8 (3-2 μ)$^{2}$)

dWh=FullSimplify[Wh/.{z→dz}]

1/(8 μ (-3+2 μ)) (-2 cf (ch+4 α)+8 cf (3 ch+α+θ) μ-8 cf (2 ch+θ) μ2-4 (α-θ μ)$^{2}$+8 ch (-2+μ) (-α+θ μ)+cf$^{2}$ (5+8 (-2+μ) μ)+ch$^{2}$ (-7+8 (-1+μ) μ))

dWf=FullSimplify[Wf/.{z→dz}]

1/(8 μ (-3+2 μ)) (8 ch (-1+μ) (α-θ μ)-4 (α-θ μ)$^{2}$+ch$^{2}$ (5+8 (-2+μ) μ)+cf$^{2}$ (-7+8 (-1+μ) μ)-2 cf (4 (-2+μ) (α-θ μ)+ch (1+4 μ (-3+2 μ))))

dWT=FullSimplify[WT/.{z→dz}]

**SECOND ORDER CONDITIONS AND STABILITY CONDITIONS**

**STAGE 1**

SOC of Stage 1

D[derW,z]

1/9 (-24 μ+16 μ2)

SOC of stage 2

H2={{D[derpr1,xh],D[derpr1,xf]},{D[derpr2,xh],D[derpr2,xf]}}

{{-2,0},{0,-2}}

H1={{D[derpr1,xh]}}

{{-2}}

Reduce[Det[H1]<0&&Det[H2]>0]

True

SOC Condition

Reduce[1/9 (-24 μ+16 μ2)<0&&μ>0]

0<μ<3/2

**COMPARATIVE STATICS**

"Comparative statics of Stage 1"

"Comparative Statics on Policy Arguments:"

D[dz,ch]

(-3+4 μ)/(4 μ (-3+2 μ))

Reduce[(-3+4 μ)/(4 μ (-3+2 μ))≥0&&0<μ<3/2]

0<μ≤3/4

Reduce[(-3+4 μ)/(4 μ (-3+2 μ))≤0&&0<μ<3/2]

3/4≤μ<3/2

D[dz,cf]

(-3+4 μ)/(4 μ (-3+2 μ))

Reduce[(-3+4 μ)/(4 μ (-3+2 μ))≥0&&0<μ<3/2]

0<μ≤3/4

Reduce[(-3+4 μ)/(4 μ (-3+2 μ))≤0&&0<μ<3/2]

3/4≤μ<3/2

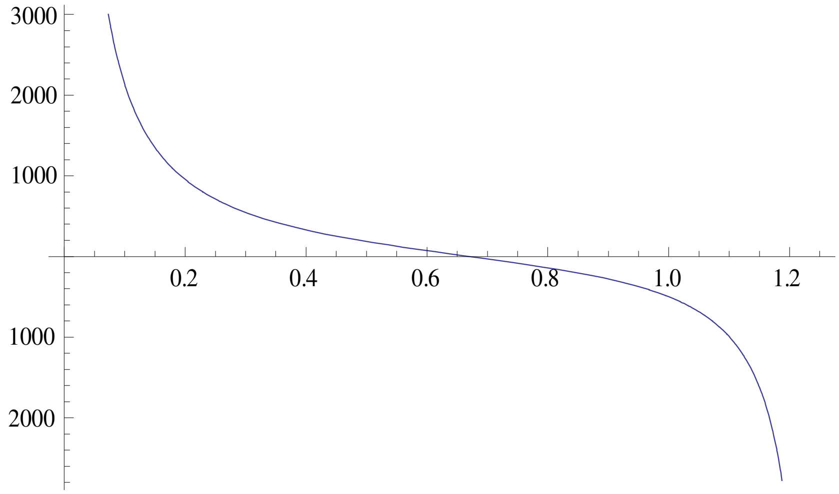
D[dz,μ]

(θ (-3+4 μ))/(2 μ (-3+2 μ))+(cf+ch-2 α+2 θ μ)/(μ (-3+2 μ))-((-3+4 μ) (cf+ch-2 α+2 θ μ))/(2 μ (-3+2 μ)$^{2}$)-((-3+4 μ) (cf+ch-2 α+2 θ μ))/(4 μ2 (-3+2 μ))

```
D[dz, θ ]
(-3+4 μ)/(2 (-3+2 μ))
Reduce[(-3+4 μ)/(2 (-3+2 μ))≥0&&0<μ<3/2]
0<μ≤3/4
Reduce[(-3+4 μ)/(2 (-3+2 μ))≤0&&0<μ<3/2]
3/4≤μ<3/2
D[dz, α]
-(-3+4 μ)/(2 μ (-3+2 μ))
Reduce[-(-3+4 μ)/(2 μ (-3+2 μ))≥0&&0<μ<3/2]
3/4≤μ<3/2
Reduce[-(-3+4 μ)/(2 μ (-3+2 μ))≤0&&0<μ<3/2]
0<μ≤3/4-((cf+ch-2 α)^2+4 (3 (cf-ch)^2+(cf+ch-2 α) θ) μ+4 (-2 (cf-ch)^2+θ2) μ2)/(4 μ (-3+2 μ))
```

**COMPARISON:Non-cooperative and cooperation in z**

```
"0<μ<5/4"
α=100
100
θ=50
50
ch=1000
1000
cf=1
1
zh30=(cf (-6+7 μ)+ch (21-44 μ+20 μ2)-(α-θ μ) (15-37 μ+20 μ2))/(μ (45-61 μ+20 μ2))
(-6+7 μ+1000 (21-44 μ+20 μ2)-(100-50 μ) (15-37 μ+20 μ2))/(μ (45-61 μ+20 μ2))
z31=((-3+4 μ) (cf+ch-2 α+2 θ μ))/(4 μ (-3+2 μ))
((-3+4 μ) (801+100 μ))/(4 μ (-3+2 μ))
FullSimplify[farkzh=zh30-z31]
951/(6-4 μ)+4659/(20 μ)+3996/(5 (-5+4 μ))+1635/(-9+5 μ)
Plot[farkzh,{μ,0,5/4}]
```



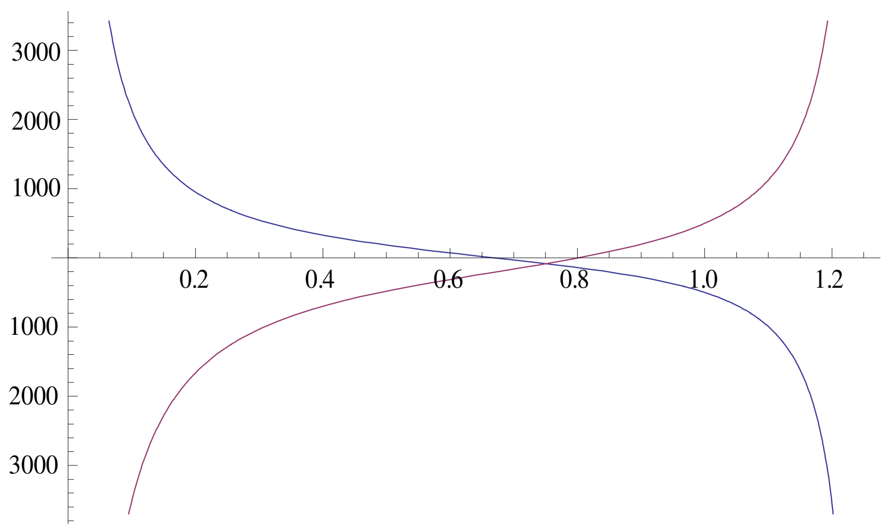

zf30=(ch (-6+7 μ)+cf (21-44 μ+20 μ2)-(α-θ μ) (15-37 μ+20 μ2))/(μ (45-61 μ+20 μ2))

(21-44 μ+20 μ2+1000 (-6+7 μ)-(100-50 μ) (15-37 μ+20 μ2))/(μ (45-61 μ+20 μ2))

FullSimplify[farkzf=zf30-z31]

3996/(25-20 μ)+951/(6-4 μ)-7329/(20 μ)+1635/(-9+5 μ)

Plot[{farkzh,farkzf},{μ,0,5/4}]




**NON-COOPERATIVE CASE: LIBERALIZING TRADE**

"0<μ<5/4"

α=100

100

θ=50

50

ch=1000

1000

cf=1

1

zhm=(cf (-1215-1035 μ+2782 μ2)+α (1215-12519 μ+22322 μ2-10168 μ3)+μ (2 ch (6777-12552 μ+5084 μ2)+θ (-1215+12519 μ-22322 μ2+10168 μ3)))/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4)

(-1215-1035 μ+2782 μ2+100 (1215-12519 μ+22322 μ2-10168 μ3)+μ (2000 (6777-12552 μ+5084 μ2)+50 (-1215+12519 μ-22322 μ2+10168 μ3)))/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4)

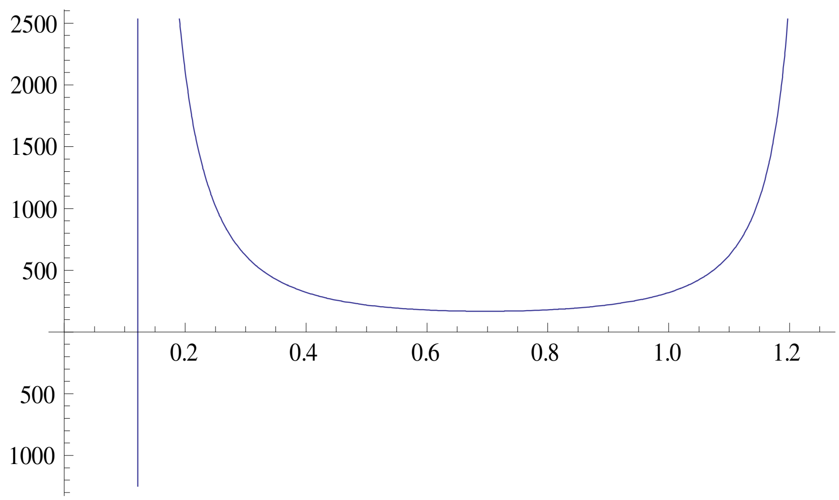
zht=(cf (-6+7 μ)+ch (21-44 μ+20 μ2)-(α-θ μ) (15-37 μ+20 μ2))/(μ (45-61 μ+20 μ2))

(-6+7 μ+1000 (21-44 μ+20 μ2)-(100-50 μ) (15-37 μ+20 μ2))/(μ (45-61 μ+20 μ2))

FullSimplify[farkzh=zhm-zht]

1/10 (16350/(9-5 μ)+7992/(5-4 μ)-4332/μ+(5 (-35145+57062 μ))/(-9+μ (-119+62 μ))+(4995 (-135+164 μ))/(27+μ (-241+164 μ)))

Plot[farkzh,{μ,0,5/4}]




zfm=(ch (-1215-1035 μ+2782 μ2)+α (1215-12519 μ+22322 μ2-10168 μ3)+μ (2 cf (6777-12552 μ+5084 μ2)+θ (-1215+12519 μ-22322 μ2+10168 μ3)))/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4)

(1000 (-1215-1035 μ+2782 μ2)+100 (1215-12519 μ+22322 μ2-10168 μ3)+μ (2 (6777-12552 μ+5084 μ2)+50 (-1215+12519 μ-22322 μ2+10168 μ3)))/(-243-1044 μ+28877 μ2-34458 μ3+10168 μ4)

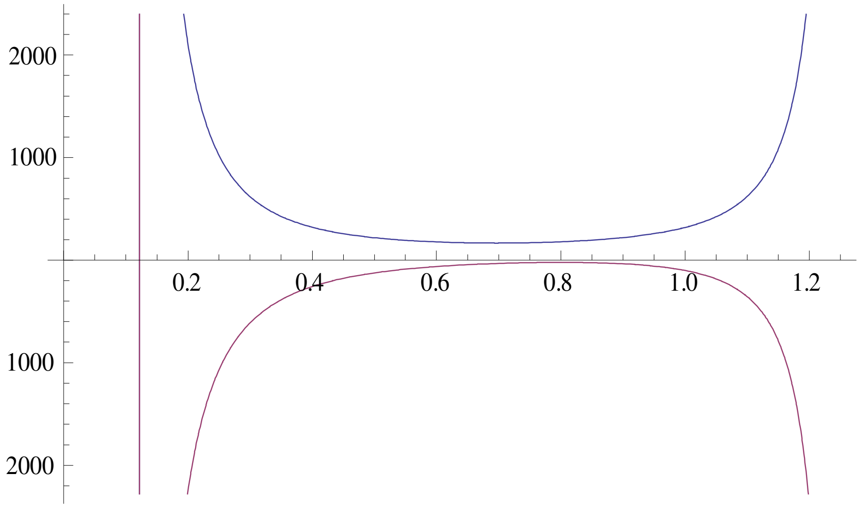
zft=(ch (-6+7 μ)+cf (21-44 μ+20 μ2)-(α-θ μ) (15-37 μ+20 μ2))/(μ (45-61 μ+20 μ2))

(21-44 μ+20 μ2+1000 (-6+7 μ)-(100-50 μ) (15-37 μ+20 μ2))/(μ (45-61 μ+20 μ2))

FullSimplify[farkzf=zfm-zft]

1635/(9-5 μ)+831/(5 μ)+3996/(5 (-5+4 μ))+(35145-57062 μ)/(18+2 (119-62 μ) μ)-(999 (-135+164 μ))/(54-482 μ+328 μ2)

Plot[{farkzh,farkzf},{μ,0,5/4}]




Reduce[zhm>zht]

μ<Root[-2368521-8077806 #1+28404945 #1$^2$-42759744 #1$^3$+31447144 #1$^4$-8784232 #1$^5$+32800 #1$^6$&,1]||1/124 (119-13 $\sqrt{97}$ )<μ<0||1/328 (241-$\sqrt{40369}$ )<μ<5/4||1/328 (241+$\sqrt{40369}$ )<μ<9/5||1/124 (119+13 $\sqrt{97}$ )<μ<Root[-2368521-8077806 #1+28404945 #1$^2$-42759744 #1$^3$+31447144 #1$^4$-8784232 #1$^5$+32800 #1$^6$&,2]

**COOPERATION CASE: BEFORE AND AFTER TRADE LIBERALIZATION**

"0<μ<5/4"

α=100

100

θ=50

50

ch=1000

1000

cf=1

1

zm=((-41+65 μ) (cf+ch-2 α+2 θ μ))/(2 (-19-82 μ+65 μ2))

((-41+65 μ) (801+100 μ))/(2 (-19-82 μ+65 μ2))

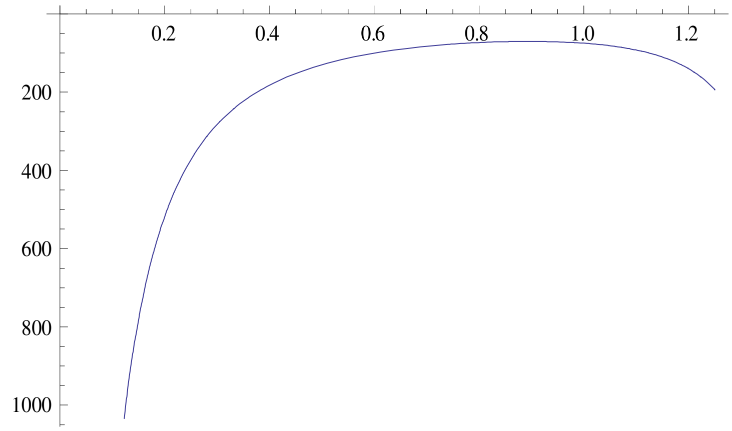
zt=((-3+4 μ) (cf+ch-2 α+2 θ μ))/(4 μ (-3+2 μ))

((-3+4 μ) (801+100 μ))/(4 μ (-3+2 μ))

FullSimplify[farkz=zm-zt]

-((801+100 μ) (57-76 μ+31 μ2))/(4 μ (57+208 μ-359 μ2+130 μ3))

Plot[farkz,{μ,0,5/4}]



## CURRICULUM VITAE

Suphi Şen was born in Kiraz. He had his elementary education in Kiraz Elemantary School and continued his education at Ödemiş Anatolion High School. He graduated from Isparta Science High School. His undergraduate degrees are Civil Engineering and Management Engineering from Istanbul Technical University.  He is about to earn his master of arts degree from Istanbul Technical University, Master of Arts in Economics Program of Social Sciences Institute.