ISTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SOCIAL SCIENCES

INTRA-INDUSTRY TRADE AND CROSS-BORDER POLLUTION: THE IMPACT OF FDI

M.Sc. THESIS

Merve KUMAŞ

Department of Economics

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JANUARY 2015

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ SOSYAL BİLİMLER ENSTİTÜSÜ

ENDÜSTRİ İÇİ TİCARET VE SINIR ÖTESİ KİRLİLİK: DOĞRUDAN YABANCI SERMAYE YATIRIMLARI (DYY)'NIN ETKİSİ

YÜKSEK LİSANS TEZİ

Merve KUMAŞ
412121013

Ekonomi Anabilim Dalı

İktisat Programı

Tez Danışmanı: Prof. Dr. M. Özgür KAYALICA

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Merve Kumaş, a **M.Sc.** student of ITU **Institute of Social Science** student ID **412121013**, successfully defended the **thesis** entitled "**INTRA-INDUSTRY TRADE AND CROSS-BORDER POLLUTION: THE IMPACT OF FDI**", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Prof. Dr. M.Özgür KAYALICA** ....
Istanbul Technical University

Jury Members : **Assoc. Prof. Sencer Ecer** ....
Istanbul Technical University

Prof. Dr. Ensar Yılmaz ....
Yildiz Technical University

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FOREWORD

In the beginning of my undergraduate education, I had no idea or any interest about Economics. Then, when I was in second year, I registered in Microeconomics class. I never forgot that lesson and what I learned there. Besides being enlightening, it was the most fun and enjoyable course during my whole educational life. In fact, I was so impressed, ultimately, today I even wrote a thesis in economics. Needless to say, the course was held by Özgür Kayalıca who is the main actor of my last year and one of the most valuable members of the rest of my life. His sincerity and congeniality are priceless and I am really incapable to express his value to me. He is not just a supervisor for me. Family member, mentor, confidant, guru, brother…. I could say many words but still all of them would be inadequate. Actually, this foreword must be only for him cause I learned a lot from him, not only about economics. He literally tried to teach me everything about everything. I owe him a lot but now I can only say thanks a lot to him.

I am greatly indebted to Suat Küçükçiftçi who encouraged and motivated me when I was confused about my academic life. His speech was a turning point to complete my master degree and continue my education. I thank Ahmet Atıl Aşıcı for challenging me to work on the environment with his valuable opinions about green economy. I would not improve myself in this field, if we did not make such an inspiring and informative conversations during our study.

After almost seven years, I am leaving from İTÜ Management Faculty as an extremely enlightened and trained. I would like to thank distinguished academic staff of the faculty. Thanks to my very special friends and finally, most of the thanks to my parents for their love and support.

December 2014 Merve KUMAŞ

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SUMMARY

In this study, we examine environmental regulations conditions that determine the level of these policies. In the presence of consumption of non-renewable resources and irreversible environmental damage, these policies lead to important consequences. It is, therefore, important to determine optimal policy levels by taking many factors (e.g., market conditions, producers' efficiency, etc.) and to conduct environmental regulations in parallel with economic development instead of seeing these regulations as obstacles to economic development. Regulations that require the coordination of economy and ecology are naturally affected by the economic features of countries. Governments tighten or untighten environmental standards depending on the conditions of market and competition. When governments determine policy levels that bring their welfare to optimum, they consider many factors such as efficiency level of producers, technologies, level of consumer demand, competitive conditions in international markets etc. One of these important factors is the foreign investment. Especially the foreign investors, which have production activities in host countries, determine their location and production decisions depending on the policies of these countries. Moreover, these investors may play an active role in determining policies by creating a reciprocal influence. Based on these facts, this thesis aims to examine the impact of foreign direct investment on the environmental policies of countries in the presence of intra-industry trade and cross-border pollution.

In our study, we first develop a benchmark model and examine the optimal emission quotas of countries under three scenarios: (i) non-cooperation; (ii) cooperation; (iii) uniform policy. In the model, there are two countries and each country has one domestic firm. These firms produce a homogeneous product and serve both local and foreign markets through intra-industry trade. We assume that both countries have unemployment, i.e., both economies benefit from domestic production in terms of employment creation. It is also assumed that pollution occurs during production and there is no firm-specific abatement technology to reduce pollution. Only way to reduce pollution is cutting down the production level (which could be achieved by governments' severe environmental policies). Moreover, there is cross-border pollution between two countries so the welfares of countries are assumed to be negatively affected by the pollution caused by both domestic production and foreign production. It is considered that the marginal disutility from pollution is identical for both countries. However, welfare of both countries is affected more by pollution resulted from domestic production than cross-border pollution. Within the framework of these assumptions, countries try to determine emission quotas that maximize their welfares. Model is solved as a two-stage game. In the first stage, governments simultaneously set their own emission quotas. In the second stage, domestic firms determine the amount of production based on the given emission quotas.

The results of the model are not possible to interpret due to the excessive number of variables and size of the equations. Therefore, although the results will be valid in a more limited context, we make simulations in order to make clearer and more reliable comments. We assign numerical values that satisfy all the conditions and assumptions for each variable in the model.

According to the results, an increase in the market size will lead governments to impose less severe emission policy, whereas it results in more severe policy under cooperative behavior. In the absence of cooperation, both governments encourage their own domestic firms to produce more in order to meet the demands of growing market. Thus, they increase their level of emission quotas. However, under the cooperative behavior, although there is an international competition to meet the growing demands, governments can mutually decrease emission quotas and reduce the pressure of increased production on the environment. It is found that an increase in the fixed unit cost of domestic firm or rival firm will lead to an increase in the optimal policy levels for both non-cooperative and cooperative scenarios. When the production cost of domestic firm increases, the government wants to increase emission quota in order to avoid a decrease in production level and an increase in prices. This is because the negative impact of environmental pressure caused by this incentive will be lower than the negative impact of losses in consumer surplus, producer surplus and employment level caused by decreased production. On the other hand, when the cost of domestic firm in rival country increases and the government relaxes its pollution policy, the other government will also relax its policy level in order to protect the competitiveness of its domestic firm in the international market.

In the second part, the scope of the study is expanded by adding a multinational company (MNC) to the model. The purpose of this stage is to examine the impacts of foreign direct investment on the environmental policies of host country and rival country and to compare these impacts with each other and with the results of the benchmark model. It is assumed that multinational company has a sufficiently large fixed cost so it cannot operate in both countries at the same time. The fixed cost is also assumed to be only firm specific, not country-specific. The location decision of MNC is posited to depend on only the efficiency levels of domestic firms. Therefore, due to less competition, MNC makes relatively more profit in the country with less efficient firm so it wants to settle in that country. It is assumed that MNC fully repatriates its profit to the source country so there is no any contribution in this regard to the welfare of host country. By considering that all the other assumptions are identical with the benchmark model, the model is solved as a two-stage game and optimal policy levels are determined.

In the literature, there are many studies about the impact of foreign direct investment on the environmental policies and sometimes these studies offer conflicting results with each other depending on their contents. Some studies suggest that foreign direct investment leads to policy race between countries and it eventually makes the host countries to become environmentally devastated. In this study, under the accepted assumptions and determined simulation values, it is seen that multinational company decreases the emission level in host country and therefore, it mitigates the pressure of pollution on the welfare. Since it has not any concern to benefit from MNC through the profit, the host country can increase its policy enforcement power and use this power to tighten the permitted emission policy in order to reduce pollution. The results show that although MNC reduces producer surplus generated by domestic firm’s production and employment level because of its relatively efficient production, it can provide a significant decline in the pollution level. It is found that MNC reduces the pollution level not only in the host country but also in the rival country. This is because the advantageous position of domestic firm compared to its rival in the host country allows government to apply stricter environmental policies. Consequently, the welfare increases due to increasing employment level and producer surplus whilst the pollution level is reduced thanks to lower emission quotas. Although the pressure of pollution on welfare is more in the rival country compared to the host country, it is found that the rival country's welfare level is higher than the host country's welfare level. While MNC reduces the producer surplus and employment level in the host country, the domestic firm in the rival country provides more producer surplus and employment than the host country and these earnings can compensate the negative effect of environmental pressure caused by pollution.

In both models, the results show that cooperation always makes both countries better off due to eliminating negative externalities. As a result of the cooperation, countries mutually increase their emission quotas, hence, production levels decrease in both countries due to the increased production costs. Although the consumer surplus, producer surplus and employment level are adversely affected by decreasing production and rising prices, significant decline in the pressure of pollution on the welfare can compensate for these losses and move the welfare to the higher level. In the extended model, under cooperation, although the change in the welfare of host country is higher, the level of welfare is still below that of the rival. The most important difference between the levels of welfare of countries arises from producer surplus. Even though the producer surplus decline in both countries as a result of the cooperation, it is relatively much lower in the host country because of the impact of MNC. In the case of uniform policy, the welfare of host country reaches the highest level among the three scenarios (it is above the welfare level of rival country). In contrast, the rival country has a lower level of welfare compared to the cooperative behavior. This time, the main difference arises from the employment level and host country reaches a higher level of employment.

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ÖZET

Hazırlanan çalışmada ülkelerin önemli bir politika aracı olarak kullandıkları çevresel düzenlemeler ve bu politikaların düzeyini belirleyen koşullar incelenmiştir. Yenilenemeyen kaynakların tüketimi ve geriye dönüşün imkansız olduğu çevresel tahribatların varlığı söz konusu olduğunda uygulanan bu politikalar, ülkeler açısından son derece önemli sonuçlar doğurmaktadır. Dolayısıyla politika seviyelerinin pek çok faktör göz önünde bulundurularak belirlenmesi ve bu çevresel düzenlemelerin ekonomik gelişmelerin önünde bir engel olarak değil aksine ekonomik gelişme ile uyumlu bir şekilde yürütülmesi gerekmektedir. Ekonomi ve ekolojinin koordinasyonunu gerektiren bu düzenlemeler doğal olarak ülkelerin ekonomik koşullarından etkilenmekte ve hükümetlerin pazar ve rekabet koşullarına bağlı olarak çevresel standartlarını sıkılaştırmasına ya da serbestleştirmesine neden olmaktadır. Hükümetler refah düzeylerini optimum seviyeye taşıyacak politika seviyelerini belirlerken üretici firmaların verimlilik düzeyi, kullanılan teknolojiler, tüketicilerin talep düzeyleri, uluslararası pazardaki rekabet koşulları vs. gibi pek çok etmeni hesaba katmaktadırlar. Çevresel politika düzeylerinin bağlı olduğu bu etmenlerden önemli biri de yabancı yatırımlar olmaktadır. Özellikle gittikleri ülkede üretim faaliyetlerinde bulunan yabancı yatırımlar, bu ülkelerin politika düzeylerine bağlı olarak yerleşim ya da üretim kararlarını belirlemekte aynı zamanda karşılıklı bir etki yaratarak söz konusu ülkelerin politika seviyelerinin belirlenmesinde de etkin bir rol oynamaktadırlar. Bu görüşlerden yola çıkarak gerçekleştirilen tez çalışması, doğrudan yabancı yatırımların endüstri-içi ticaret ve sınır ötesi kirlilik varsayımları altında ülkelerin çevresel politikaları üzerindeki etkisini gözlemlemeyi hedeflemektedir.

Doğrudan yabancı sermaye girişlerinin özellikle son 20-30 yıldaki artışı ile beraber yabancı yatırımların daha uygun şartlarda üretim gerçekleştirebilecekleri ve daha fazla kar elde edebilecekleri ülke arayışlarına hız verdikleri görülmektedir. Doğrudan yabancı yatırımların bu yerleşim yeri arayışı ülkelerin yapısal özelliklerinden ve politika kararlarından etkilenmektedir. Bu durum özellikle yabancı sermayeye bağımlılığı yüksek olan ülkeler arasında bir yatırım çekme yarışına yol açabilmektedir. Ülkeler politikalarını yabancı yatırımlar lehine düzenleme yoluna gitmekte ve bu amaçla çevre politikalarını da daha serbest bir düzeye getirmektedirler. Pek çok ülkenin bu yolu tercih etmesi çevresel standartları oldukça aşağılara çekmekte ve neticede yabacı yatırım çekmek uğruna çevresel tahribatı göze almak gibi bir ödünleşim durumunu doğurmaktadır. Kirlilik sığınağı hipotezinin tanımladığı bu durum, çevresel standartları düşürerek bir rekabet üstünlüğü yaratmayı ve kirli endüstriler açısından uygun bir yatırım ortamı yaratmayı işaret etmektedir. Üstelik bu durum ülkeler arasındaki çevresel bozulma farklılıklarının da bir açıklayıcı olarak görülmektedir. Çünkü gelişmiş ülkelerdeki yüksek çevresel standartlardan kaçan kirli endüstrilerin, ekonomik yönden bu yatırımlara daha çok ihtiyaç duyan ve bu sebeple daha düşük çevresel standartlara sahip olan az gelişmiş ülkelere taşındıkları

dolayısıyla da bu bölgelerde çevrenin tahrip edilmesine sebep oldukları öne sürülmektedir. Fakat tüm bunların yanında, yerli firmalara kıyasla daha verimli ve çevre açısından daha az kirlilik yaratan çok uluslu firmaların, bu teknolojiyi gittikleri ülkelere götürebilecekleri ve buralardaki yerli üretimin kalitesinin artmasına katkı sağlayabilecekleri de göz ardı edilmemelidir. Dolayısıyla doğrudan yabancı yatırımların ülkelerin çevresel durumları üzerindeki net etkisi oldukça karmaşık bir durumdur. Üstelik bazen bu yatırımlar, çevresel standartların serbestleştirilmesi değil aksine daha da sıkılaştırılması gibi bir sonuca da yol açabilmektedir. Çevresel duyarlılığın yüksek olduğu veya yabancı yatırımın getirisinin çevresel kayıptan daha düşük olduğu durumlarda ülkeler standartlarını arttırmak isteyebilmektedirler. Bu tezde ele alınan modelde de bu duruma örnek olarak verilebilecek bir sonuç elde edilmiştir.

Çalışmada ilk olarak temel bir model kurulmuş ve ülkelerin işbirliği yapmadıkları daha sonra ise işbirliği yaptıkları ve son olarak da ortak (uniform) bir politika aracı belirledikleri senaryolarda optimum emisyon kotaları incelenmiştir. Çalışmada her birinin içerisinde bir yerli firmanın faaliyet gösterdiği iki ülkeli bir model ele alınmıştır. Bu firmalar homojen ürün üretmekte ve hem yerli pazara hem de endüstri içi ticaret yolu ile yabancı pazara ürün sunmaktadırlar. Her iki ülkede de işsizlik probleminin olduğu ve dolayısıyla ülkelerin yerli üretimden istihdam yolu ile fayda sağlayabildikleri varsayılmıştır. Üretim aşamasında bir miktar kirliliğin meydana geldiği ve bu kirliliği azaltmak için üretimi kısmaktan başka bir teknolojinin olmadığı kabul edilmiştir. Bunun yanında ülkeler arasında sınır ötesi kirliliğin bulunduğu, bu sebeple ülkelerin refahlarının hem yerli üretimin hem de yabancı üretimin sebep olduğu kirlilikten olumsuz etkilendiği varsayılmıştır. Her iki ülkenin de kirlilikten etkilenme oranlarının birbirleri ile eş olduğu ve yerli üretimden kaynaklanan kirliliğe daha fazla duyarlı oldukları da göz önünde bulundurulmuştur. Bu varsayımlar çerçevesinde ülkeler, refahlarını maksimum düzeye getirecek emisyon kotasını belirlemeye çalışmaktadırlar. Model iki aşamalı bir oyun olarak çözülmüştür. Birinci aşamada hükümetler eş zamanlı olarak kendi emisyon kotalarını belirlemiş daha sonra yerli firmalar oyunun ilk aşamasında belirlenen bu kirlilik kotalarını baz alarak kendi üretim miktarlarını belirlemişlerdir.

Modelin çözülmesi neticesinde elde edilen sonuçların, gerek değişken sayısının çokluğundan gerekse denklemlerin büyüklüğünden dolayı yorumlanması mümkün olmamıştır. Dolayısıyla daha sınırlı bir çerçevede geçerli olacak olsa da daha net ve güvenilir yorumlar yapabilmek adına simülasyon yoluna gidilmiştir. Pek çok deneme neticesinde modeldeki her bir değişken için bütün şartları yerine getiren ve yapılan varsayımlara uygun sayısal değerler atanmış ve çıkan sonuçlar yalnızca bu değerlere bağlı olarak yorumlanmıştır.

Sonuçlarda, işbirliğinin olmadığı durumda pazarın genişlemesinin hükümetlerin daha rahat bir politika uygulamasına yol açacağı buna karşılık işbirliği durumunda bu durumun tam tersi olacağı gözlenmiştir. Çünkü işbirliğini olmadığı durumda her iki hükümette pazardaki boşluğu doldurmak için yerli firmalarını teşvik etmek istemekte dolayısıyla da emisyon kota seviyelerini arttırmaktadırlar. Ancak işbirliği söz konusu olduğunda hükümetler, genişleyen pazarın taleplerini karşılamaya yönelik uluslararası rekabet ortamına rağmen karşılıklı olarak emisyon kotalarını düşürebilmekte ve dolayısıyla artan üretimin çevre üzerindeki baskını azaltabilmektedirler. Hem yerli firmanın hem de rakip ülkedeki firmanın sabit birim maliyetlerinde artış gözlendiğinde hükümetlerin uyguladıkları optimum politika düzeylerini serbestleştirdikleri sonucu elde edilmiştir. Bu durum işbirliğinin olduğu durumda da geçerli olmaktadır. Yerli firmanın üretim maliyeti arttığında, hükümetler üretimin azalmasının dolayısıyla da fiyatların artmasının önüne geçmek için emisyon kotalarını arttırmak istemektedirler. Çünkü bu teşvik sonucunda artacak olan çevresel baskı, üretici ve tüketici rantlarında ve istihdam düzeyinde yaşanacak olan kayıplara kıyasla daha düşük olmaktadır. Aynı şekilde, rakip ülkedeki firma, bir maliyet artışı ile karşılaştığında ve o ülkedeki hükümet benzer şekilde bir yol izlediğinde, diğer ülke hükümeti de kendi firmasının uluslararası pazardaki rekabet gücünü korumak için politika düzeyini rahatlatacaktır.

Çalışmanın ikinci aşamasında, modele çok uluslu bir şirket eklenerek çalışmanın kapsamı genişletilmiştir. Bu aşamadaki amaç yabancı sermayenin ev sahibi ülkenin ve rakip ülkenin çevresel politikaları üzerindeki etkisini incelemek ve bunları hem birbirleri ile hem de temel modeldeki sonuçlarla karşılaştırmaktır. Çok uluslu şirketin her iki ülkede de faaliyet göstermesini engellemek için yeterince büyük bir sabit maliyete sahip olduğu ve bu sabit maliyetin ülkelere bağlı olarak değişmediği varsayılmıştır. Bu sebeple firma iki ülkeden birini seçmek durumundadır. Çalışmada bu seçim kararının yalnızca ülkelerdeki yerli firmaların verimlilik düzeylerine bağlı olduğu varsayılmıştır. Dolayısıyla rekabetin daha az olması sebebiyle, çok uluslu şirket verimliliği daha düşük olan yerli firmaya sahip ülkede görece daha fazla kar elde etmekte ve yerleşim seçimini de bu yönde yapmaktadır. Çok uluslu şirket karının tamamını kendi ülkesine göndermekte dolayısıyla ev sahibi ülkenin refahına bu açıdan bir katkıda bulunmamaktadır. Bunların dışındaki tüm varsayımların ilk modelle eş olduğu göz önünde bulundurularak model yine iki aşamalı olarak çözülmüş ve optimum politika düzeyleri belirlenmeye çalışılmıştır.

Literatürde yabancı sermayenin ülkelerin çevresel politikaları üzerindeki etkisi adına pek çok farklı çalışma mevcuttur ve bu çalışmalar içeriklerine bağlı olarak bazen birbirleri ile çelişen sonuçlar da sunmaktadır. Kimi çalışmalar yabancı sermayelerin ülkeler arasında bir politika yarışına neden olduklarını ve neticede girdikleri ülkeleri çevresel açıdan yıkıma uğrattıklarını öne sürmektedir. Bu çalışmada yapılan varsayımlar altında ve kullanılan simülasyon değerleri sonucunda, çok uluslu şirketin girdiği ülkedeki emisyon değerini azalttığı ve buna bağlı olarak kirliliğin refah üzerindeki baskısını hafiflettiği görülmüştür. Ev sahibi ülke, çokuluslu şirketten kar elde etme kaygısı gütmediğinden politika uygulama gücünü arttırabilmiş ve bu gücünü, izin verilen emisyon düzeyini düşürerek kirliliği azaltma yolunda kullanılmıştır. Sonuçlar, çok uluslu şirketin ev sahibi ülkede yerli firmanın karından elde edilen üretici rantını ve nispeten gerçekleştirdiği verimli üretimden dolayı istihdam düzeyini azaltsa da bunların yanında kirlilik düzeyinde de önemli bir düşüş meydana getirdiğini göstermektedir. Çalışmada çok uluslu şirketin sadece ev sahibi ülkede değil, rakip ülkede de kirlilik düzeyinin azalmasına olanak sağladığı sonucuna ulaşılmıştır. Çünkü bu ülkedeki yerli firmanın diğer ülkedeki rakiplerine göre elde ettiği avantajlı konum, hükümetin daha rahat bir şekilde sıkı çevresel politika uygulamasına izin vermektedir. Neticede ülke refahı üretici rantı ve istihdam açısından daha iyi duruma gelirken aynı zamanda daha düşük emisyon kotaları sayesinde ülkedeki kirlilik düzeyi de azaltılabilmektedir. Çevrenin refah üzerinde yarattığı olumsuz baskı daha yüksek olsa da rakip ülkenin refah seviyesinin ev sahibi ülkeden daha yüksek olduğunu sonucuna ulaşılmıştır. Çünkü çok uluslu şirketin ev sahibi ülkede üretici rantını ve istihdam düzeyini azaltmasına karşılık rakip ülkedeki yerli firma daha fazla üretici rantına ve istihdama sebep olmakta ve bu kazançlar çevresel baskının neden olduğu olumsuz durumu telafi edebilmektedir.

Genişleyen pazarın ve birim maliyetlerde gözlenen artışın temel modeldeki ile benzer sonuçlara yol açtığı gözlenmiştir. Fakat temel modelden farklı olarak burada, ev sahibi ülkedeki emisyon düzeyinin rakip ülkedeki yerli firmanın maliyetinde meydana gelen değişikliklere karşı duyarsız olduğu görülmüştür. Bu durum, ev sahibi ülkedeki çok uluslu şirketin bu ülkenin politika düzeyi üzerindeki etkisinin çok büyük olması, dolayısıyla da rakip ülkedeki firmanın etkisini önemsiz hale getirmesi olarak yorumlanmıştır. Bunun yanında çok uluslu firmanın sabit birim maliyetinde meydana gelen bir artış işbirliğinin olmadığı durumda her iki ülkede de emisyon kotalarının arttırılmasına yol açmaktadır. Ev sahibi ülke çok uluslu firmanın artan üretim maliyetinden dolayı yaşanacak bir üretim kaybı ve buna bağlı olarak istihdam azalışı ve fiyat artışı durumlarını önlemek için politikalarını rahatlatır. Rakip ülke ise ev sahibi ülkedeki çok uluslu firmanın ve yerli firmanın bu politika düzeyindeki rahatlamadan dolayı elde edecekleri rekabet avantajının önüne geçmek ve kendi yerli firmasını uluslararası pazarda korumak için emisyon kota düzeyini arttırır. İşbirliği durumunda ise ev sahibi ülkede aynı durum söz konusu iken rakip ülkede, üretim artışının meydana getirdiği çevresel baskı üretimin diğer olumlu etkilerinin önüne geçmekte ve dolayısıyla hükümetin emisyon kota seviyesini düşürmesine yol açmaktadır.

Sonuçlar negatif dışşallıklar sebebiyle işbirliği yapmanın her iki modelde de ülkeleri her zaman daha iyi bir refah düzeyine çıkardığını göstermektedir. İşbirliği neticesinde ülkeler karşılıklı olarak emisyon kotalarını arttırmakta dolayısıyla artan üretim maliyeti neticesinde her iki ülkedeki üretim miktarları azalmaktadır. Azalan üretim üretici rantını ve istihdamı ve artan fiyatlar da tüketici rantını olumsuz etkilese de kirlilik seviyesinin refah üzerinde yarattığı baskıdaki önemli miktardaki düşüş, söz konusu bu kayıpları telafi edebilmekte ve refah seviyesini daha üst düzeye taşıyabilmektedir. Genişletilmiş modelde, işbirliği durumunda ev sahibi ülkenin refahında meydana gelen değişim çok daha fazla olsa da hala rakip ülkenin refah düzeyinin altında kalmaktadır. Ülkelerin refah düzeyleri arasındaki en önemli fark üretici rantından kaynaklanmakta ve her ne kadar işbirliği neticesinde azalan üretim her iki ülkede de üretici rantını düşürse de ev sahibi ülkedeki üretici rantı çok uluslu şirketin etkisiyle görece çok daha düşük düzeyde olmaktadır. Ortak bir eş politika belirlenen durumda ise ev sahibi ülkenin refahı hem en üst düzeye ulaşmakta hem de rakip ülke refahının da üstüne çıkmaktadır. Buna karşılık rakip ülke sadece işbirliğinin olduğu duruma göre daha düşük bir refah düzeyine gelmektedir. Buradaki temel farklılık istihdam düzeylerinden kaynaklanmakta ve bu sefer ev sahibi ülkenin istihdam düzeyi rakip ülkeden daha yüksek bir değere ulaşmaktadır.

1. INTRODUCTION

Governments use environmental policy instruments in order to combat environmental degradation and to reduce pollution caused by economic activities. Environmental regulations have different impacts on different firms. These effects can depend on factors such as firm size, relative efficiency, abatement technology or being incumbent or potential firm. It is generally discussed that severe policies lead to an increase in the production cost and thus they affect production adversely. However, regulations can be a potential advantage for the markets because they encourage firms to increase efficiency and develop new abatment technologies. Firms can adapt their operations in accordance with the applied policies so environmental policies should not be considered to be always against the producers.

It is generally claimed that trade liberalization has three main impacts on environment: (i) scale effect; (ii) composition effect; (iii) technique effect. Scale effect indicates increasing production to meet increasing demand created by international market while composition effect indicates the structure of this production depending on features of countries and industries. On the other hand, technique effect explains the technology impact with environmentally-friendly techniques on production activities. Therefore, the net effect of trade on environment depends on the weights of these effects (Barrett, 2000). Furthermore, governments can apply different types of trade and environmental policies to combat undesirable consequences of these effects and to balance their concerns for environment and international trade. As a result of the international trade, environmental regulations affect not only the welfare of the country in which they are imposed but also the rival countries' welfare. Governments may use these policies to make domestic firms more competitive in the international market and they can affect each other's policy decisions. In addition, environmental policies and trade policies can be applied to offset each other. For example, when governments set severe environmental policies, they can protect domestic firms in international market by using trade policies on foreign products (Xing and Kolstad, 1996).

Environmental regulations are seen one of the most important determinants for location decision of Foreign Direct Investment (FDI). Since the regulations can affect the production decision of firms and hence the market conditions, foreign investors try to locate in a country in which they can optimally benefit from such policies. On the other hand, these interactions are likely to be mutual, that is, FDI may also affect the government policy decisions. Since these investments can provide technology transfer, competitive environment, employment creation or decline in prices, governments may prefer to relax environmental standards in order to attract FDI. This can lead to international competition and policy racing of governments especially between the countries with high dependency on foreign capital. Countries arrange their policies in favor of FDI and for this purpose, they may set more liberal environmental policies. This situation lowers environmental standards and consequently causes a trade-off between to attract FDI and to risk of environmental damage. As stated by pollution heaven hypothesis, this points to create a competitive advantage and suitable investment environment for dirty industries by lowering environmental standards (Xing and Kolstad, 1996). Moreover, this case can be seen as an explanatory for the differences between environmental degradation of countries. It is stated that dirty industries move from developed countries with severe environmental standards to less developed countries with less severe environmental standards. Hence, such investments can cause destruction of the environment in these countries (Cole, 2004). In spite of all, it should not be ignored that foreign companies, which create more efficient and less environmentally polluting production compared to domestic firms, can spread their technologies to these countries and contribute to improve the quality of domestic production. Therefore, the net effect of FDI on the environmental status of countries is a very complex situation. Moreover, in some cases, these investments may lead not the liberalization of environmental standards but the tightening of them. In the case of high environmental awareness or lower return on foreign investment than the environmental losses, countries may want to set more severe policies / standards.

In this thesis, we develop a model in which there are two countries and each country has one domestic firm. The domestic firms produce a homogeneous product and they serve both domestic and foreign markets through intra-industry trade. Both countries are assumed to have unemployment and pollution problem. The pollution occurs during production and there is cross-border pollution between two countries. It is also assumed that the countries are more sensitive to the pollution caused by local production than the pollution caused by foreign production. In the extended model, there is a multinational company, which wants to invest in one of the countries with more inefficient domestic firm. We want to investigate the impact of the foreign direct investment on the environmental policies of countries.

1.1. Purpose of Thesis

In this thesis, we aim to analyze the difference in environmental policies of countries in the case of foreign direct investment (FDI) and cross-border pollution. To see the effect of entry of FDI on welfare, we compare the environmental policies of two countries also we compare the before and after policies of host country. Furthermore, we want to see the effects of changes in specific parameters on the equilibrium emission levels and we intend to examine the welfares of countries under the non-cooperative and cooperative behaviors.

1.2. Literature Review

In the literature review, the concept of environmental policy and the relationship between these policies and different market conditions are examined. Different policy instruments and their different impacts on the market and industry are also discussed. In addition, we investigate the changes in the industry structure and firms' decisions in terms of production or location caused by the policy level.

In the following section, we review the competition of countries to attract FDI and the factors affecting the location decision of these investments. The papers that discuss the impacts of FDI on the countries' environmantal policies are included. Then by adding the subject of trade, we expand the concept of study and we examine the effect of trade liberalization on the environment. Finally, intra-industry trade and FDI are discussed together in the presence of environmental concern. Both empirical and theoretical studies are examined and studies providing opposite results are evaluated.

1.3. The Motivation for Environmental Policy

Governments implement various emission restrictions on firms to combat pollution generated by production and they create interventionist impact on the amount of production. There are many policy instruments in terms of environmental protection but tradable emission permits (TEP) and Command and Control (CAC) are the most widely used. (Sartzetakis and Constantatos, 1995). It is claimed that the policy instruments with price mechanism (taxes or subsidies) give better results than the instruments with command and control mechanism. Although CAC programs are considered as greater restricter of emission, they include great information problems that make hard to implement right level of policy (Cropper and Oates, 1992). Similarly Lotspeich (1998) says that market-based approaches can handle the information problems of policy makers but even if it is cost-effective, CAC policy cannot be implemented efficiently without the information of the level of technologies and the marginal costs of firms. However if the market is competitive and there is fixed number of firms, these regulations provide similar results unlike the imperfect market conditions (Requate, 2005, Xing and Kolstad, 1996). Market-based systems provide the ability to control the quantity of emission for policy makers. On the other hand, permit systems have lower compliance cost so they are more preferable for both firms and policy makers (Cropper and Oates, 1992). In addition, while the CAC approaches restrict the firms' decision-making power, market-based approaches encourage firms to improve their abatement technologies and give them a freedom to determine their own abatement activities which provide less costly solutions (Lotspeich, 1998).

In their study, Sartzetakis and Constantatos (1995) develop a model in which two countries, North (N) and South (S), compete in international market with differentiated product. The government of country N applies CAC policy while the government of country S applies TEP policy. According to the results, the firms with low abatement cost make more abatement in country S than they do in country N because TEP regulations leads to more efficient abatement decisions if the technologies are not similar across the countries. Moreover, the firms under the TEP system can increase their market share more than their initial level while the firms under the CAC system have to decrease.

Environmental subsidies and taxes have different impacts on market conditions and emission level. Environmental taxes lead to increase in market prices more than subsidies do. Also, they result in a net transfer from producers to consumers. Furthermore, they reduce emission by restricting the amount of output, encouraging the technological innovations and forcing firms to adapt cleaner plants and to decrease their capacity utilization of polluting plants (Carraro and Soubeyran, 1993). While early studies indicate that subsidy per unit of emission reduction gives same results as setting tax per unit of waste discharge, now it is known that these policies have different impacts on economy. First of all, subsidy increases firms' profits while tax system reduces them also subsidy leads to an increase in the number of firms and output but tax system decreases market size. However, an increase in pollution is more likely to occur in a subsidy system (Cropper, Oates, 1992). Government subsidizes the using of clean technology in production as long as the environmental benefits exceed the environmental policy cost. If there is a limit for clean technology, environmental tax should be more preferable since it makes firms to choose less polluting plants, creates tax revenue and therefore increases the social welfare. Moreover, if the amount of polluting plants already used in production is high, the government should decide to imply environmental tax policy. However, if it is not preferred to restrict the amount of output, the government should choose environmental subsidies policy (Carraro and Soubeyran, 1993). Lahiri and Ono (2007) compare emission standard with tax under both fixed number of firms and free entry and exit. Under the assumption of fixed number of firms, an increase in tax leads to decrease in production by increasing the marginal cost but a decrease in emission standard does not affect the marginal cost so it does not cause any change in oligopolistic distortion. Therefore, a decrease in emission standard is better for welfare than an increase in emission tax. Under the assumption of free entry and exit, when the inverse demand function is concave, the results are the opposite.

In his study, Ulph (1996) found that the response of one producer to change in output of the rival producer in another country is higher when the government of that country uses emission taxes instead of emission standards. When both countries choose taxes, there are higher output and capital investment but lower profit and tax revenue. When countries choose different instruments, the firm that operates in the country with taxes will produce more output than the firm that operates in the country with standards. In addition, using taxes is better for welfares of the countries if the consumer surplus dominates the profits and emission taxes. This result conflicts with the Ulph's (1992) previous study that says that the use of standards is a dominant strategy. Furthermore, emission standards always have positive impact on firms by encouraging them to make innovations to reduce costs. In this way, firms can increase their profits and outputs while those of their rivals' remain unchanged. However, permits may have a negative impact on the decision of R&D since they lead to "spill over" effect for innovations in the market so firms and their rivals both can increase their profits and outputs. Therefore, standards encourage firms to invest in R&D more than permits do (Montero**,** 2002). Helfand (1991) examines the effects of five different forms of pollution standards (fixed level of emission, a fixed level of emission per unit of output, a fixed level of emission per unit of input, a fixed level of output, and a fixed level of input) on input, production and profits. According to the study, firms gain the highest profit and efficiency through the direct restriction on pollution but they can reach the highest production/output through the polluting-abating input. On the other hand, restriction on production or polluting input leads to highest reduction in production/output.

1.3.1. Environmental policies and industry

The main argument about the effects of environmental policies is that the strict emission standards deter entry of new firms to the market. This is because stricter policies lead to increases in production costs and make firms lose competitive edge. As a result, the production and output will decrease. By using data from U.S manufacturing sector in between 1967-1987, Greenstone (2002) finds that environmental regulations inhibit the production activities of polluting manufacturers in terms of job, capital stock and output. However, environmental quality can affect the consumption of products if there is a demand for clean product. In this case, the decrease in pollution in the industry may result in an increase in demand (Farzin, 2003). Besides, environmental standards have also productivity impact resulting from innovations. Therefore, regulations do not have to reduce the level of competitiveness of firms, instead they can encourage the firms to improve their resource utilization and production system so they can make them more competitive (Porter and van der Linde, 1995).

Millimet (2003) finds that if the pollution abatement intensity is low, the number of small establishments increase in industries with high state environmental abatement cost and decrease in industries with low state environmental abatement cost. This stiuation is opposite in the case of high pollution abatement intensity. The number of large establishments rises if there is high state environmental abatement cost and fall if there is low state environemntal abatement cost. He states that the optimal size of establishments increase in industries with the high pollution abatement intensity because the large establishments may choose to invest in abatement technology to deal with the pollution restriction. On the other hand, when there is low state environmental abatement cost, small firms may not find it profitable to invest in any abatement technology because they can benefit from their smaller size in the face of pollution restriction.

Sengupta (2009) investigates the effect of stringency of environmental regulation on industries with endogenous entry and exit. He states that an increasing in environmental regulations can cause differences in compliance cost and size of firms and also it has three effects on number of firms. First, it increases the market price and decreases the total output so the number of firms is affected adversely (direct effect). Second, it leads to an increase in average and marginal cost of firms that changes optimal scale and number of firms (direct effect). Finally, they encourage the firms to invest in cost reducing expenditures so the optimal scale of firms may be expanded and therefore the number of firms in market may be reduced (indirect effect).

1.3.2. Environmental policies and market structure

Environmental regulations can affect the market structure by changing the cost of production. Since the cost of productions are associated the profits of firms, they can affect incentives for the entry and exit of firms (Millimet et al., 2009). According to the theoretical analysis, in the case endogenous entry and symmetric firms, an increase in emission tax may cause similar effect if three conditions hold. First, since there is no feasible abatement technology for firms, they can reduce emission only by reducing output. Second, the demand function satisfies the concavity condition and lastly, firms do not interact with each other. Under these conditions, strict environmental restrictions deter entry of firms and increase market concentration if there is no any change in demand because of the improvement in environmental quality. On the other hand, in the case of emission standards with equilibrium number of firms, this effect is ambiguous (Millimet et al., 2009). Kohn (1997) argues that the Pigouvian tax reduces the total output but when there is a decreasing return to scale in abatement, the number of firms is less influenced by this reduction of total output. However if there is an increasing return to scale in abatement, the total output of polluting firms and the number of firms may increase with emission tax. The reasons are that the demand increases as a result of reduction in price and the productivity of firms may dominate the decreasing in output caused by producing at a smaller scale.

Environmental regulations discourage new firms to enter into the market by raising the cost, increasing capital for new operations or facilities for pollution intensive industry. However, these regulations can be a potential advantage for firms. In some cases, strict regulations are in favor of small firms due to the effective abatement technology or capability of easily adapting these regulations thanks to firm's scale (Dean and Brown, 1995). Moreover, when they have a new abatement technology, incumbent firms may have a request for increasing environmental regulation to make their rivals more costly. In this way, they can reduce their own costs and have a competitive advantage while their rivals have a barrier to entry (Dean and Brown, 1995; Millimet et al., 2009, Levinson, 1996). Even if their own cost increase, the efficient firms can benefit from stricter regulations in terms of their competitors' costs (Denicolo, 2008). Helland and Matsuno (2003) found that strict environmental regulations cause an increase in entry barrier to the market and the largest firm is better off with the tough regulations. Hence, the environmental regulations create more intense market by decreasing competitiveness. Similarly, in their study, Schoonbeek and de Vries (2008) say that the incumbent firm may want to high level of emission standard so that the potential entrant (the rival firm) has to face with an entry barrier. The government also may want to impose a high level of emission tax since it causes a decrease in market competition and therefore a less environmental damage.

Lahiri and Symeonidis (2007) search that multilateral environmental policy under asymmetric oligopoly in two countries. According to the results, in the case of no product differentiation and similar pollution intensity, an increase in emission tax in one of the countries decreases total emissions. On the other hand, if one of the countries has more pollution-intensive technology, an increase in emission tax in the country, which has less pollution-intensive technology, may leads total emission to increase. In addition, an equal increase in emission taxes reduces the global emissions under different assumptions. In the case of free entry and exit, an increase in emission tax in one country can increase global emissions but not depending on the difference between pollution intensities as in the first case, rather depending on change in the number of firms thereby the number of outputs. They conclude the analysis by saying that the asymmetry cannot be an excuse for country to be not involve any multilateral agreement on environment. Carrora and Soubeyran (1996) search for the effects of environmental taxation in oligopoly. They find that unlike the case of perfect competition or monopoly, an increase in emission tax does not always decrease the firms' profits in oligopoly, some firms may increase their profits while others profits decrease.

Katsoulacos and Xepapadeas (1996) show that for both monopoly and fixed number oligopoly, the optimal emission tax is lower than the marginal external damages of pollution but under imperfect competition, the optimal emission tax increases as the number of firms increase. When there is free-entry, the optimal tax rate may be higher than the marginal external damages. If the abatement cost and fixed cost are small enough, the optimal tax is close to the marginal external damages because tax rate will increase due to the reduction in output distortion caused by increasing number of firms. Similarly, Gautier (2013) analyzes the impact of emission tax and abatement subsidy in a two-country model. The result says that the multilateral equal increase in subsidy leads to increase in emission in both the home country and the foreign country, also in the case of product differentiation, the increase in global emission is greater than the former situation. On the other hand, under the unilateral equal increase in subsidy and tax, the effect of tax is balanced by the effect of subsidy. Moreover, under the product differentiation the emission effect on foreign country is small so the global emission level may decrease becasue an increase in tax (reduction in emission) dominates the increase in subsidy (increase in emission).

1.3.3. Environmental policies and plant location

Since there are many factors affecting the decision of location (to access to resources or markets, transportation costs, labor market, political condition etc.) and some of these factors cannot be related to the environment, many researchers may not find a significant evidence to support the relationship between the locational decision of firms and environmental standards (Xing and Kolstad, 1996). However, there are some studies that can be considered as evidence for this relationship (Dean and Brown, 1995; Gray, 1997; List and Co, 2000; Jeppesen et al., 2002; Gray and Shadbegian, 2002). Some researches show that the environmental regulations are one of the determinants for location choice of FDI and there is a negative relationship between FDI and tough environmental regulations (Xing and Kolstad, 2002; Waldkirch and Gopinath, 2008; Kalamova and Johnstone, 2011).

In addition, some firms may prefer to shift their existing plants rather than to open a new plant because of the regulations. The reason is that the impact of regulations can be larger for new plants since they are more likely to be strict for new plants and protective (grandfathered) for existing plants. Hence the birth of new plants is more sensitive to these regulations than the deaths of existing ones (Gray and Shadbegian, 2002, Levinson, 1996, Tannenwald, 1997). Similarly, Gray (1997) says that the plant births have a negative relationship with the strict regulations so new plants are more likely to locate in places with lax environmental regulations. He argues that these regulations seem to have similar impacts on both polluting and non-polluting industries. Moreover, Levinson (1996) states that the locational decision of plants of large firms is more affected by string environmental regulations than the other firms. On the other hand, he says that there are little evidence to support that strict regulations deter opening of new plants. The reason is that firms may think that to adapt their production system according to most stringent regulations is less costly than to adapt different production systems for different locations.

1.3.4. Environmental policies and trade

Trade liberalization has three main effects on environment. Since it causes to redistribution of resources and production based on the comparative advantages, it increases output level. This increase in output is called scale effect and the reallocation of production is called composition effect. Finally, it may lead to more efficient and environmental production system, which is called technique effect. The net effect of trade liberalization on the environment is determined based on the weights of these three effects (Barrett, 2000). Furthermore, trade liberalization is criticized on three main points regarding the environmental issues. First, it is claimed that trade liberalization exacerbates the existing environmental damage. Second, it causes to decrease in countries' environmental standards in order to attract foreign investments since firms are allowed to export their products to the countries with high environmental standards by trade liberalization. Finally, it is said that WTO gives priority to the interests of trade rather than the environmental concern (Neumayer, 2000).

The environmental standards vary across the countries but the costs of pollution abatement also vary across the countries depending on their infrastructure, technology or factor prices. Hence, under the assumption that there is no transboundary externalities and these standards are locally optimal; the differences between countries' environmental standards should not create too much problem (Brunnermeier and Levinson, 2004). However, it is also claimed that even if the resources are efficiently allocated and the management of environment is optimum, trade liberalization can lead to depletion of resources and environmental damage (Neumayer, 2000). Moreover, there are other factors affecting comparative advantages in polluting industries (assimilative capacity, demand for environmental goods, property rights etc.) so setting common environmental policies across countries may not be enough to reduce differences in terms of competitiveness in industries with strict environmental regulations (Xing and Kolstad, 1996). Moreover, when the globalization increases, the cost of sub-optimal environmental policy rises because of the more competitive international market (Neary, 2006). On the other hand, Cropper and Oates (1992) claim that domestic environmental standards do not have important effects on international competitiveness and trade. Hence, there is no need to compete for relaxing environmental policies.

Cole and Elliott (2003) say that the effect of trade liberalization on the environment depends on the comparative advantages of countries determined by factor endowment and income. These country specific features affect the level of environmental regulations applied by governments. Environmental Regulation Effect (ERE) implies that the countries with less strict standards have comparative advantages in pollution-intensive production so; they can specialize in dirty industries. Eventually they become a pollution heaven while the countries with more strict standards specialize in clean industries. On the other hand, Capital–Labor Effect (KLE) focuses on the factor endowments of countries and it implies that the countries with more capital endowments specialize in capital intensive (relatively pollution intensive) sectors while the countries with more labor endowments specialize in labor intensive (clean) sectors (Cole and Elliott, 2003). For example, high-income countries may seem to be moving away from a material involved economy. In fact, these countries become relatively dematerialized as they export material-intensive stages of their production to the low-income countries (Roberts and Parks, 2007). In his study, Copeland (2000) analyzes the trade liberalization and environment. According to the results, trade causes to shift some pollution from rich country to poor country by changing relative price of polluting good. In the case of tariffs and pollution taxes, government should choose trade policy to protect polluting industry rather than weak environmental policy. The reason is that the trade policy is more efficient while the weak environmental policy is more distortionary. If there are externalities, the trade policy should be implemented as a second-best trade policy to protect environment. Duval and Hamilton (2002) developed a model with asymmetric consumption, production and pollution diffusion across countries. They found that in the case of asymmetric production cost, the optimal cooperative environmental tax policy is non-harmonized across countries but in the case of same production cost, this policy is harmonized even if the other asymmetries hold. For the non-cooperative situation, the optimal environmental tax policy depends on three effects: terms of trade, imperfect competition and pollution leakage.

1.4. The Motivation for FDI

Globalization allows capital to move across borders and settle in the place that will bring the most profit. This mobility of capital creates significant impacts on the economies and policy decisions of countries and it takes place in many different ways. Foreign investments is one of the most common capital flows and they can be examined in many different headings. FDI (foreign direct investment) is one of these headings and it can start a race between countries to attract investment due to its effects on welfare. The reason of this competition is the benefits provided by FDI like technology transfer, substituting imports, creating export revenues and new jobs (Barros and Cabral, 2000). In addition, they can decrease the price of goods; also, they stimulate competition in the local economy by creating demand for inputs and labor. On the other hand, they may harm to the domestic firms especially when the domestic firms are inefficient compared to the foreign firms. In this case, governments should consider three main points; the cost-benefit analysis for FDI, the situation of domestic firms and the non-tax instruments to increase the advantageous of FDI (Lahiri and Ono, 1998).

There are many studies studying the competition amongst countries to attract FDI and factors affecting locational decision of foreign investment. Bjorvatn and Eckel (2006) study policy competition for FDI. If there are high trade costs, the country without local firm attracts FDI because of the protected and less competitive national market also due to the higher willingness to pay for the investment; the policy competition makes this country more attractive to invest. On the other hand, if trade costs and market size effects are balanced, the argument that affects the locational decision will be subsidy. Barros and Cabral (2000) show that if two asymmetric countries offer zero subsidy, the large country attracts foreign firm because of the transportation cost but if countries are the same size then the foreign firm chooses the country which offers higher subsidy. Moreover, if employment gain is small, FDI chooses the large country to locate but if employment gain is large, FDI chooses the small country to locate because in this case, the large country wants to equilibrium with subsidy competition instead of the first-best solution. Similarly, Fumagalli (2003) analyzes the effect of subsidies on the competition to attract FDI. The countries benefit from FDI through the technological spillover. According to the results, if there is a strong spillover, the country with less efficient firm is always willing to offer higher subsidy. When there is export as an alternative to FDI and the trade costs are high, the welfare of both countries are more likely to decrease with the allowing subsidies because of the weaker competitiveness of domestic firms. In addition, Haaparanta (1996) finds that develops high wage countries can increase their foreign investment rates because subsidies can be raised more quickly in the high wage countries than in the low wage countries. Moreover, these high subsidies can eliminate the negative impact of high wage on firms' production costs. On the other hand, Görg et al. (2009) research the relationship between tax competition, social expenditure and FDI. They claim that the location decision of MNC (Multinational Corporation) is affected by not only the level of tax but also by what the governments do with tax revenues. They analyze 18 OECD countries for the period of 1984-1998 and they found that the corporate tax does not necessarily have a negative effect on MNC rather it can promote more convenient economic environment for MNC.

When there is unemployment in countries, the country with larger gap between wage and shadow price of labor attracts investment. Since the larger country has a larger job creation effect, this country becomes more willing to subsidy (Bjorvatn and Eckel (2006). Lahiri and Ono (1998) say that if FDI is inefficient and there is small number of domestic firms, the employment effect will be high but if FDI is efficient and there is an oligopolistic market in the host country, the price-lowering effect will be high. Moreover, if the number of domestic firms is low and FDI is more efficient when they use inputs from home country, government has more incentive to attract investment because of the consumer surplus and the price-lowering effect so it does not apply any restriction on local content. However, if the market is already competitive and so the price-lowering effect of FDI is unimportant, the government may choose the high level of local content requirement. Finally, Brander and Spencer (1987) show that if the host country suffers from high unemployment, the government imposes reasonable tax policy and disincentive tariff policy so that the foreign firm prefers to invest in that country rather than exporting.

1.4.1. Competition for FDI in the presence of environmental policies

One of the preferred ways for countries to attract investment is to create a comparative advantage by decreasing environmental standards. In some cases, this situation leads to environmental improvements and economic growth in some countries like Northern countries but also it leads to environmental destruction and economic blockage in other countries like Southern countries (Muradian and Martinez-Alier, 2001). The reason is that, the extraction and production operations controlled by transnational capital is generally less eco-efficient in less developed countries since they consume more energy, creates more waste and destroy natural resources (Jorgenson, Dick and Shandra, 2011). These transnational corporations can benefit economically from the moving their environmental cost created by ecologically harmful production system to the other countries. Moreover, they can hide more easily the environmental consequences of their operations from the public and consumers (Jorgenson, Dick and Shandra, 2011). Jorgenson (2009) found that between 1975 and 2000, the total carbon dioxide emissions and carbon dioxide emissions per unit of production have a positive relationship with the foreign direct investment in the secondary sector in less developed countries. Hence, he claims that the manufacturing industry controlled by foreign capital in those countries is less eco-efficient so it is more likely to damage to the environment. For instance, considering the amount of emission intensity per output, the emission intensity in Southern countries is about five times higher than in Northern countries (Grether, Mathys and Melo, 2007).

As a result of this competition to attract or keep FDI, countries may feel pressure on them to reduce their environmental standards so this situation causes to the *race to the bottom* in terms of environmental regulation (Neumayer, 2000). To examine FDI flows, Kalamova and Johnstone (2011), analyzed the data from 27 OECD source countries and 99 host countries for between 2001 and 2007. According to the results, there is an inverse U-shape relation between the lax environmental standards and FDI inflows for both developed and developing countries. They interpret this situation by saying that when the environmental standards fall below a certain level, countries lose their ability to attract investments. Accordingly, Lee et al. (2014) build a model in which two countries (North and South) compete to attract two MNFs. They show that the location decisions of firms are affected by the fixed costs, the technology spillover and the environmental policies of countries. Although the lax environmental policy in developing countries can attract MNC to locate, if the fixed costs of firms are low enough, a continuous reduction in environmental standards eventually does not influence the decision of MNC. In addition, Ohori (2011) analyzes the environmental policy instruments and foreign ownership. He finds that when the number of domestic firms increases, the environmental standards become more severe and the environmental tax decreases. In addition, for both environmental tax and environmental standards, foreign ownership restriction leads to mitigate the environmental policies and improve welfare.

Waldkirch and Gopinath (2008) found a positive relationship between FDI inflows into Mexico and pollution from sulfur dioxide, which is a highly regulated pollutant. They say that lax environmental regulations may have an ability to attract foreign investment so these regulations do not have to deter FDI by making emission intensity lower. Similarly, in their study, Xing and Kolstad (2002) search the relationship between US FDI and environmental regulations of foreign host countries for several industries. They found that the environmental regulations are one of the determinants for location choice of FDI and there is a negative relationship between FDI and tough environmental regulations especially for pollution-intensive industries such as chemical and metal. Therefore, some countries develop clean production system while others specialize pollution-intensive production. These results can be an interpretation for a pollution heaven hypothesis, which indicates the relocation of pollution based on the difference between environmental regulations of countries. Pollution haven hypothesis states that differences in environmental regulations and standards between countries provide comparative advantage to some countries in pollution-intensive industry. This argument is also called Industry Flight Hypothesis (Xing and Kolstad, 1996) and it creates an alternative space for transnational corporations who want to reduce their environmental costs also it gives an alternative explanation for EKC hypothesis that suggests that there is an inverted-U relationship between income and pollution. Since, pollution does not decrease because of increasing income rather it is shifted to other countries through the transportation of production (Cole, 2004). Another important evidence for the relationship between location decision of FDI and environmental regulations is that the rate of pollution in developing countries where the pollution restrictions are generally mitigated has reached the highest level in the period that OECD countries have tightened their environmental standards (Cole, 2004). Furthermore, researches show that many OECD countries are net importers of carbon-intensive goods from developing countries while they tend to be exporter in service sectors like banking, tourism, advertising, sales, design and distribution (Parks and Robert, 2008).

To see the impacts of FDI on the environmental policy in the presence of intra-industry trade and cross-border pollution, we develop a benchmark model and an extended model. In the benchmark model there are two countries and each country has one domestic firm. The domestic firms produce a homogeneous product and they serve both domestic and foreign markets. Both countries are assumed to have unemployment and pollution problem. In the extended model, there is a multinational company, which wants to invest in one of the countries with more inefficient domestic firm. It is assumed that MNC fully repatriates its profit to the source country so the host country can not benefit from MNC through the producer surplus. In this study, due to the excess of variables and the size of equations, the results are difficult to interpret. In order to have clearer results we have to make a simulation and determine appropriate values for parameters with respect to our assumptions and second order and stability conditions. Based on these simulation values, we find that when there is a MNC in the market, the host country and rival country always set stricter environmental policy.

The negative effect of pollution on welfare decreases in both countries but the decline is much more in the host country since it applies more severe policy than the rival country does. On the other hand, the rival country is in a better position in terms of welfare because of the advantageous situation of its domestic firm. Finally, the results show the cooperative behaviour always results in a higher level of welfare for both countries.

2. TRADE AND ENVIRONMENT

Environmental policies and trade policies can be applied to offset each other. When the trade policy is restrained, the environmental policies should be less severe or when the environmental policy is restrained, tariff will improve welfare. Furthermore, if one of these instruments cannot be increased (decreased) to be close its optimal level then the other one should be decreased (increased) from its optimal level (Neary, 2006). Nannerup (1998) finds that the incentives of governments to capture foreign rent decreases less when they use environmental standards as a policy instrument rather than subsidies. It is claimed that since they can lead to deviation on trade, to impose trade instruments (tariffs or sanctions) should not be preferable way instead; the governments should choose to apply trade policy to create effective mechanism to control pollution. However, governments, which put domestic firms in a disadvantageous situation in terms of international competition by imposing strict environmental policy, may choose to apply trade sanctions on other countries' firms to ensure equivalence (Xing and Kolstad, 1996). Barrett (1994) shows that if domestic market is a monopoly and foreign market is imperfectly competitive, domestic government chooses to impose weak environmental standards. However if domestic market is oligopoly and foreign market is perfectly competitive, environmental standards become stronger. In addition, under price competition (Bertrand), governments set stronger standards compared to quantity competition (Cournot).

An increase in pollution control costs of domestic firms leads to a reduction in international market share and also it increases the amount of imported polluting goods. On the other side, the differences between abatements technologies can eliminate the differences between environmental regulations of countries, if there is an efficient regulatory regime. In this way, the competitive disadvantageous arising from strict regulations can be dominated and international market share can be increased with better environmental conditions (Sartzetakis and Constantatos, 1995). While to adapt cleaner technology increases fixed costs, other abatement activities influence variable costs of firms hence the environmental regulations can affect market price and total output. An increase in fixed cost raises the cost of entry into markets and discourages firms from innovations so decreases the variety of domestic products. However, it results in a lower price so the competitiveness of domestic firms in international market increase. On the other hand, an increase in variable cost deteriorates the international market share of domestic firms by increasing price and decreasing output (Haupt, 2006). If the marginal benefit of abatement is lower than the marginal cost of pollution control, the welfare will be better off as the government relax the environmental standards (Cropper, Oates, 1992).

Conrad (1996) shows that when there are two countries and international homogeneous product duopoly, governments have an incentive to implement emission tax rate below the marginal damages. The reason is that if the tax rate is high, there will be a reduction in consumer's surplus because of the increasing price. In addition, governments want to ensure the competitiveness of domestic firms against the foreign firms in the both domestic and international markets. Finally, they want to offset the amount of pollution and abatement activities between the countries (transboundary externality effect). Kayalica and Kayalica (2005) find that under the assumption of transboundary pollution, if there is a higher disutility of pollution or less efficient firms, government sets higher consumption tax and lower tariff rates. On the other hand, if there is a larger demand, government sets lower consumption tax and higher tariff rates. In the case of cross border pollution, the changes in foreign country's spill-over affect home country's pollution indirectly through the emission taxes so to increase equally the spill-over parameters of both countries gives better results in terms of pollution and welfare for both countries (Hatzipanayotou et al., 2008).

In this section, we develop a benchmark model to analyze the optimal environmental policies of countries in the presence of intra-industry trade and cross-border pollution. We aim to investigate welfare conditions and policy level decisions of countries under non-cooperative and cooperative behaviors.

2.1. The Benchmark Model

In our model, there are two countries, labelled A and B. Each country has one domestic firm. The domestic firms produce a homogeneous product and they serve both domestic markets and foreign markets. It is assumed that there is an intra-industry trade between the countries. All firms have constant marginal (average) cost and constant per unit cost. The inverse demand functions for the good are given by[1]

$$\mathrm{pa} = \alpha - \mathrm{b.Da} \qquad \textbf{(2.1)}$$

$$\mathrm{pb} = \alpha - \mathrm{b.Db} \qquad \textbf{(2.2)}$$

where *pa* and *pb* are the prices in each country. The firm in country A produces *qa* for the consumption of local market and *qax* for export to the country B. Similarly, the firm in country B produces *qb* for the consumption of local market and *qbx* for export to the country A. Hence, the total demands of countries consist of the demand for local production and the demand for exported product. These are given by

$$\mathrm{Da} = \mathrm{qa} + \mathrm{qbx} \qquad \textbf{(2.3)}$$

$$\mathrm{Db} = \mathrm{qb} + \mathrm{qax} \qquad \textbf{(2.4)}$$

Profit of each firm is given by π

$$\pi\mathrm{a} = (\mathrm{pa} - \kappa\mathrm{a}).\mathrm{qa} + (\mathrm{pb} - \kappa\mathrm{a}).\mathrm{qax} \qquad \textbf{(2.5)}$$

$$\pi\mathrm{b} = (\mathrm{pb} - \kappa\mathrm{b}).\mathrm{qb} + (\mathrm{pa} - \kappa\mathrm{b}).\mathrm{qbx} \qquad \textbf{(2.6)}$$

where *κa* and *κb* are the constant marginal (average) cost of domestic firms in country A and B. These are given by

$$\kappa\mathrm{a} = \mathrm{ca} + \mu.(\theta\mathrm{a} - \mathrm{za}) \qquad \textbf{(2.7)}$$

$$\kappa\mathrm{b} = \mathrm{cb} + \mu.(\theta\mathrm{b} - \mathrm{zb}) \qquad \textbf{(2.8)}$$

where *ca* and *cb* are the constant per unit cost determined by technological and factor market conditions, *θa* and *θb* are the gross pollution before abatement, *za* and *zb* are the maximum quantity of allowed pollution for per unit of output that the firms are allowed to emit into the atmosphere. μ is the constant unit abatement cost and we assume that this is equal for both countries.

[1]The inverse demand functions are derived from the quasi-linear utility function $U(D^a, D^b, y) = \alpha^a D^a + \alpha^b D^b - [\beta^a D^{a^2} + \beta^b D^{b^2} + 2\gamma D^a D^b]/2 + y$, where y is the consumption of the good.

The firms are assumed to behave in a Cournot–Nash. The first order profit maximizing conditions are found as

$$\mathrm{b.qa} = \mathrm{pa} - \kappa\mathrm{a} \qquad \mathrm{b.qax} = \mathrm{pb} - \kappa\mathrm{a} \tag{2.9}$$

$$\mathrm{b.qb} = \mathrm{pb} - \kappa\mathrm{b} \qquad \mathrm{b.qbx} = \mathrm{pa} - \kappa\mathrm{b} \tag{2.10}$$

By using (2.1) (2.2) and (2.9) (2.10) when the closed form solutions are solved, we find the output and price as

$$\mathrm{qa} = \mathrm{qax} = \frac{\alpha - 2\kappa\mathrm{a} + \kappa\mathrm{b}}{3\mathrm{b}} \tag{2.11}$$

$$\mathrm{qb} = \mathrm{qbx} = \frac{\alpha - 2\kappa\mathrm{b} + \kappa\mathrm{a}}{3\mathrm{b}} \tag{2.12}$$

$$\mathrm{pa} = \mathrm{pb} = \frac{\alpha + \kappa\mathrm{a} + \kappa\mathrm{b}}{3} \tag{2.13}$$

Differentiating equation (2.11) and (2.12) we obtain

$$\mathrm{dqa} = \mathrm{dqax} = \frac{2\mu}{3\mathrm{b}}\,\mathrm{dza} - \frac{\mu}{3\mathrm{b}}\mathrm{dzb} \tag{2.14}$$

$$\mathrm{dqb} = \mathrm{dqbx} = -\frac{\mu}{3\mathrm{b}}\mathrm{dza} + \frac{2\mu}{3\mathrm{b}}\,\mathrm{dzb} \tag{2.15}$$

Each firm will increase (decrease) its production for both local market and foreign market when it is allowed to emit more (less) pollution or its rival firm in other country is allowed to emit less (more) pollution. As expected, the firms are more sensitive to their own country's policy than the rival country's policy.

Totally differentiating the profit functions we get

$$3\mathrm{b}\;\; \mathrm{d}\pi\mathrm{a} = 8\mu.\mathrm{qa}\,\mathrm{dza} - 4\mu.\mathrm{qa}\,\mathrm{dzb} \tag{2.16}$$

$$3\mathrm{b}\;\; \mathrm{d}\pi\mathrm{b} = -4\mu.\mathrm{qb}\,\mathrm{dza} + 8\mu.\mathrm{qb}\,\mathrm{dzb} \tag{2.17}$$

As in Brander and Spencer (1987) and Lahiri and Ono (1998), we assume that there is an unemployment problem in both countries. The variable inputs costs of local production provide income related to job creation for country's welfare. Therefore, countries can benefit from the employment and profits generated by domestic firms however, they both dislike pollution. It is assumed that pollution occurs during production and there is cross border pollution between two countries. It is also assumed that the countries are more sensitive to the pollution caused by local production than the pollution caused by foreign production.

The welfare functions of country A and B are given by Wa and Wb, respectively, as:

$$\mathrm{Wa} = \frac{(\alpha - \mathrm{pa})^2}{2\mathrm{b}} + \pi\mathrm{a} + \mathrm{ca}.(\mathrm{qa} + \mathrm{qax}) - \phi 1.(\mathrm{qa} + \mathrm{qax}).\mathrm{za} - \phi 2.(\mathrm{qb} + \mathrm{qbx}).\mathrm{zb}$$

(2.18)

$$\mathrm{Wb} = \frac{(\alpha - \mathrm{pb})^2}{2\mathrm{b}} + \pi\mathrm{b} + \mathrm{cb}.(\mathrm{qb} + \mathrm{qbx}) - \phi 1.(\mathrm{qb} + \mathrm{qbx}).\mathrm{zb} - \phi 2.(\mathrm{qa} + \mathrm{qax}).\mathrm{za}$$

(2.19)

The welfare function of each country consists of five terms. First term is the consumer surplus, second term is the profit gain generated by domestic firms, third one is the employment effect and the last two terms are the disutility of pollution generated by local production and foreign production. $\phi 1$ and $\phi 2$ are the marginal disutility of pollution caused by local and foreign production and both are assumed to be constant.

Totally differentiating the profit functions we get

$$3\mathrm{b}\ \ \mathrm{dWa} = \mathrm{A1}.\mathrm{dza} + \mathrm{A2}.\mathrm{dzb} \qquad \textbf{(2.20)}$$

$$3\mathrm{b}\ \ \mathrm{dWb} = \mathrm{A3}.\mathrm{dza} + \mathrm{A4}.\mathrm{dzb} \qquad \textbf{(2.21)}$$

where

$$\mathrm{A1} = 4\mu.\mathrm{ca} + \mathrm{b}\mu.\mathrm{Da} + \mathrm{b}.(4\mu - 3\phi 1).(\mathrm{qa} + \mathrm{qax}) - 2\mu.(2\phi 1\mathrm{za} - \phi 2\mathrm{zb})$$

(2.22)

$$\mathrm{A2} = -2\mu.\mathrm{ca} + \mathrm{b}\mu.\mathrm{Da} - \mathrm{b}.\big(2\mu.(\mathrm{qa} + \mathrm{qax}) + 3\phi 2.(\mathrm{qb} + \mathrm{qbx})\big) - 2\mu.(-\phi 1\mathrm{za} + 2\phi 2\mathrm{zb})$$

(2.23)

$$\mathrm{A3} = -2\mu.\mathrm{cb} + \mathrm{b}\mu.\mathrm{Db} - \mathrm{b}.\big(3\phi 2.(\mathrm{qa} + \mathrm{qax}) + 2\mu.(\mathrm{qb} + \mathrm{qbx})\big) - 2\mu.(2\phi 2\mathrm{za} - \phi 1\mathrm{zb})$$

(2.24)

$$\mathrm{A4} = 4\mu.\mathrm{cb} + \mathrm{b}\mu.\mathrm{Db} + \mathrm{b}.(4\mu - 3\phi 1).(\mathrm{qb} + \mathrm{qbx}) - 2\mu.(-\phi 2\mathrm{za} + 2\phi 1\mathrm{zb})$$

(2.25)

A1 and A3 represent the effect of each government's environmental policy on its own welfare. A2 and A4 represent the externalities, which show the effect of one government's environmental policy on the other country's welfare.

2.1.1. Non-cooperative solution

In the first case, we consider that governments act in a non-cooperative game. There is a two-stage game in which first the governments determine the pollution quota and then the domestic firms determine their output levels based on the pollution quotas taken from the first stage of the game.

To assure the concavity conditions are hold, we need to show that the welfare functions of countries are concave in za and zb. The conditions are found as

$$\mu.(17\mu - 24\phi 1) < 0 \qquad \textbf{(2.26)}$$

Therefore, the concavity conditions hold if

$$17\mu < 24\phi 1 \qquad \textbf{(2.27)}$$

In addition, we have to assure the stability condition. The condition is given by

$$\mathrm{Wza(za).\,Wzb(zb)} - \mathrm{Wza(zb).\,Wzb(za)} > 0 \qquad \textbf{(2.28)}$$

$$12\mu^2.(4\mu - 5\phi 1 - \phi 2).(5\mu - 9\phi 1 + 3\phi 2) > 0 \qquad \textbf{(2.29)}$$

The stability condition holds if

$$4\mu < 5\phi 1 + \phi 2 \ \text{ and } \ 5\mu < 9\phi 1 - 3\phi 2 \qquad \textbf{(2.30)}$$

Setting A1 and A4 equal to zero, we find the countries' non-cooperative policy instruments as

$$\begin{aligned}\mathcal{F}\,\mathrm{za}^{\mathrm{N}} = {} & 2\alpha.(3\phi 1 - 5\mu).(-4\mu + 5\phi 1 + \phi 2) + \mathrm{ca}.(6\mu^2 + 6\phi 1.(7\phi 1 - \phi 2) - \\ & (40\phi 1 - 7\phi 2).\mu) - \mathrm{cb}.(14\mu^2 + 12\phi 1.(\phi 1 - \phi 2) - (26\phi 1 - \\ & 5\phi 2).\mu) + \mu\theta\mathrm{a}.(40\mu^2 + 6\phi 1.(7\phi 1 - \phi 2) + (7\phi 2 - 88\phi 1).\mu) - \\ & \mu\theta\mathrm{b}.(12\phi 1.(\phi 1 - \phi 2) - (14\phi 1 - 17\phi 2).\mu)\end{aligned}$$

(2.31)

$$\mathcal{F}\,zb^{N} = 2\alpha.(3\phi1 - 5\mu).(-4\mu + 5\phi1 + \phi2) - ca.(14\mu^2 + 12\phi1.(\phi1 - \phi2) - (26\phi1 - 5\phi2).\mu) + cb.(6\mu^2 + 6\phi1.(7\phi1 - \phi2) - (40\phi1 - 7\phi2).\mu) - \mu\theta a.(12\phi1.(\phi1 - \phi2) - (14\phi1 - 17\phi2).\mu) + \mu\theta b.(40\mu^2 + 6\phi1.(7\phi1 - \phi2) - (88\phi1 - 7\phi2).\mu) \tag{2.32}$$

where

$$\mathcal{F} = 2\mu.(4\mu - 5\phi1 - \phi2).(5\mu - 9\phi1 + 3\phi2) \tag{2.33}$$

Due to the excessive variables and the size of equations, these and following result are difficult to interpret. In order to have better results we have to determine appropriate simulation values for parameters with respect to our assumptions, second order conditions and stability conditions. After many long-term studies, we assign the following values providing all the necessary conditions. Table 2.1 represents these simulation values and the ranges of possible values for parameters that will be used to observe the effect of the change in parameters on the optimal policies.

Table 2.1 Simulation values and ranges for parameters

Parameters	Values	Range of possible values	
		Min	Max
α	14.0	13.0	14.0
b	0.7	0.6	0.75
ca	2.013	2.0125	2.02
cb	2.012	2.0122	2.0128
θa	8.013	8.0125	8.02
θb	8.012	8.0119	8.0129
μ	1.02	1.02	1.03
ϕ1	1.15	1.12	1.155
ϕ2	0.4	0.39	0.405

For all domestic firms in both country A and B, the intercept (α) and the slope (b) of the demand function are assumed as 14 and 0.7 respectively. The domestic firms differ with respect to their constant per unit costs that are assumed as 2.013 and 2.012 for ca and cb. The firm in country A is assumed to be less efficient compared to the firm in country B. Based on this, is it also assumed that the firm in country A produce more pollution than the firm in country B so the gross pollutions before abatement are posited as 8.013 and 8.012 for θa and θb, respectively. The maximum values of the constant per unit cost and the level of gross pollution of firm in country B is always lower than the accepted value of the firm in country A. Therefore, the ranges of possible values are determined based on these assumptions. We also assume that the disutility of pollution generated by domestic production, $\phi 1$, is always higher than the disutility of pollution generated by foreign production, $\phi 2$, due to the decaying effect with distance from the source of transboundary pollution. Hence the disutility of pollution of domestic production is counted as 1.15 while the disutility of pollution of foreign production is counted as 0.4. Finally, the constant unit abatement cost, μ, is assumed identical for all firms and its value is posited to be 1.02.

2.1.2. Reform from a non-cooperative equilibrium

In this section, we examine the effect of cooperative action of governments' environmental policy on the firms' output level. Like in the non-cooperative case, there is a two-stage game. First, the governments set their pollution quotas cooperatively, second, the firms determine their production level.

Using the equations (2.20) and (2.21), the welfare function of cooperative equilibrium is shown as

$$3\mathrm{b}\ \mathrm{dW} = (\mathrm{A1} + \mathrm{A3}).\mathrm{dza}^{\mathrm{C}} + (\mathrm{A2} + \mathrm{A4}).\mathrm{dzb}^{\mathrm{C}} \tag{2.34}$$

The concavity condition is found as

$$11\mu - 12.(\phi 1 + \phi 2) < 0 \tag{2.35}$$

The condition holds if

$$11\mu < 12.(\phi 1 + \phi 2) \tag{2.36}$$

The stability condition holds if

$$(2\mu^2 - 5\mu.(\phi 1 + \phi 2) + 3.(\phi 1 + \phi 2)^2) > 0 \tag{2.37}$$

Setting the coefficients of $\mathrm{dza}^{\mathrm{C}}$ and $\mathrm{dzb}^{\mathrm{C}}$ equal to zero, we find the cooperative solutions as

$$\begin{aligned}\mathcal{H}\ \mathrm{za}^{\mathrm{C}} = {} & -2\alpha.(4\mu^2 - 7\mu.(\phi 1 + \phi 2) + 3.(\phi 1 + \phi 2)^2) + 3\mathrm{ca}.(\mu^2 - 3\mu.(\phi 1 + \\ & \phi 2) + 2.(\phi 1 + \phi 2)^2) - \mu\mathrm{cb}.(\mu - \phi 1 - \phi 2) + \mu\theta\mathrm{a}.(8\mu^2 - \\ & 15\mu.(\phi 1 + \phi 2) + 6.(\phi 1 + \phi 2)^2) + \mu^2\theta\mathrm{b}.(\phi 1 + \phi 2)\end{aligned} \tag{2.38}$$

$$\mathcal{H}\ zb^{C} = -2\alpha.(4\mu^2 - 7\mu.(\phi1 + \phi2) + 3.(\phi1 + \phi2)^2) - \mu ca.(\mu - \phi1 - \phi2) + 3cb.(\mu^2 - 3\mu.(\phi1 + \phi2) + 2.(\phi1 + \phi2)^2) + \mu^2\,\theta a.(\phi1 + \phi2) + \mu\theta b.(8\mu^2 - 15\mu.(\phi1 + \phi2) + 6.(\phi1 + \phi2)^2)) \tag{2.39}$$

where

$$\mathcal{H} = 4\mu.(2\mu^2 - 5\mu.(\phi1 + \phi2) + 3.(\phi1 + \phi2)^2) \tag{2.40}$$

2.1.3. Uniform policy

In this section, we assume that the cooperative solutions are restricted to be uniform. First, the governments determine their uniform pollution levels and then the firms determine their production levels.

Using the equations (2.20), (2.21) and setting za = zb = z^U, we get the welfare function of uniform equilibrium

$$3b\ dW = (A1 + A2 + A3 + A4).\,dz^U \tag{2.41}$$

The concavity condition is found as

$$2\mu - 3.(\phi1 + \phi2) < 0 \tag{2.42}$$

The condition holds if

$$2\mu < 3.(\phi1 + \phi2) \tag{2.43}$$

Setting the coefficient of dz^U equal to zero, we find the uniform emission level as

$$z^U = \frac{\alpha.\left(8\mu - 6.(\phi1 + \phi2)\right) - (ca + cb).\left(\mu - 3.(\phi + \phi2)\right) + \mu.\left(4\mu - 3.(\phi1 + \phi2)\right).(\theta a + \theta b)}{4\mu.(3.(\phi1 + \phi2) - 2\mu)} \tag{2.44}$$

To compare the welfare conditions of countries for non-cooperative, cooperative and uniform solutions, we use the simulation values. We examine all the terms in welfare: (i) consumer surplus; (ii) producer surplus; (iii) employment; (iv) disutility of pollution. The results are shown in the following table.

Table 2.2 Total welfare for optimal policies of non-cooperative, cooperative and uniform solutions

The Optimal Policies	Consumer Surplus	Producer Surplus	Employment	Disutility of Pollution	Total Welfare
za^N	22.4535	22.4403	16.1185	55.9238	**5.08838**
zb^N	22.4535	22.4667	16.1199	55.9375	**5.10253**
za^C	6.65318	6.6445	8.77083	5.05488	**17.0136**
zb^C	6.65318	6.66187	8.77793	5.05798	**17.035**
za^U	6.65318	6.64438	8.77075	5.05481	**17.0135**
zb^U	6.65318	6.66199	8.77801	5.05805	**17.0351**

When there is cooperation between countries in terms of their environmental standards, the permitted pollution levels will be lower than the non-cooperative case and the welfare of both countries will strictly improve. If the governments impose stricter environmental policies, the production cost of firms will increase so the production and the total pollution generated by domestic and foreign production will decrease. Although the price will increase because of the reduction in production, the gain from the decrease in pollution is larger than the total loss of consumer surplus, producer surplus and employment. Therefore, when countries cooperate, governments apply stricter environmental standards because of the negative externalities of pollution.

2.2. Comparative Statics

By using the optimal non-cooperative, cooperative and uniform solutions above, we examine the effects of changes in parameters on the equilibrium emission levels. The parameters studied below are market size (α), constant per unit cost (ci), per unit gross pollution (θi), disutility of pollution resulted from domestic and foreign production ($\phi 1$, $\phi 2$) and the abatement cost (μ) where i = a,b. To determine the signs of some equations are not possible in the parametric modes. Therefore, to make the signs clear, we use the simulation values for parameters in the equations and these results are shown in the following table.

Table 2.3 The signs of the effects of changes in parameters on equilibrium emission levels

The Optimal Pollution Quotas	Parameters							
	α	ca	cb	θa	θb	μ	ϕ1	ϕ2
za^N	+	+	+	-	-	+	-	+
zb^N	+	+	+	-	-	+	-	+
za^C	-	+	+	-	+	+	-	-
zb^C	-	+	+	+	-	+	-	-
z^U	-	+	+	+	+	+	-	-

Pollution quotas and market size: For non-cooperative solution, when the market size increases, governments impose less severe pollution quotas in both countries. This is because, an increase in market size creates demand and governments want to meet this growing demand with domestic production. As a result, total output and employment will increase and the price will decrease. The positive effects of consumer surplus, producer surplus and employment on welfare will dominate the negative effect of relaxing pollution standards. However, when there is cooperation, higher market size leads to stricter pollution quotas. Higher total domestic and foreign productions resulted from growing demand increase the negative effect of pollution so the governments try to mitigate this effect by decreasing emission quotas.

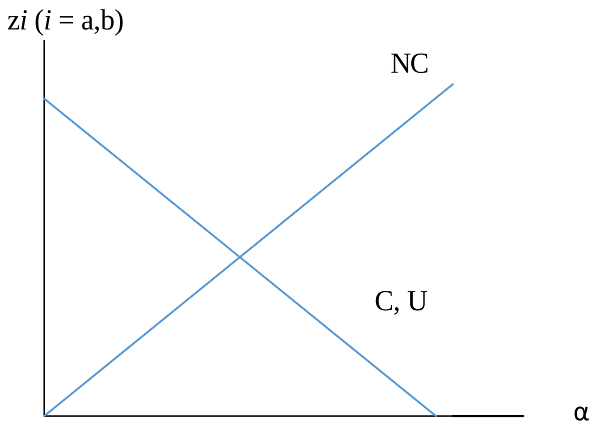

Figure 2.1 The effect of changes in market size on optimal pollution quotas

Pollution quotas and constant per unit cost: For three solutions, when the constant per unit costs increase, the cost of production will increase so the firms will decrease their productions. Because of the reduction in production, profits of firms and employment will decrease also price will rise. The governments allow firms to emit more pollution in order to compensate these negative impacts on welfare caused by consumer surplus, producer surplus and employment effect. Although this leads an increase in the negative effect of relaxing the pollution standards on welfare, this effect will be minor in comparison to the other positive effects on welfare.

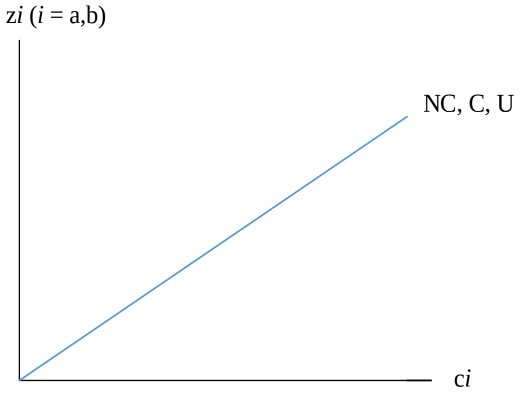

Figure 2.2 The effect of changes in constant per unit cost on optimal pollution quotas

When the rival firm's constant per unit cost increases, the government increases pollution level to protect its domestic firms. An increase in marginal cost leads to government impose less severe pollution quota so it gives a competitive advantage to firms in that country. Therefore, to provide balance in the market, the other government will also impose less severe pollution quota.

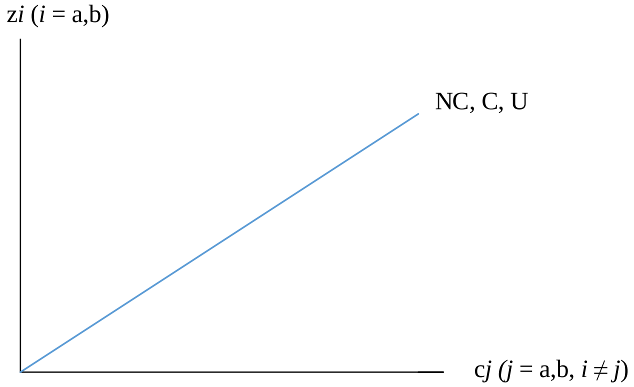

Figure 2.3 The effect of changes in constant per unit cost of rival firm on optimal pollution quotas

Pollution quotas and gross pollution: In the case of non-cooperation, and cooperation, an increase in the level of gross pollution generated by domestic firms' productions will increase the negative effect of disutility of pollution on welfare.

Hence, governments will decrease their optimal pollution levels that firms are allowed to emit so that the total production and pollution will reduce. On the other hand, in the uniform solution, higher gross pollution generated by production of domestic or foreign firms will lead to less strict emission quota. This can be explained by lower negative impact of relaxing standards on welfare compared to the negative impact of reduced production.

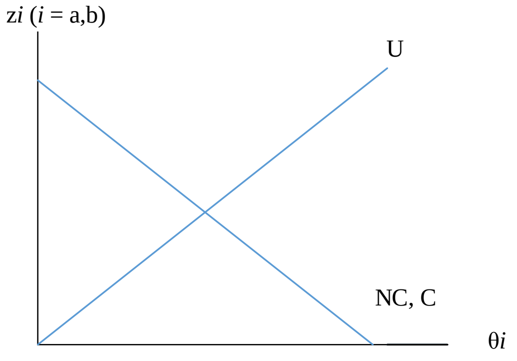

Figure 2.4 The effect of changes in gross pollution on optimal pollution quotas

On the other hand, when the rival firm's gross pollution increase, the government of other country will decrease its level of non-cooperative emission quota. Since its firm is in an advantageous position in the market, the government can benefit from that and it can force firm to decrease its production in order to reduce pollution. However, when there is cooperation, an increase in the level of rival firm's gross pollution leads government to apply stricter quotas so the production in that country will decline. To take advantage of this lack of production in the domestic and foreign markets, the other government will encourage its domestic firm to produce more by increasing emission level.

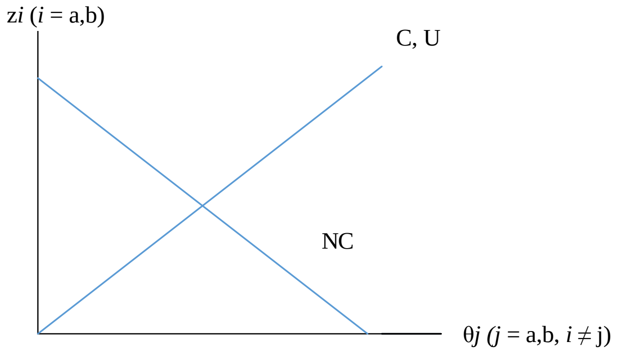

Figure 2.5 The effect of changes in gross pollution of rival firm on optimal pollution quotas

Pollution quotas and abatement cost: For non-cooperative, cooperative and uniform solutions, when the abatement cost increases, the consumer surplus, the producer surplus and the employment will be affected adversely because of the reduction in production. Therefore, governments increase their optimal policy levels since the negative effect of relaxing the pollution standards will be minor comparing to these three positive effects on welfare.

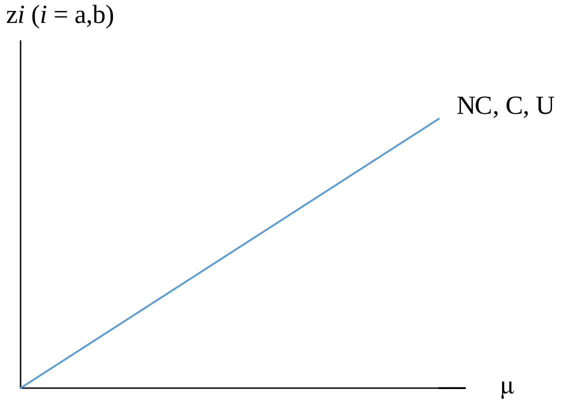

Figure 2.6 The effect of changes in per unit abatement cost on optimal pollution quotas

Pollution quotas and the marginal disutility of pollution: For all cases, an increase in the disutility of pollution generated by local production leads governments to apply more severe pollution quota. When the disutility of pollution increase, the welfare is affected adversely and this negative effect dominates the other parts of welfare so the government sets the stricter environmental standards to mitigate the total pollution level by decrementing total output.

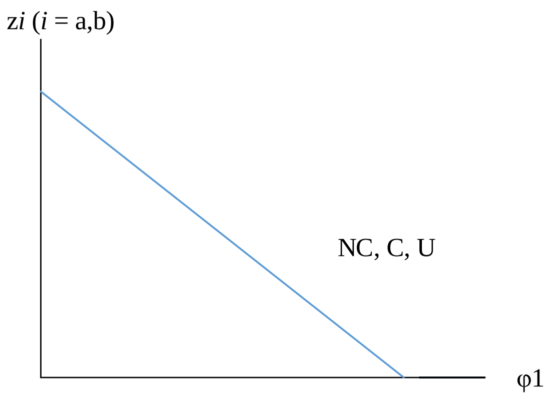

Figure 2.7 The effect of changes in marginal disutility of pollution generated by domestic production on optimal pollution quotas

In the case of non-cooperative solution, an increase in the disutility of pollution resulted from foreign production will lead the optimal policy level to increase. This is because when the disutility of trans-boundary pollution increases, governments may want to encourage domestic production by relaxing emission standards so that the price of domestic good decreases. By making its own domestic firm more competitive in market, governments can reduce the demand for foreign good and so the negative effect of disutility of trans-boundary pollution on welfare.

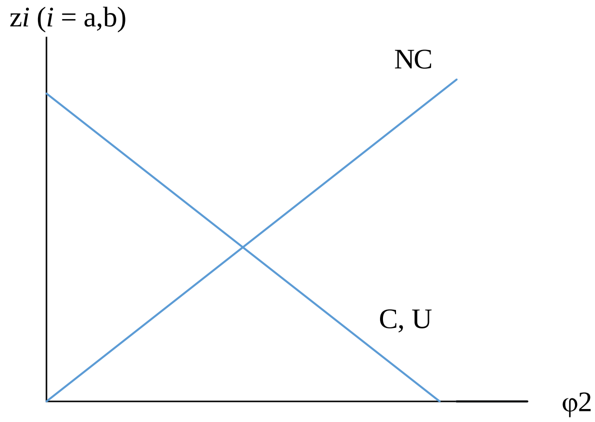

Figure 2.8 The effect of changes in marginal disutility of pollution generated by foreign production on optimal pollution quotas

Conversely, in the cooperative and uniform solutions, an increase in the disutility of pollution generated by foreign production results in a decrease in the optimal pollution level that firms are allowed to emit. Since the higher disutility of pollution causes welfare to deteriorate, both governments impose strict pollution standards to mitigate this negative effect by restricting their local production.

2.3. Conclusion

In the benchmark model, we develop two-country model and analyze the behaviors of governments in terms of their environmental policy in the non-cooperative, cooperative and uniform cases. We assume that there is one domestic firm in each country and there is an intra-industry trade between the countries so the domestic firms serve both domestic and foreign market. Governments try to set optimal emission quotas to maximize welfare affected by consumer surplus, producer surplus, employment level and disutility of pollution caused by domestic and foreign production.

We find that starting from the non-cooperative behavior, a uniform reduction in emission quotas is strictly Pareto improving. With these given simulation values, the results show that when there is a cooperation, all parts of welfare decline because of the reduction in production and the increase in price but the reduction in disutility of pollution is higher than the losses in other parts. Since this reduction in negative part of welfare dominates the other losses in positive parts, the welfare of both countries will be better off when the governments cooperate and reduce the level of their pollution quotas.

3. TRADE, ENVIRONMENT AND FDI

When there is trade between countries and concern for attracting foreign direct investment (FDI), governments can use policy instruments related with both trade and environment. These instruments can bu used to compensate for their mutual influence on welfare. In the literature, it is indicated that asymmetric market structure of countries has different impacts on the level of these instruments and hence locational decision of foreign investment. Haufler and Wooton (1999) find that when there are exogenous and identical transport costs and countries offer subsidies tax, the country with larger number of residents always offers a higher subsidy to FDI because the residents can share the tax burden. In the case of trade costs (tariff or consumption tax), the FDI is willing to invest into the large market in order to small number of its customers have to pay the tariff. Besides, the tariff imposed by country with large number of residents is higher than the other country. In addition, when trade costs are exogenous, country with larger number of residents is willing to higher subsidy. However when trade costs are endogenous this country is less willing to subsidize FDI. For asymmetric market condition, Kayalica and Lahiri (2005b) analyze the location decisions of FDI between a country with one domestic firm and a country with n identical foreign firms. When the market size increases, the environmental regulations are became more severe for both consuming country and host country. In the scenario of free entry and exit of foreign firms, the same is true for host country and for consuming country if the emission standards are strategic complement. For both exogenous and endogenous number of foreign firms, when there is an economic integration, host country applies more severe emission standards. This situation is viable for consuming country if the level of cross border pollution is sufficiently high. In the case of multilateral reform, a uniform reduction in emission standards has a positive effect on the welfare of host country and consuming country if the marginal disutility of pollution is sufficiently high there. In another study, they show when the number of foreign firms is exogenous, the host country applies stricter emission standard. In addition, when market size decreases, both countries apply less severe pollution restriction also when the gross pollution increases in one country, the emission restriction is mitigated in that country and increased in the other country. However, when there is a free entry and exit, the host country applies less severe emission standard for both non-cooperative and cooperative situations (2005a).

Rauscher (1995) says that if the tax revenue is higher than the environmental damage, the countries want to decrease their tax level in order to attract foreign investment. However when the tax revenue approaches to the environmental damage, the motivation of governments to cut their emission tax level decreases. Similarly, Markusen et al. (1995) show that if foreign firm chooses one country to locate based on its relatively low level of tax, this will not be a Nash equilibrium. The reason is that other country will be worsen in terms of welfare because of the lower consumer surplus and higher price increased by transport cost. Therefore, that country has an incentive to decrease its tax level. If the export revenue dominates the disutility of pollution, countries keep cutting their tax so this competition will result in a low level of tax and a high level of environmental damage. In addition, the amount and the efficiency of domestic firms affect the decision of FDI through the market condition. When domestic firms do not export, MNC locates in a country with less domestic firms but if domestic firms are sufficiently inefficient, MNC prefers to locate in a country with more domestic firms. On the other hand, when domestic firms export, MNC always locates in a country with less domestic firms (Lahiri and Hao 2009). Finally, Vlad and Lahiri (2009) develop a North-South model in which there is pollution caused by production in South and by cross-border effect in North. The North determines level of aid financing the abatement activities in South and the South determines allocation of aid and pollution tax. An increase in foreign capital inflows to the South results in an increase in pollution in both the North and the South. Therefore, the North raises the aid level because of the marginal willingness to pay for abatement so the pollution abatement in South decreases. In the case of exogenous foreign investment, an increase in foreign capital raises the amount of pollution by increasing production. However, it expands the market and therefore increases the pollution tax revenue which finances the abatement activities so there is also a decrease in pollution. Hence, if the tax rate is higher than the unit cost of abatement, the net effect of foreign investment on pollution is negative. In the case of endogenous foreign investment, a reduction in emission tax rate on foreign investment decreases the level of emission and increases the welfares in both countries.

In this section, we want to examine the impact of FDI on the environmental policies of host country and rival country. We intend to compare these results with the results of benchmark model. In this study, FDI is represented by multinational company (MNC).

3.1. The General Model

In the model, we extend the benchmark model by allowing entry of MNC that wants to locate in one of the countries A and B. There is a fixed cost (*F*) for MNC and it is assumed to be sufficiently large so that the MNC cannot operate in both countries at the same time. The fixed cost is also assumed to be only firm-specific not the country-specific so the location decision of MNC is affected by only the difference in effectiveness between the domestic firms. In that case, MNC wants to locate in country with more inefficient firm since it can gain more profit there.

Like in the benchmark model, the domestic firms in country A and B produce *qa* and *qb* for domestic consumption and *qax* and *qbx* for foreign consumption. MNC produces *qm* for domestic market in host country and also produces *qmx* for export to the other country. The domestic firms and MNC produce homogeneous good that creates pollution during the production. It is assumed that MNC has the same constant unit abatement cost with the domestic firms. All firms have constant marginal cost and constant per unit cost. It is assumed that MNC is technologically superior to the domestic firms in terms of production and abatement activities ($cm < ci$, $i = a,b$). Similarly, the firm in country B is technologically superior to the firm in country A in terms of production and abatement activities ($cb < ca$). Therefore, MNC will choose country A to locate because of the weaker domestic rival (see Appendix B for numeric results). The inverse demand functions for the good are given by,

$$\mathrm{pa} = \alpha - \mathrm{b.Da} \quad \textbf{(3.1)}$$

$$\mathrm{pb} = \alpha - \mathrm{b.Db} \quad \textbf{(3.2)}$$

Total demand of countries consists of the demand for local production and the demand for export. These are given by

$$\mathrm{Da} = \mathrm{qa} + \mathrm{qm} + \mathrm{qbx} \tag{3.3}$$

$$\mathrm{Db} = \mathrm{qb} + \mathrm{qax} + \mathrm{qmx} \tag{3.4}$$

Profit of each firm is given by π

$$\pi\mathrm{a} = (\mathrm{pa} - \kappa\mathrm{a}).\,\mathrm{qa} + (\mathrm{pb} - \kappa\mathrm{a}).\,\mathrm{qax} \tag{3.5}$$

$$\pi\mathrm{b} = (\mathrm{pb} - \kappa\mathrm{b}).\,\mathrm{qb} + (\mathrm{pa} - \kappa\mathrm{b}).\,\mathrm{qbx} \tag{3.6}$$

$$\pi\mathrm{m} = (\mathrm{pa} - \kappa\mathrm{m}).\,\mathrm{qm} + (\mathrm{pb} - \kappa\mathrm{m}).\,\mathrm{qmx} - \mathrm{F} \tag{3.7}$$

The constant marginal cost of firms are given by

$$\kappa\mathrm{a} = \mathrm{ca} + \mu.\,(\theta\mathrm{a} - \mathrm{za}) \tag{3.8}$$

$$\kappa\mathrm{b} = \mathrm{cb} + \mu.\,(\theta\mathrm{b} - \mathrm{zb}) \tag{3.9}$$

$$\kappa\mathrm{m} = \mathrm{cm} + \mu.\,(\theta\mathrm{m} - \mathrm{za}) \tag{3.10}$$

It is assumed that MNC has its own constant per unit cost, *cm* and gross pollution before abatement, θm also it has the same constant unit abatement cost with the domestic firms.

The firms are assumed to behave in a Cournot–Nash. The first order profit maximizing conditions are found as

$$\mathrm{b.\,qa} = \mathrm{pa} - \kappa\mathrm{a} \qquad \mathrm{b.\,qax} = \mathrm{pb} - \kappa\mathrm{a} \tag{3.11}$$

$$\mathrm{b.\,qb} = \mathrm{pb} - \kappa\mathrm{b} \qquad \mathrm{b.\,qbx} = \mathrm{pa} - \kappa\mathrm{b} \tag{3.12}$$

$$\mathrm{b.\,qm} = \mathrm{pa} - \kappa\mathrm{m} \qquad \mathrm{b.\,qmx} = \mathrm{pb} - \kappa\mathrm{m} \tag{3.13}$$

When the closed form solutions are solved by using (3.1) (3.2) and (3.11) (3.12) (3.13), we find the output and price as

$$\mathrm{qa} = \mathrm{qax} = \frac{\alpha - 3\kappa\mathrm{a} + \kappa\mathrm{b} + \kappa\mathrm{m}}{4\mathrm{b}} \tag{3.14}$$

$$\mathrm{qb} = \mathrm{qbx} = \frac{\alpha - 3\kappa\mathrm{b} + \kappa\mathrm{a} + \kappa\mathrm{m}}{4\mathrm{b}} \tag{3.15}$$

$$\mathrm{qm} = \mathrm{qmx} = \frac{\alpha - 3\kappa\mathrm{m} + \kappa\mathrm{a} + \kappa\mathrm{b}}{4\mathrm{b}} \tag{3.16}$$

$$pa = pb = \frac{\alpha + \kappa a + \kappa b + \kappa m}{4}$$

(3.17)

Differentiating equation (3.14) (3.15) and (3.16) we obtain

$$dqa = dqax = \frac{2\mu}{4b}\, dza - \frac{\mu}{4b} dzb$$

(3.18)

$$dqb = dqbx = -\frac{2\mu}{4b} dza + \frac{3\mu}{4b}\, dzb$$

(3.19)

$$dqm = dqmx = \frac{2\mu}{4b}\, dza - \frac{\mu}{4b} dzb$$

(3.20)

Each domestic firm will increase (decrease) its production for both local market and foreign market when it is allowed to emit more (less) pollution or its rival firm in other country is allowed to emit less (more) pollution. Similarly, MNC will increase (decrease) its production for both local market and foreign market when it is allowed by host country A to emit more pollution or its rival firm in country B is allowed to emit less (more) pollution. In addition, the firms are more sensitive to their own country's policy than the rival country's policy. However, this sensitivity is higher for domestic firm in country B since the emission policy of country A has both positive and negative effect for the domestic firm in that country and MNC.

Totally differentiating the profit functions, we get

$$d\pi a \ = \ 2\mu.qa\, dza - \ \mu.qa\, dzb \qquad \textbf{(3.21)}$$

$$d\pi b \ = -2\mu.qb\, dza + 3\mu.qb\, dzb \qquad \textbf{(3.22)}$$

$$d\pi m \ = \ 2\mu.qm\, dza - \ \mu.qm\, dzb \qquad \textbf{(3.23)}$$

As stated before, we assume that there is an unemployment problem in both countries. Countries can benefit from consumer surplus and profits and employment generated by domestic firms. It is assumed that the profit of MNC is fully repatriated to the source country so the host country can benefit from MNC through only the creation of employment. Again, it is assumed that pollution occurs during production and all domestic firms and MNC generate pollution. The welfare functions of country A and B are given by Wa and Wb.

$$\mathrm{Wa} = \frac{(\alpha - \mathrm{pa})^2}{2\mathrm{b}} + \pi\mathrm{a} + \mathrm{ca}.(\mathrm{qa} + \mathrm{qax}) + \mathrm{cm}.(\mathrm{qm} + \mathrm{qmx}) - \phi 1.(\mathrm{qa} + \mathrm{qax} + \mathrm{qm} + \mathrm{qmx}).\mathrm{za} - \phi 2.(\mathrm{qb} + \mathrm{qbx}).\mathrm{zb} \quad \textbf{(3.24)}$$

$$\mathrm{Wb} = \frac{(\alpha - \mathrm{pb})^2}{2\mathrm{b}} + \pi\mathrm{b} + \mathrm{cb}.(\mathrm{qb} + \mathrm{qbx}) - \phi 1.(\mathrm{qb} + \mathrm{qbx}).\mathrm{zb} - \phi 2.(\mathrm{qa} + \mathrm{qax} + \mathrm{qm} + \mathrm{qmx}).\mathrm{za} \quad \textbf{(3.25)}$$

The welfare function of country B consists of four parts: (i) consumer surplus; (ii) domestic firm's profit; (iii) employment effect; (iv) disutility from pollution generated by local and foreign production. The welfare function of country A has one more part which is the employment effect generated by MNC.

Totally differentiating the profit functions, we get,

$$4\mathrm{b}\ \ \mathrm{dWa} = \mathrm{A5}.\mathrm{dza} + \mathrm{A6}.\mathrm{dzb} \quad \textbf{(3.26)}$$

$$4\mathrm{b}\ \ \mathrm{dWb} = \mathrm{A7}.\mathrm{dza} + \mathrm{A8}.\mathrm{dzb} \quad \textbf{(3.27)}$$

where

$$\mathrm{A5} = 2.(2\mu.[(\mathrm{ca} + \mathrm{cm}) - (2\phi 1\mathrm{za} - \phi 2\mathrm{zb})] + \mathrm{b}\mu.\mathrm{Da} + 2\mathrm{b}.[(\mathrm{qa} + \mathrm{qax}).(\mu - \phi 1) - \phi 1.(\mathrm{qm} + \mathrm{qmx})]) \quad \textbf{(3.28)}$$

$$\mathrm{A6} = -2\mu.[(\mathrm{ca} + \mathrm{cm}) - (2\phi 1\mathrm{za} - 3\phi 2\mathrm{zb})] + \mathrm{b}\mu\mathrm{Da} - 2\mathrm{b}[\mu.(\mathrm{qa} + \mathrm{qax}) - 2\phi 2(\mathrm{qb} + \mathrm{qbx})] \quad \textbf{(3.29)}$$

$$\mathrm{A7} = -4\mu.[\mathrm{cb} + (2\phi 2\mathrm{za} - \phi 1\mathrm{zb})] + 2\mathrm{b}\mu.\mathrm{Db} - 4\mathrm{b}.[\mu.(\mathrm{qb} + \mathrm{qbx}) + \phi 2.(\mathrm{qa} + \mathrm{qax} + \mathrm{qm} + \mathrm{qmx})] \quad \textbf{(3.30)}$$

$$\mathrm{A8} = 6\mu.\mathrm{cb} + \mathrm{b}\mu.\mathrm{Db} + 2\mathrm{b}.(3\mu - 2\phi 1).(\mathrm{qb} + \mathrm{qbx}) + 2\mu.(2\phi 2\mathrm{za} - 3\phi 1\mathrm{zb}) \quad \textbf{(3.31)}$$

A5 and A8 represent the effect of each government's environmental policy on its own welfare and A6 and A7 represent the effect of one government's environmental policy on the other country's welfare.

3.1.1. Non-cooperative solution

In scope of Cournot–Nash equilibrium, we develop a two-stage game in which first the governments determine the level of pollution quotas simultaneously. Second, the domestic firms and MNC determine output levels based on these pollution quotas. The game is solved by using backwards induction. To show that the solutions satisfy the concavity and stability conditions we need to check that welfare functions are concave in za and zb. The conditions find as

$$(5\mu - 16\phi 1) < 0 \ \text{ and } \ (37\mu - 48\phi 1) < 0 \qquad \textbf{(3.32)}$$

Therefore the concavity conditions hold if

$$5\mu < 16\phi 1 \ \text{ and } \ 37\mu < 48\phi 1 \qquad \textbf{(3.33)}$$

We also have to assure the stability condition. The condition is given by

$$\text{Wza(za)}.\,\text{Wzb(zb)} - \text{Wza(zb)}.\,\text{Wzb(za)} > 0 \qquad \textbf{(3.34)}$$

The stability condition holds if

$$(19\mu^2 - 90\mu\phi 1 + 88\phi 1^2 + 14\mu\phi 2 - 16\phi 1\phi 2 - 8\phi 2^2) > 0 \qquad \textbf{(3.35)}$$

Setting A5 and A8 equal to zero, we find the countries' non-cooperative policy instruments as

$$\begin{aligned} 2\mathcal{M}\ \text{za}^{\text{N}} = {} & \alpha.(-38\mu^2 - 8\phi 1.(7\phi 1 + \phi 2) + (97\phi 1 + 15\phi 2).\mu) + \text{ca}.(19\mu^2 + \\ & 8\phi.(5\phi 1 - \phi 2) + (11\phi 2 - 53\phi 1).\mu) - \text{cb}.(9\text{b}\mu^2 + 24\phi 1.(\phi 1 + \phi 2) - \\ & (33\phi 1 - 13\phi 2).\mu) - \text{cm}.(55\mu^2 - 8\phi 1.(5\phi 1 - \phi 2) - (43\phi 1 + 11\phi 2).\mu) + \\ & \mu\theta\text{a}.(56\mu^2 + 8\phi 1.(5\phi 1 - \phi 2) - (101\phi 1 - 11\phi 2).\mu) - \mu\theta\text{b}.(24\phi 1.(\phi 1 + \\ & \phi 2) - (9\phi 1 - 37\phi 2).\mu) - \mu\theta\text{m}.(18\mu^2 - \ \phi 1(5\phi 1 - \phi 2) + (5\phi 1 - 11\phi 2).\mu) \end{aligned}$$

(3.36)

$$\begin{aligned} \mathcal{M}\ \text{zb}^{\text{N}} = {} & \alpha.(-19\mu^2 - 8\phi 1.(3\phi 1 + \phi 2) + (53\phi 1 + 7\phi 2).\mu) + \text{ca}.\big((11\phi 1 - 5\phi 2).\mu + \\ & 8\phi 1(-\phi 1 + \phi 2)\big) + \text{cb}.(4\mu^2 + 8\phi 1.(5\phi 1 - \phi 2) + (\phi 2 - 9\phi 1).3\mu) - \\ & \text{cm}.(22\mu^2 + 8\phi 1.(\phi 1 - \phi 2) - (27\phi 1 + 11\phi 2).\mu) + \mu\theta\text{a}.(11\mu^2 + \\ & 8\phi 1.(-\phi 1 + \phi 2) + \ (3\phi 1 - 13\phi 2).\mu) + \mu\theta\text{b}.(19\mu^2 + 8\phi 1(5\phi 1 - \phi 2) + \\ & (3\phi 2 - 75\phi 1).\mu) - \mu\theta\text{m}.(11\mu^2 + \ 8\phi 1.(\phi 1 - \phi 2) - (19\phi 1 + 3\phi 2).\mu) \end{aligned}$$

(3.37)

where

$$\mathcal{M} = \mu.(19\mu^2 - 90\mu\phi 1 + 88\phi 1^2 + 14\mu\phi 2 - 16\phi 1\phi 2 - 8\phi 2^2) \qquad \textbf{(3.38)}$$

We use same simulation values in the benchmark model and add new values for parameters of MNC with respect to the second order conditions and stability conditions. Table 3.1 represents the simulation values and the ranges of possible values for parameters.

Table 3.1 Simulation values and ranges for parameters of MNC case

Parameters	Values	Possible values range	
		Min	Max
α	14.0	13.0	14.0
b	0.7	0.6	0.75
ca	2.013	2.0125	2.02
cb	2.012	2.0122	2.0128
cm	2.01	2.0	2.0119
θa	8.013	8.0125	8.02
θb	8.012	8.0119	8.0129
θm	8.01	8.0	8.0119
F	3.0	2.0	3.0
μ	1.02	1.02	1.03
ϕ1	1.15	1.12	1.155
ϕ2	0.4	0.39	0.405

Since it is assumed that MNC is technologically superior to the domestic firms in terms of production and abatement activities, it generates less pollution than domestic firms in country A and B. Therefore, constant per unit cost and gross pollution before abatement of MNC are posited as 2.01 and 8.01 for cm and θm. The ranges of possible values are determined based on the assumption which maximum values of the constant per unit cost and the level of gross pollution of MNC are always lower than the determined value of domestic firms. The fixed cost of MNC, F, is counted as 3.0. Finally, the constant unit abatement cost, μ, is assumed identical for all firms so its value for MNC is also 1.02.

3.1.2. Reform from a non-cooperative equilibrium

In this section, we examine the effect of cooperative action of governments' environmental policy on the firms' output level. Like in the non-cooperative case, there is a two-stage game. First, the governments set their pollution quotas cooperatively, second the firms determine their production level.

Using the equations (3.26) and (3.27), the welfare function of cooperative equilibrium is shown a

$$4b\ dW = (A5 + A7).\, dza^{C} + (A6 + A8).\, dzb^{C} \qquad \textbf{(3.39)}$$

The concavity conditions are found as

$$(5\mu - 8.(\phi1 + \phi2)) < 0 \ \text{ and } \ (7\mu - 8.(\phi1 + \phi2)) < 0 \qquad \textbf{(3.40)}$$

The conditions hold if

$$5\mu < 8(\phi1 + \phi2) \qquad \textbf{(3.41)}$$

$$7\mu < 8(\phi1 + \phi2) \qquad \textbf{(3.42)}$$

The stability condition holds if

$$7\mu < 8(\phi1 + \phi2) \text{ and } \mu < 2(\phi1 + \phi2) \qquad \textbf{(3.43)}$$

Setting the coefficients of dza^{C} and dzb^{C} equal to zero, we find the cooperative solutions as

$$\mathcal{R}1\ za^{C} = 2\alpha.(\mu - \phi1 - \phi2) + ca.(-\mu + \phi1 + \phi2) + cm.(\mu + \phi1 + \phi2) + \mu\theta a.(-2\mu + \phi1 + \phi2) + \mu\theta m.(\phi1 + \phi2)) \qquad \textbf{(3.44)}$$

$$\mathcal{R}2\ zb^{C} = \alpha.(-7\mu^2 + 16\mu(\phi1 + \phi2) - 8(\phi1 + \phi2)^2) + ca\mu.(\phi1 + \phi2) + cb.(3\mu^2 - 10\mu.(\phi1 + \phi2) + 8.(\phi1 + \phi2)^2) - cm\mu.(2\mu - \phi1 - \phi2) + \mu^2\theta a.(\mu + \phi1 + \phi2) + \mu\theta b.(7\mu^2 - 18\mu.(\phi1 + \phi2) + 8.(\phi1 + \phi2)^2) - \mu^2\theta m.(\mu - \phi1 - \phi2) \qquad \textbf{(3.45)}$$

$$\mathcal{R}1 = 2\mu.(2.(\phi1 + \phi2) - \mu) \ \text{ and } \ \mathcal{R}2 = \mu.(7\mu^2 - 22\mu(\phi1 + \phi2) + 16(\phi1 + \phi2)^2) \qquad \textbf{(3.46)}$$

3.1.3. Uniform policy

In this section, we analyze the optimal emission level when the governments determine a uniform pollution quota. Using the equations (3.26), (3.27) and setting za = zb = z^U, we get the welfare function of uniform equilibrium as

$$4b\ dW = (A5 + A6 + A7 + A8).\, dz^U \qquad \textbf{(3.47)}$$

The concavity condition is found as

$$13\mu - 24.\,(\phi 1 + \phi 2) < 0 \qquad \textbf{(3.48)}$$

The condition holds if

$$13\mu < 24.\,(\phi 1 + \phi 2) \qquad \textbf{(3.49)}$$

To find an optimal emission level, we set the coefficient of dz^U equal to zero and solve the equation. The results are given by

$$\Upsilon\ z^U = \alpha.\big(13\mu - 12.\,(\phi 1 + \phi 2)\big) + (ca + cb).\big(-3\mu + 4(\phi 1 + \phi 2)\big) + cm.\big(5\mu + 4.\,(\phi 1 + \phi 2)\big) - \mu.\big(7\mu - 4.\,(\phi 1 + \phi 2)\big).\,(\theta a + \theta b) + \mu.\,\theta m.\big(\mu + 4.\,(\phi 1 + \phi 2)\big) \qquad \textbf{(3.50)}$$

where

$$\Upsilon = \mu.\,(24.\,(\phi 1 + \phi 2) - 13\mu) \qquad \textbf{(3.51)}$$

By using simulations values posited before, we get the following tables showing the signs of differences between optimal policies and the welfare conditions of three solutions. The subscript “M” represents the policies of MNC case.

Table 3.2 The comparison of the optimal pollution quotas

The Benchmark Model	The Extended Model	The Comparison of Two Models
$\mathrm{za}^{\mathrm{N}} - \mathrm{zb}^{\mathrm{N}} > 0$	$\mathrm{za}_{\mathrm{M}}^{\mathrm{N}} - \mathrm{zb}_{\mathrm{M}}^{\mathrm{N}} < 0$	$\mathrm{za}^{\mathrm{N}} - \mathrm{za}_{\mathrm{M}}^{\mathrm{N}} > 0$
$\mathrm{za}^{\mathrm{C}} - \mathrm{zb}^{\mathrm{C}} > 0$	$\mathrm{za}_{\mathrm{M}}^{\mathrm{C}} - \mathrm{zb}_{\mathrm{M}}^{\mathrm{C}} < 0$	$\mathrm{zb}^{\mathrm{N}} - \mathrm{zb}_{\mathrm{M}}^{\mathrm{N}} > 0$
$\mathrm{za}^{\mathrm{N}} - \mathrm{za}^{\mathrm{C}} > 0$	$\mathrm{za}_{\mathrm{M}}^{\mathrm{N}} - \mathrm{za}_{\mathrm{M}}^{\mathrm{C}} > 0$	$\mathrm{za}^{\mathrm{C}} - \mathrm{za}_{\mathrm{M}}^{\mathrm{C}} > 0$
$\mathrm{zb}^{\mathrm{N}} - \mathrm{zb}^{\mathrm{C}} > 0$	$\mathrm{zb}_{\mathrm{M}}^{\mathrm{N}} - \mathrm{zb}_{\mathrm{M}}^{\mathrm{C}} > 0$	$\mathrm{zb}^{\mathrm{C}} - \mathrm{zb}_{\mathrm{M}}^{\mathrm{C}} > 0$
$\mathrm{za}^{\mathrm{N}} - \mathrm{z}^{\mathrm{U}} > 0$	$\mathrm{za}_{\mathrm{M}}^{\mathrm{N}} - \mathrm{z}_{\mathrm{M}}^{\mathrm{U}} > 0$	$\mathrm{z}^{\mathrm{U}} - \mathrm{z}_{\mathrm{M}}^{\mathrm{U}} > 0$
$\mathrm{zb}^{\mathrm{N}} - \mathrm{z}^{\mathrm{U}} > 0$	$\mathrm{zb}_{\mathrm{M}}^{\mathrm{N}} - \mathrm{z}_{\mathrm{M}}^{\mathrm{U}} > 0$	
$\mathrm{za}^{\mathrm{C}} - \mathrm{z}^{\mathrm{U}} > 0$	$\mathrm{za}_{\mathrm{M}}^{\mathrm{C}} - \mathrm{z}_{\mathrm{M}}^{\mathrm{U}} < 0$	
$\mathrm{zb}^{\mathrm{C}} - \mathrm{z}^{\mathrm{U}} < 0$	$\mathrm{zb}_{\mathrm{M}}^{\mathrm{C}} - \mathrm{z}_{\mathrm{M}}^{\mathrm{U}} > 0$	

In the benchmark model, the difference between the optimal non-cooperative emission policies of the countries results from the constant per unit cost and gross pollution values of domestic firms given in the simulation. The country with less efficient firm applies less severe pollution quota to ensure competitiveness in international markets and stimulate the domestic production. This situation is same when the countries cooperate.

When there is a multinational company in the market, the host country always imposes more severe emission policy than the other country. Since the MNC fully repatriates its profit to the source country, host country does not have any concern about losing the profits of foreign company. Although the pollution generated by MNC is less than the domestic firms and it gives a positive impact on the host country' welfare, the welfare will be deteriorate because of the reduction in producer surplus and employment. Since the MNC is more efficient, it creates less employment than in the case where there is only domestic firm in the market. Therefore, the government decrease the allowed emission level to decrease negative effect of pollution in order to compensate declining parts of welfare.

For the benchmark and extended model, cooperative behavior is always Pareto improving because of the negative externalities of pollution. Countries will decrease their optimal policy level when they cooperate. Furthermore, when there is MNC in rival country, country B always imposes more severe environmental policy in comparison with the benchmark model. Since the domestic firm in this country is in a more advantageous position compared to its rival in host country, the government can impose more stringent policy without losing in producer surplus and employment effect. For this reason, government wants to decrease emission quotas to reduce pollution while it can still benefit from its market condition. Similarly, the host country A sets stricter non-cooperative and cooperative environmental policy in comparison to the benchmark model. This is because, the government wants to balance the losses in welfare caused by MNC by reducing total pollution.

Table 3.3 Total welfare for optimal policies of non-cooperative, cooperative and uniform solutions in MNC case

The Optimal Policies	Consumer Surplus	Producer Surplus	Employment	Disutility of Pollution	Total Welfare
za_M^N	19.6342	3.36441	12.5078	33.0667	**2.43971**
zb_M^N	19.6342	26.8676	17.6282	50.5206	**13.6095**
za_M^C	6.67904	1.68625	8.86514	1.34761	**15.8828**
zb_M^C	6.67904	6.56081	8.71109	3.71891	**18.232**
za_M^U	6.40456	2.83113	11.4766	1.32953	**19.3828**
zb_M^U	6.40456	2.84263	5.73395	0.959784	**14.0214**

According to the results, although the total disutility of pollution in country B is larger than in the host country because of the inefficient domestic firm, total welfare of country B is strictly better than host country. This is because, when there is a foreign firm in country, the gain from producer surplus of domestic firm will decrease. In addition, since the foreign firm is more efficient than domestic firms are, the gain from employment will fall. On the other hand, domestic firm in country B can create more producer surplus and employment because of the being less efficient than MNC. Therefore, these gains can dominate the loss resulted from disutility of pollution.

Moreover, when the countries cooperate, the welfare of both countries will improve but although the increase in host country's welfare is much more, still the total welfare of country B is higher than the host country' welfare. The reduction in pollution quotas will decrease the negative effect of pollution. In addition, consumer surplus, producer surplus and employment in both countries will also decrease because of the reduction in production but the gain from reduction in disutility of pollution is larger than these losses. The main difference between the welfare of countries is producer surplus. Although the producer surplus will decrease in both countries when they cooperate, the host country will still have less producer surplus because of the impact of MNC.

In the uniform solution, the welfare of host country is better than all three cases and it is also better than the welfare of rival country. Many parts of welfare are similar for both countries but MNC affects the host countries welfare by employment effect. Although total disutility of pollution is higher than the rival country, the employment is also higher in the host country.

3.2. Comparative Statics

We use the simulation values for parameters and examine the signs of the effects of changes in parameters on the equilibrium emission levels of three solutions. The results are shown in the following table.

Table 3.4 The sign of the effects of changes in parameters on equilibrium emission levels in MNC case

The Optimal Pollution Quotas	Parameters									
	α	ca	cb	cm	θa	θb	θm	μ	ϕ1	ϕ2
za^N_M	+	+	+	+	-	-	+	+	-	+
zb^N_M	+	+	+	+	+	-	+	+	-	+
za^C_M	-	+		+	-		+	+	-	-
zb^C_M	-	+	+	-	+	-	+	+	-	-
z^U_M	-	+	+	+	-	-	+	+	-	-

Pollution quotas and market size: For non-cooperative solution, when the market size increases, the governments in both countries impose less strict pollution quotas. Since the higher market size means the higher production, the price will decrease and the employment level will increase. Therefore, to meet growing demand in the market and stimulate the production, the governments in both countries will increase the optimal non-cooperative pollution level that the firms are allowed to emit. On the other hand, for cooperative and uniform cases, an increase in the market size leads more severe pollution quota in both country because of the pollution effect of higher production of domestic firms and MNC. This negative effect dominates the other parts of welfare so the governments will set stricter cooperative environmental policies.

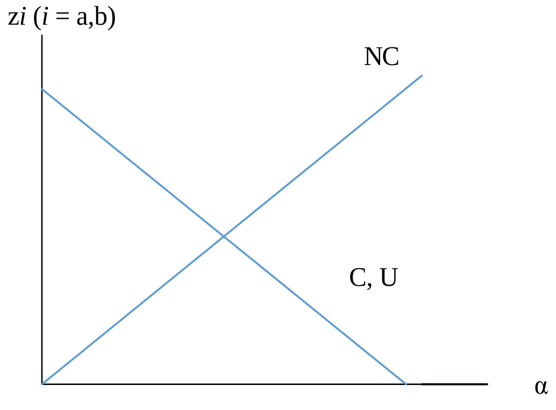

Figure 3.1 The effect of changes in market size on optimal pollution quotas for MNC case

Pollution quotas and constant per unit cost: For three solutions, an increase in the constant per unit costs of domestic firm or rival domestic firm will lead an increase in the optimal pollution levels because of the reasons explained before. However, when there is cooperation, domestic firm in host country is insensitive to the change in constant per unit cost of domestic firm in country B. This situation can be explained by the higher effect of MNC on domestic firm. MNC has a significant impact on domestic firm of host country and this makes the impact of changes in the constant per unit cost of rival domestic firm less important or even ineffective.

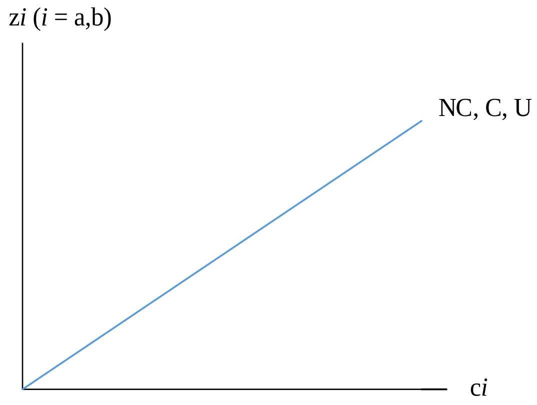

Figure 3.2 The effect of changes in constant per unit cost on optimal pollution quota for MNC case

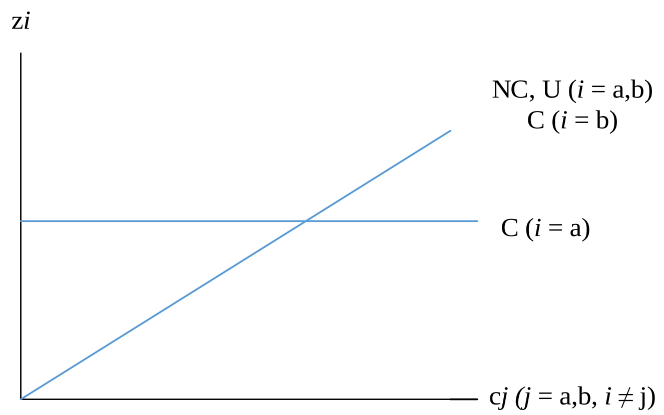

Figure 3.3 The effect of changes in constant per unit cost of rival firm on optimal pollution quotas for MNC case

An increase in the constant per unit cost of MNC will lead an increase in non-cooperative emission levels in both countries. Since the constant per unit cost means the higher production cost, MNC will decrease its production. The host country can benefit from MNC through the consumer surplus and employment effect but these effects will deteriorate if the MNC's production falls. Therefore, the government of country A wants to encourage MNC to produce more by increasing pollution quota because the negative effect of pollution caused by increased production of MNC will be small. In addition, the domestic firm in country B competes with MNC so when there is an increase in the constant per unit cost of MNC and hence there is a relaxation in the emission standards of country A, this will give a competitive advantages for MNC and domestic firm in country A. For this reason, the government of country B will also increase pollution quota to protect its own domestic firm.

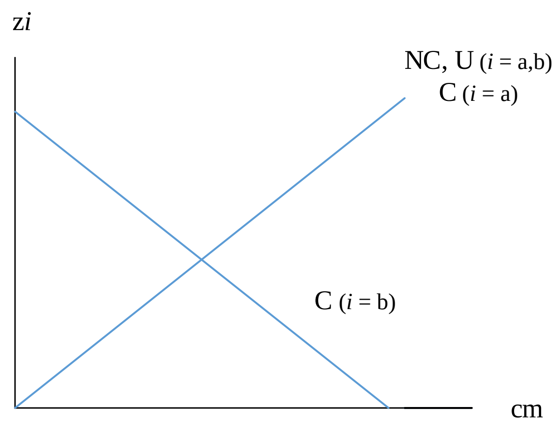

Figure 3.4 The effect of changes in constant per unit cost of MNC on optimal pollution quotas for MNC case

In the cooperative case, an increase in the constant per unit cost of MNC increases the emission quota in country A because of the reasons explained above. On the other hand, this increase will give a competitive advantage for domestic firm in country B. Domestic firm in country B will produce more and hence create more pollution. The negative effect of pollution on welfare will be high so the government will try to reduce production by tightening cooperative emission policy.

Pollution quotas and gross pollution: An increase in the level of gross pollution caused by production of domestic firm will increase the negative effect of disutility of pollution on welfare. Despite the degradation in price and employment level, the welfare will be better off when the negative effect of pollution disutility decline. Therefore, to reduce the production and hence the pollution, the governments will decrease their optimal pollution quotas for three solutions.

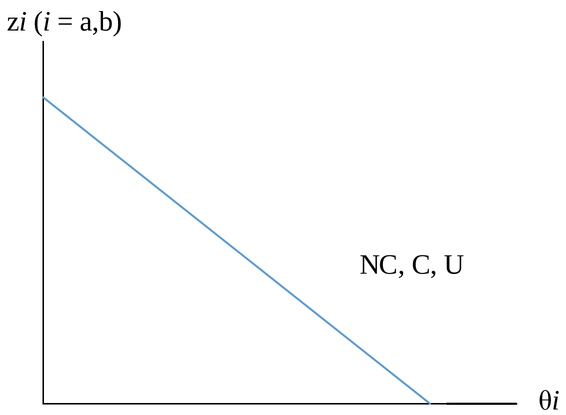

Figure 3.5 The effect of changes in gross pollution on optimal pollution quotas for MNC case

For non-cooperative case, since the higher gross pollution of domestic firm in country B causes stricter environmental policy in that country because of the higher negative effect of the pollution disutility, the country A also will also try to set stricter environmental policy. This is because the stricter environmental policy in country B will lead domestic firm to decrease its production. As a result, the firms in host country will increase their production but this increase in total output will generate more pollution. Although high production provides profit and employment effect, the negative effect of pollution on welfare will dominate them so the government of country A will decrease its emission quota. On the other hand, when the gross pollution of domestic firm in country A increases, the country B will set less severe pollution quota. An increase in the gross pollution will lead to decrease the production of domestic firm for both local and foreign market so MNC will increase its production for both markets. Therefore, to protect its domestic firm in the local market, the country B will allow to emit more pollution. When there is cooperation, this situation is viable for domestic firm in country B but domestic firm in country A is again insensitive to the change in gross pollution of rival domestic firm. This is because the higher impact of MNC dominates the impact of other domestic firm. Finally, if there is a uniform emission standard, the countries apply more severe pollution quotas when the gross pollution of domestic firms increase.

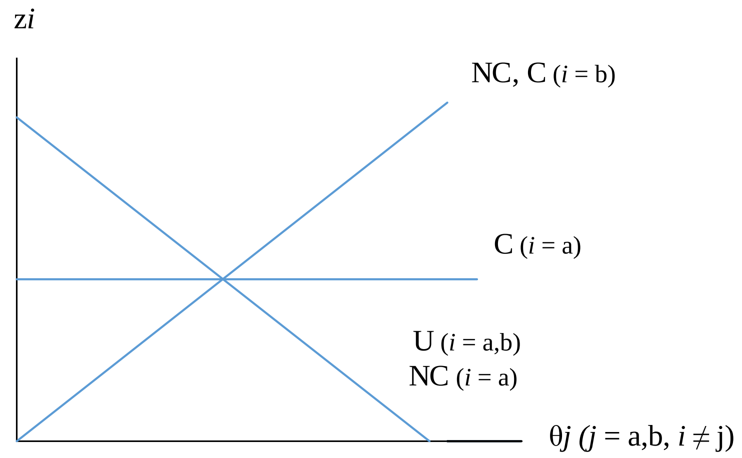

Figure 3.6 The effect of changes in gross pollution of rival firm on optimal pollution quotas for MNC case

For three cases, an increase in the level of gross pollution by MNC increases its production cost and hence decreases its output. This reduction in production affects the host country's welfare adversely because it increases price level and also decreases the employment level. Therefore, country A will impose less severe environmental policy to encourage MNC to produce more. When the gross pollution of MNC increases, the country B will also impose less severe pollution quota because the higher gross pollution of MNC will causes to increase the cost of MNC and therefore to increase the production of domestic firm in country A. Since the domestic firm in country B competes with this firm, the government will raise the level of pollution quota to encourage domestic production.

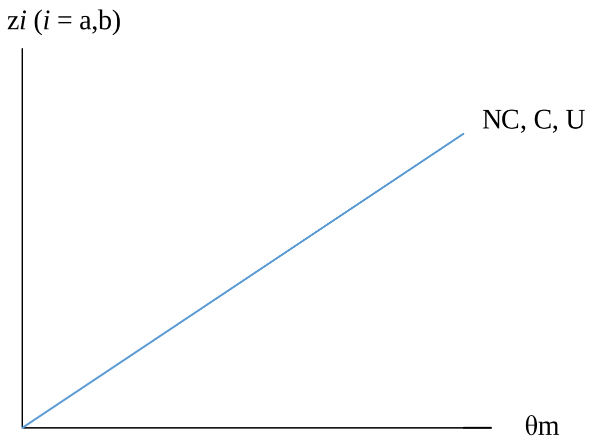

Figure 3.7 The effect of changes in gross pollution of MNC on optimal pollution quotas for MNC case

Pollution quotas and abatement cost: As explained in the benchmark model, when the per unit abatement cost increases, governments will increase their non-cooperative, cooperative and uniform optimal policy levels since the negative effect of relaxing the pollution standards will be small comparing to the other positive effects on welfare.

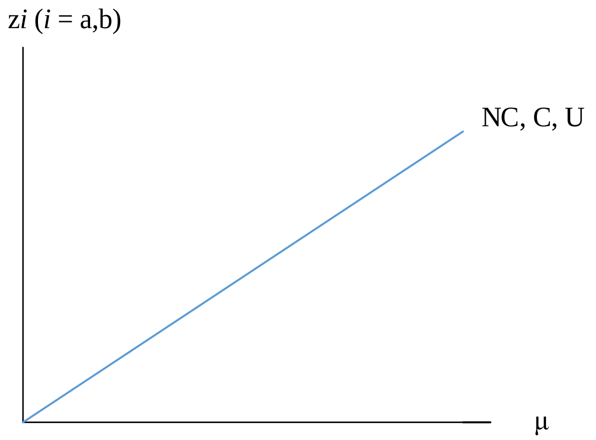

Figure 3.8 The effect of changes in per unit abatement cost on optimal pollution quotas for MNC case

Pollution quotas and the marginal disutility of pollution: An increase in the disutility of pollution generated by local production will reduce the optimal non-cooperative and cooperative pollution levels like in the benchmark model.

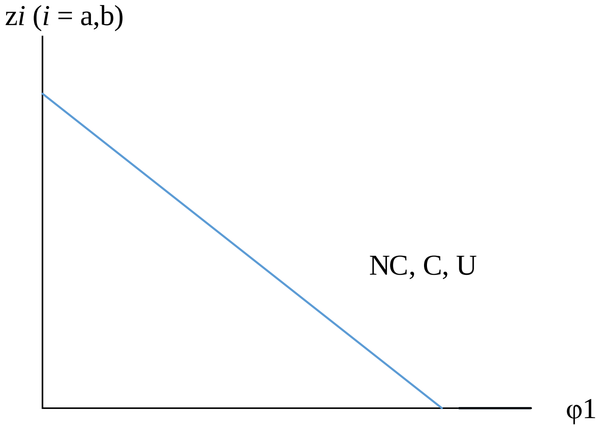

Figure 3.9 The effect of changes in marginal disutility of pollution generated by domestic production on optimal pollution quotas for MNC case

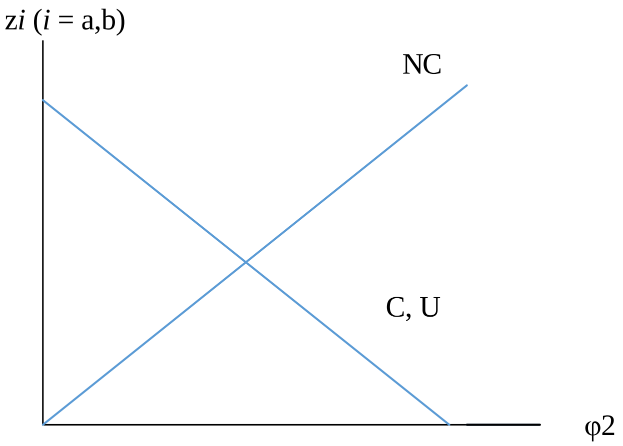

Figure 3.10 The effect of changes in marginal disutility of pollution generated by foreign production on optimal pollution quotas for MNC case

On the other hand, an increase in the disutility of pollution generated by foreign production increases the optimal non-cooperative emission levels and decreases the optimal cooperative and uniform emission levels because of the reasons explained before.

3.3. Conclusion

In the extended model, we analyze environmental policy decisions of two asymmetric countries with different market conditions. All the features of countries are same with the benchmark model but we add a multinational company which wants to locate in a country with more inefficient domestic firms to the model. It is assumed that MNC is technologically superior to the domestic firms and the profit of MNC is fully repatriated to the source country so the host country can benefit from MNC through the employment effect not the producer surplus.

We find that host country always impose stricter emission policy than other country. Since the profit of MNC is fully repatriated and the employment created by MNC is minor because of the efficiency, the most important effect of MNC on the host country's welfare is the pollution effect. According to the results, the host country always has lower emissions level. However this low pollution level does not meet enough the other losses in welfare caused by consumer surplus and employment. Although there is still a gain in welfare, this value is under the gain of other country and the gain in the benchmark model. Since the host country is affected MNC mainly by way of low pollution, the government focuses on the strict environmental policy in order to reduce pollution effect on welfare as much as possible.

On the other hand, when there is a MNC in rival country, the other country's welfare will be better off compared to the benchmark model and host country. The main difference between welfare of two countries results from producer surplus and pollution. Although the negative effect of pollution is high, the production of domestic firm in that country is also high so the benefit from producer surplus is much more than the host country. This increase in producer surplus is able to dominate the negative effects of high pollution. Additionally, domestic production only depends on local firm so this firm is in an advantageous position and it makes more profit than its rival in host country does. Therefore, the governments can use the power of policy-making and limit domestic production to reduce pollution in the country. In this way, the pressure on welfare caused by pollution can be reduced significant amount while the local firm can continue to make profit. Briefly, the competitive advantage of domestic firm allows the government to set more stringent environmental policy.

It is shown that cooperation is always Pareto-improving for the welfare of countries. When there is cooperation, governments decrease their optimal policy level because of the negative externalities so the disutility of pollution on welfare will decrease. The gain from this reduction is quite high compared to the other losses caused by decreasing production and hence increasing price.

4. CONCLUSION AND RECOMMENDATIONS

In this thesis, we examine the optimal non-cooperative and cooperative environmental policies in the case of foreign direct investment and cross border pollution. We develop a model in which there are two countries and each country has one domestic firm. Firms produce homogeneous product and it is assumed that there is an intra-industry trade between the countries so firms serve both domestic and foreign markets. Pollution occurs during production and there is cross border pollution between two countries. Both countries have unemployment. Then we extend the model by allowing the entry of MNC into the country with more inefficient domestic firm. It is assumed that MNC is technologically superior to the domestic firms in terms of production and abatement activities also it fully repatriates its profit to the source country. The welfare of both countries consists of consumer surplus, producer surplus, employment and disutility of pollution. Countries use environmental policy in order to maximize their welfare and they can restrict the pollution level that firms are allowed to emit. For two models, we find that non-cooperative behavior puts always more pressure on welfare in terms of pollution. Although the other parts of welfare decline with cooperation, the reduction in the negative effect of pollution is much more than the other losses. Therefore, cooperative behavior in environmental policy is always Pareto-improving for the countries.

According to our results, the multinational company can affect the both countries' environmental policy decisions. When there is a MNC in the market, the host country always sets more severe environmental policy than the other country. This is because the host country can benefit from MNC through only the employment effect not the producer surplus because of the fully repatriation of profit. Therefore, the government does not worry to lose profit gain from foreign company so it can keep its power of environmental policy implementation. Since the efficiency of MNC is high, the employment created by MNC is less than the created by domestic firms. Although the total pollution of host country is lower than the other country, the government imposes stricter policy to compensate the losses in welfare by decreasing negative effect of pollution. Furthermore, the other country also applies more severe environmental policy compared to the benchmark model because of the advantageous position of its domestic firm. Since there is no competition in domestic production, the local firm can continue to make more profit than its rival does even if the government reduces the level of pollution quota. Therefore, compared to the benchmark model, the government has more control power to tighten emission quotas.

It is said that countries may feel pressure to reduce their environmental standards to attract or keep FDI. However, we show that FDI can also affect the countries' policies oppositely. In the presence of multinational company, governments may set stricter environmental policy depending on the different conditions. MNC may reduce pollution in host country and it may also affect pollution level of rival country by creating asymmetric competition which increases the government's policy-making power on domestic firms. The model can be extended by developing different market structures or determining the location decision of MNC endogenously. In addition, different assumptions about international trade and transboundary pollution can be examined in future research.

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APPENDICES

APPENDIX A

The Benchmark Model

Non-cooperative solution

$$\frac{\partial za^N}{\partial \alpha} = \frac{\partial zb^N}{\partial \alpha} = \frac{5\mu - 3\phi 1}{\mu.(-5\mu + 9\phi 1 - 3\phi 2)}$$

$$\frac{\partial za^N}{\partial ca} = \frac{\partial zb^N}{\partial cb} = \frac{6\mu^2 - 40\mu\phi 1 + 42\phi 1^2 + 7\mu\phi 2 - 6\phi 1\phi 2}{2\mu.(4\mu - 5\phi 1 - \phi 2).(5\mu - 9\phi 1 + 3\phi 2)}$$

$$\frac{\partial za^N}{\partial cb} = \frac{\partial zb^N}{\partial ca} = \frac{-14\mu^2 + \mu(26\phi 1 - 5\phi 2) + 12\phi 1(-\phi 1 + \phi 2)}{2\mu.(4\mu - 5\phi 1 - \phi 2).(5\mu - 9\phi 1 + 3\phi 2)}$$

$$\frac{\partial za^N}{\partial \theta a} = \frac{\partial zb^N}{\partial \theta b} = \frac{40\mu^2 - 88\mu\phi 1 + 42\phi 1^2 + 7\mu\phi 2 - 6\phi 1\phi 2}{2.(4\mu - 5\phi 1 - \phi 2).(5\mu - 9\phi 1 + 3\phi 2)}$$

$$\frac{\partial za^N}{\partial \theta b} = \frac{\partial zb^N}{\partial \theta a} = \frac{\mu.(14\phi 1 - 17\phi 2) + 12\phi 1.(-\phi 1 + \phi 2)}{2.(4\mu - 5\phi 1 - \phi 2).(5\mu - 9\phi 1 + 3\phi 2)}$$

$$\begin{aligned}\frac{\partial za^N}{\partial \phi 1} = \frac{\partial zb^N}{\partial \phi 1} = {} & \frac{1}{2\mu.(20\mu^2 - 61\mu\phi 1 + 45\phi 1^2 + 7\mu\phi 2 - 6\phi 1\phi 2 - 3\phi 2^2)^2} \\ & - (2.(20\mu^2 - 61\mu\phi 1 + 45\phi 1^2 + 7\mu\phi 2 - 6\phi 1\phi 2 - 3\phi 2^2).(-13cb\mu \\ & + 12cb\phi 1 - 6cb\phi 2 + ca(20\mu - 42\phi 1 + 3\phi 2) \\ & + \alpha.(-37\mu + 30\phi 1 + 3\phi 2) + 44\mu^2\theta a - 42\mu\phi 1\theta a + 3\mu\phi 2\theta a - 7\mu^2\theta b \\ & + 12\mu\phi 1\theta b - 6\mu\phi 2\theta b) + (-61\mu + 90\phi 1 - 6\phi 2).(-14cb\mu^2 + 26cb\mu\phi 1 \\ & - 12cb\phi 1^2 - 2\alpha.(5\mu - 3\phi 1).(4\mu - 5\phi 1 - \phi 2) - 5cb\mu\phi 2 + 12cb\phi 1\phi 2 \\ & + ca.(6\mu^2 - 40\mu\phi 1 + 42\phi 1^2 + 7\mu\phi 2 - 6\phi 1\phi 2) + 40\mu^3\theta a - 88\mu^2\phi 1\theta a \\ & + 42\mu\phi 1^2\theta a + 7\mu^2\phi 2\theta a - 6\mu\phi 1\phi 2\theta a + 14\mu^2\phi 1\theta b - 12\mu\phi 1^2\theta b \\ & - 17\mu^2\phi 2\theta b + 12\mu\phi 1\phi 2\theta b))\end{aligned}$$

$$\frac{\partial za^N}{\partial \phi 2}=\frac{\partial zb^N}{\partial \phi 2}=\frac{1}{2\mu.(20\mu^2-61\mu\phi 1+45\phi 1^2+7\mu\phi 2-6\phi 1\phi 2-3\phi 2^2)^2}\,((20\mu^2-61\mu\phi 1+45\phi 1^2+7\mu\phi 2-6\phi 1\phi 2-3\phi 2^2).(10\alpha\mu+7ca\mu-5cb\mu-6\alpha\phi 1-6ca\phi 1+12cb\phi 1+7\mu^2\theta a-6\mu\phi 1\theta a-17\mu^2\theta b+12\mu\phi 1\theta b)-\big(7\mu-6(\phi 1+\phi 2)\big).(-14cb\mu^2+26cb\mu\phi 1-12cb\phi 1^2-2\alpha.(5\mu-3\phi 1).(4\mu-5\phi 1-\phi 2)-5cb\mu\phi 2+12cb\phi 1\phi 2+ca.(6\mu^2-40\mu\phi 1+42\phi 1^2+7\mu\phi 2-6\phi 1\phi 2)+40\mu^3\theta a-88\mu^2\phi 1\theta a+42\mu\phi 1^2\theta a+7\mu^2\phi 2\theta a-6\mu\phi 1\phi 2\theta a+14\mu^2\phi 1\theta b-12\mu\phi 1^2\theta b-17\mu^2\phi 2\theta b+12\mu\phi 1\phi 2\theta b))$$

$$\frac{\partial za^N}{\partial \mu}=\frac{\partial zb^N}{\partial \mu}=\frac{1}{2\mu.(20\mu^2-61\mu\phi 1+45\phi 1^2+7\mu\phi 2-6\phi 1\phi 2-3\phi 2^2)^2}\,(280cb\mu^4-1040cb\mu^3\phi 1+1676cb\mu^2\phi 1^2-1464cb\mu\phi 1^3+540cb\phi 1^4+200cb\mu^3\phi 2-1123cb\mu^2\phi 1\phi 2+1632cb\mu\phi 1^2\phi 2-612cb\phi 1^3\phi 2+77cb\mu^2\phi 2^2-168cb\mu\phi 1\phi 2^2+36cb\phi 1^2\phi 2^2+36cb\phi 1\phi 2^3+2\alpha(25\mu^2-30\mu\phi 1+9\phi 1(3\phi 1-\phi 2))(-4\mu+5\phi 1+\phi 2)^2+ca(-120\mu^4+40\mu^3(40\phi 1-7\phi 2)+\mu^2(-4690\phi+1031\phi 1\phi 2-67\phi 2^2)+12\mu\phi 1(427\phi 1^2-110\phi 1\phi 2+7\phi 2^2)-18\phi 1(105\phi 1^3-29\phi 1^2\phi 2-5\phi 1\phi 2^2+\phi 2^3))-680\mu^4\phi 1\theta a+1920\mu^3\phi 1^2\theta a-1398\mu^2\phi 1^3\theta a+140\mu^4\phi 2\theta a-240\mu^3\phi 1\phi 2\theta a+183\mu^2\phi 1^2\phi 2\theta a-240\mu^3\phi 2^2\theta a+264\mu^2\phi 1\phi 2^2\theta a-21\mu^2\phi 2^3\theta a-280\mu^4\phi 1\theta b+480\mu^3\phi 1^2\theta b-102\mu^2\phi 1^3\theta b+340\mu^4\phi 2\theta b-480\mu^3\phi 1\phi 2\theta b-33\mu^2\phi 1^2\phi 2\theta b-24\mu^2\phi 1\phi 2^2\theta b+51\mu^2\phi 2^3\theta b)$$

Cooperative solutions

$$\frac{\partial za^C}{\partial \alpha}=\frac{\partial zb^C}{\partial \alpha}=\frac{4\mu-3.(\phi 1+\phi 2)}{2\mu.(3.(\phi 1+\phi 2)-2\mu)}$$

$$\frac{\partial za^C}{\partial ca}=\frac{\partial zb^C}{\partial cb}=\frac{3.\big(-\mu+2.(\phi 1+\phi 2)\big)}{4\mu.(3.(\phi 1+\phi 2)-2\mu)}$$

$$\frac{\partial za^C}{\partial cb}=\frac{\partial zb^C}{\partial ca}=\frac{1}{4.(3.(\phi 1+\phi 2)-2\mu)}$$

$$\frac{\partial za^C}{\partial \theta a}=\frac{\partial zb^C}{\partial \theta b}=\frac{8\mu^2-15\mu.(\phi 1+\phi 2)+6.(\phi 1+\phi 2)^2}{4.(2\mu^2-5\mu.(\phi 1+\phi 2)+3.(\phi 1+\phi 2)^2)}$$

$$\frac{\partial za^C}{\partial \theta b}=\frac{\partial zb^C}{\partial \theta a}=\frac{\mu.(\phi 1+\phi 2)}{4.(2\mu^2-5\mu.(\phi 1+\phi 2)+3.(\phi 1+\phi 2)^2)}$$

$$\frac{\partial za^{C}}{\partial \phi 1}=\frac{\partial zb^{C}}{\partial \phi 1}=-\frac{1}{4\mu.(2\mu^{2}-5\mu.(\phi 1+\phi 2)+3.(\phi 1+\phi 2)^{2})}\,(3cb\mu^{2}-6cb\mu\phi 1$$
$$+3cb\phi 1^{2}-6cb\mu\phi 2+6cb\phi 1\phi 2+3cb\phi 2^{2}+12a(-\mu+\phi 1+\phi 2)^{2}$$
$$+3ca(-\mu+\phi 1+\phi 2)^{2}-10\mu^{3}\theta a+24\mu^{2}\phi 1\theta a-15\mu\phi 1^{2}\theta a$$
$$+24\mu^{2}\phi 2\theta a-30\mu\phi 1\phi 2\theta a-15\mu\phi 2^{2}\theta a-2\mu^{3}\theta b+3\mu\phi 1^{2}\theta b$$
$$+6\mu\phi 1\phi 2\theta b+3\mu\phi 2^{2}\theta b$$

$$\frac{\partial za^{C}}{\partial \phi 2}=\frac{\partial zb^{C}}{\partial \phi 2}=-\frac{1}{4\mu.(2\mu^{2}-5\mu.(\phi 1+\phi 2)+3.(\phi 1+\phi 2)^{2})}\,(3cb\mu^{2}-6cb\mu\phi 1$$
$$+3cb\phi 1^{2}-6cb\mu\phi 2+6cb\phi 1\phi 2+3cb\phi 2^{2}+12a(-\mu+\phi 1+\phi 2)^{2}$$
$$+3ca(-\mu+\phi 1+\phi 2)^{2}-10\mu^{3}\theta a+24\mu^{2}\phi 1\theta a-15\mu\phi 1^{2}\theta a$$
$$+24\mu^{2}\phi 2\theta a-30\mu\phi 1\phi 2\theta a-15\mu\phi 2^{2}\theta a-2\mu^{3}Tb+3\mu\phi 1^{2}\theta b$$
$$+6\mu\phi 1\phi 2\theta b+3\mu\phi 2^{2}\theta b)$$

$$\frac{\partial za^{C}}{\partial \mu}=\frac{\partial zb^{C}}{\partial \mu}=\frac{1}{4\mu.(2\mu^{2}-5\mu.(\phi 1+\phi 2)+3.(\phi 1+\phi 2)^{2})}\,(-6cb(\mu-\phi 1-\phi 2)^{3}(\mu$$
$$-3(\phi 1+\phi 2))+2a(-\mu+\phi 1+\phi 2)^{2}(8\mu^{2}-12\mu(\phi 1+\phi 2)$$
$$+9(\phi 1+\phi 2)^{2})+\mu^{2}(2ca(-\mu+\phi 1+\phi 2)^{2}-(\phi 1+\phi 2)(-24\mu(\phi 1$$
$$+\phi 2)\theta b+3(\phi 1+\phi 2)^{2}(5\theta b-\theta a)+2\mu^{2}(5\theta b+\theta a))))$$

Uniform solutions

$$\frac{\partial z^{U}}{\partial \alpha}=\frac{8\mu-6.(\phi 1+\phi 2)}{4.(3.(\phi 1+\phi 2)-2\mu)}$$

$$\frac{\partial z^{U}}{\partial ca}=\frac{\partial z^{U}}{\partial cb}=-\frac{\mu-3.(\phi 1+\phi 2)}{4.(3.(\phi 1+\phi 2)-2\mu)}$$

$$\frac{\partial z^{U}}{\partial \theta a}=\frac{\partial z^{U}}{\partial \theta b}=-\frac{4\mu-3(\phi 1+\phi 2)}{4.(3.(\phi 1+\phi 2)-2\mu)}$$

$$\frac{\partial z^{U}}{\partial \phi 1}=\frac{\partial z^{U}}{\partial \phi 2}=-\frac{3.(4\alpha+ca+cb-2\mu.(\theta a+\theta b))}{4.(3.(\phi 1+\phi 2)-2\mu)^{2}}$$

$$\frac{\partial z^{U}}{\partial \mu}=-\frac{1}{4\mu^{2}(3.(\phi 1+\phi 2)-2\mu)^{2}}\,(2cb\mu^{2}-12cb\mu\phi 1+9cb\phi 1^{2}-12cb\mu\phi 2$$
$$+18cb\phi 1\phi 2+9cb\phi 2^{2}+ca.(2\mu^{2}-12\mu.(\phi 1+\phi 2)+9(\phi 1+\phi 2)^{2})$$
$$-2\alpha.(8\mu^{2}-12\mu(\phi 1+\phi 2)+9(\phi 1+\phi 2)^{2})+6\mu^{2}\phi 1\theta a+6\mu^{2}\phi 2\theta a$$
$$+6\mu^{2}\phi 1\theta b+6\mu^{2}\phi 2\theta b)$$

APPENDIX B

MNC Case

The difference between the profits of MNC:

$$\pi m^{A} = \frac{1}{(2b\,(19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)^2)}\,(-45cm\mu^2 - 23\alpha\mu\phi1 + 143cm\mu\phi1 + 28\alpha\phi1^2 - 108cm\phi1^2 + 11\alpha\mu\phi2 - 21cm\mu\phi2 - 8a\phi1\phi2 + 16cm\phi1\phi2 - 4a\phi2^2 + 12cm\phi2^2 + ca(19\mu^2 - 77\mu\phi1 + 68\phi1^2 + 15\mu\phi2 - 16\phi1\phi2 - 4\phi2^2) + cb(3\mu^2 + 12\phi1^2 + 8\phi1\phi2 - 4\phi2^2 - \mu(15\phi1 + \phi2)) + 32\mu^3\theta a - 97\mu^2\phi1\theta a + 68\mu\phi1^2\theta a + 19\mu^2\phi2\theta a - 16\mu\phi1\phi2\theta a - 4\mu\phi2^2\theta a - 3\mu^2\phi1\theta b + 12\mu\phi1^2\theta b - 13\mu^2\phi2\theta b + 8\mu\phi1\phi2\theta b - 4\mu\phi2^2\theta b - 32\mu^3\theta m + 123\mu^2\phi1\theta m - 108\mu\phi1^2\theta m - 17\mu^2\phi2\theta m + 16\mu\phi1\phi2\theta m + 12\mu\phi2^2\theta m)^2$$

$$\pi m^{B} = \frac{1}{(2b\,(19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)^2)}\,(-45cmM^2 - 23\alpha\mu\phi1 + 143cm\mu\phi1 + 28\alpha\phi1^2 - 108cm\phi1^2 + 11\alpha\mu\phi2 - 21cm\mu\phi2 - 8\alpha\phi1\phi2 + 16cm\phi1\phi2 - 4\alpha\phi2^2 + 12cm\phi2^2 + cb(19\mu^2 - 77\mu\phi1 + 68\phi1^2 + 15\mu\phi2 - 16\phi1\phi2 - 4\phi2^2) + ca(3\mu^2 + 12\phi1^2 + 8\phi1\phi2 - 4\phi2^2 - \mu(15\phi1 + \phi2)) - 3\mu^2\phi1\theta a + 12\mu\phi1^2\theta a - 13\mu^2\phi2\theta a + 8\mu\phi1\phi2\theta a - 4\mu\phi2^2\theta a + 32\mu^3\theta b - 97\mu^2\phi1\theta b + 68\mu\phi1^2\theta b + 19\mu^2\phi2\theta b - 16\mu\phi1\phi2\theta b - 4\mu\phi2^2\theta b - 32\mu^3\theta m + 123\mu^2\phi1\theta m - 108\mu\phi1^2\theta m - 17\mu^2\phi2\theta m + 16\mu\phi1\phi2\theta m + 12\mu\phi2^2\theta m)^2$$

$$\pi m^{A} - \pi m^{B} = 0.0014158$$

Non-cooperative solution

$$\frac{\partial za^{N}}{\partial \alpha} = \frac{-38\mu^2 - 8\phi1.(7\phi1 + \phi2) + \mu.(97\phi1 + 15\phi2)}{2\mu.(19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)}$$

$$\frac{\partial zb^{N}}{\partial \alpha} = \frac{-19\mu^2 - 8\phi1.(3\phi1 + \phi2) + \mu.(53\phi1 + 7\phi2)}{\mu.(19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)}$$

$$\frac{\partial za^{N}}{\partial ca} = \frac{19\mu^2 - 53\mu\phi1 + 40\phi1^2 + 11\mu\phi2 - 8\phi1\phi2}{2\mu.(19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)}$$

$$\frac{\partial zb^{N}}{\partial cb} = \frac{4\mu^2 + 8\phi1.(5\phi1 - \phi2) + 3\mu.(-9\phi1 + \phi2)}{\mu.(19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)}$$

$$\frac{\partial za^N}{\partial cb} = \frac{-9\mu^2 + \mu.(33\phi1 - 13\phi2) + 24\phi1.(-\phi1 + \phi2)}{2\mu.(19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)}$$

$$\frac{\partial zb^N}{\partial ca} = \frac{\mu.(11\phi1 - 5\phi2) + 8\phi1.(-\phi1 + \phi2)}{\mu.(19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)}$$

$$\frac{\partial za^N}{\partial cm} = \frac{-55\mu^2 + 43\mu\phi1 + 40\phi1^2 + 11\mu\phi2 - 8\phi1\phi2}{2\mu.(19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)}$$

$$\frac{\partial zb^N}{\partial cm} = \frac{-22\mu^2 + 8\phi1.(-\phi1 + \phi2) + \mu.(27\phi1 + 11\phi2)}{\mu.(19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)}$$

$$\frac{\partial za^N}{\partial \theta a} = \frac{56\mu^2 - 101\mu\phi1 + 40\phi1^2 + 11\mu\phi2 - 8\phi1\phi2}{2.(19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)}$$

$$\frac{\partial zb^N}{\partial \theta b} = \frac{19\mu^2 - 75\mu\phi1 + 40\phi1^2 + 3\mu\phi2 - 8\phi1\phi2}{19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2}$$

$$\frac{\partial za^N}{\partial \theta b} = \frac{\mu.(9\phi1 - 37\phi2) + 24\phi1.(-\phi1 + \phi2)}{2.(19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)}$$

$$\frac{\partial zb^N}{\partial \theta a} = \frac{11\mu^2 + 3\mu\phi1 - 8\phi1 - 13\mu\phi2 + 8\phi1\phi2}{19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2}$$

$$\frac{\partial za^N}{\partial \theta m} = \frac{-18\mu^2 - 5\mu\phi1 + 40\phi1^2 + 11\mu\phi2 - 8\phi1\phi2}{2.(19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)}$$

$$\frac{\partial zb^N}{\partial \theta m} = \frac{-11\mu^2 + 8\phi1.(-\phi1 + \phi2) + \mu.(19\phi1 + 3\phi2)}{19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2}$$

$$\begin{aligned}\frac{\partial za^N}{\partial \phi1} = {} & \frac{1}{2\mu\,(19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)^2}\,(-(19\mu^2 - 90\mu\phi1 \\ & + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)(-33cb\mu - 43cm\mu + 48cb\phi1 \\ & - 80cm\phi1 - 24cb\phi2 + 8cm\phi2 + ca(53\mu - 80\phi1 + 8\phi2) + \alpha(-97\mu \\ & + 8(14\phi1 + \phi2)) + 101\mu^2\theta a - 80\mu\phi1\theta a + 8\mu\phi2\theta a - 9\mu\theta b + 48\mu\phi1\theta b \\ & - 24\mu\phi2\theta b + 5\mu^2\theta m - 80\mu\phi1\theta m + 8\mu\phi2\theta m) + 2(45\mu - 88\phi1 \\ & + 8\phi2)(-9cb\mu^2 - 55cm\mu^2 + 33cb\mu\phi1 + 43cm\mu\phi1 - 24cb\phi1^2 \\ & + 40cm\phi1^2 - 13cb\mu\phi2 + 11cm\mu\phi2 + 24cb\phi1\phi2 - 8cm\phi1\phi2 \\ & + ca(19\mu^2 - 53\mu\phi1 + 40\phi1^2 + 11\mu\phi2 - 8\phi1\phi2) + \alpha(-38\mu^2 \\ & - 8\phi1(7\phi1 + \phi2) + \mu(97\phi1 + 15\phi2)) + 56\mu^3\theta a - 101\mu^2\phi1\theta a \\ & + 40\mu\phi1^2\theta a + 11\mu^2\phi2\theta a - 8\mu\phi1\phi2\theta a + 9\mu^2\phi1\theta b - 24\mu\phi1^2\theta b \\ & - 37\mu^2\phi2\theta b + 24\mu\phi1\phi2\theta b - 18\mu^3\theta m - 5\mu^2\phi1\theta m + 40\mu\phi1^2\theta m \\ & + 11\mu^2\phi2\theta m - 8\mu\phi1\phi2\theta m))\end{aligned}$$

$$\frac{\partial za^N}{\partial \phi 2} = \frac{1}{2\mu\,(19\mu^2 - 90\mu\phi 1 + 88\phi 1^2 + 14\mu\phi 2 - 16\phi 1\phi 2 - 8\phi 2^2)^2}\,((19\mu^2 - 90\mu\phi 1$$
$$+ 88\phi 1^2 + 14\mu\phi 2 - 16\phi 1\phi 2 - 8\phi 2^2)(15\alpha\mu + 11ca\mu - 13cb\mu$$
$$+ 11cm\mu - 8a\phi 1 - 8ca\phi 1 + 24cb\phi 1 - 8cm\phi 1 + 11\mu^2\theta a - 8M\phi 1\theta a$$
$$- 37\mu^2\theta b + 24\mu\phi 1\theta b + 11\mu^2\theta m - 8\mu\phi 1\theta m) - 2(7\mu - 8(\phi 1$$
$$+ \phi 2))(-9cb\mu^2 - 55cm\mu^2 + 33cb\mu\phi 1 + 43cm\mu\phi 1 - 24cb\phi 1^2$$
$$+ 40cm\phi 1^2 - 13cb\mu\phi 2 + 11cm\mu\phi 2 + 24cb\phi 1\phi 2 - 8cm\phi 1\phi 2$$
$$+ ca(19\mu^2 - 53\mu\phi 1 + 40\phi 1^2 + 11\mu\phi 2 - 8\phi 1\phi 2) + \alpha(-38\mu$$
$$- 8\phi 1(7\phi 1 + \phi 2) + \mu(97\phi 1 + 15\phi 2)) + 56\mu^3\theta a - 101\mu^2\phi 1\theta a$$
$$+ 40\mu\phi 1^2\theta a + 11\mu^2\phi 2\theta a - 8\mu\phi 1\phi 2\theta a + 9\mu^2\phi 1\theta b - 24M\phi 1^2\theta b$$
$$- 37\mu^2\phi 2\theta b + 24\mu\phi 1\phi 2\theta b - 18\mu^3\theta m - 5\mu^2\phi 1\theta m + 40\mu\phi 1^2\theta m$$
$$+ 11\mu^2\phi 2\theta m - 8\mu\phi 1\phi 2\theta m))$$

$$\frac{\partial zb^N}{\partial \phi 1} = \frac{1}{\mu\,(19\mu^2 - 90\mu\phi 1 + 88\phi 1^2 + 14\mu\phi 2 - 16\phi 1\phi 2 - 8\phi 2^2)^2}\,((19\mu^2 - 90\mu\phi 1$$
$$+ 88\phi 1^2 + 14\mu\phi 2 - 16\phi 1\phi 2 - 8\phi 2^2)(-27cb\mu + 27cm\mu + 80cb\phi 1$$
$$- 16cm\phi 1 - 8cb\phi 2 + 8cm\phi 2 + ca(11\mu - 16\phi 1 + 8\phi 2) + \alpha(53\mu$$
$$- 8(6\phi 1 + \phi 2)) + 3\mu^2\theta a - 16\mu\phi 1\theta a + 8\mu\phi 2\theta a - 75\mu^2\theta b + 80\mu\phi 1\theta b$$
$$- 8\mu\phi 2\theta b + 19\mu^2\theta m - 16\mu\phi 1\theta m + 8\mu\phi 2\theta m) + 2(45\mu - 88\phi 1$$
$$+ 8\phi 2)(-22cm\mu^2 + 11ca\mu\phi 1 + 27cm\mu\phi 1 - 8ca\phi 1^2 - 8cm\phi 1^2$$
$$- 5ca\mu\phi 2 + 11cm\mu\phi 2 + 8ca\phi 1\phi 2 + 8cm\phi 1\phi 2 + cb(4\mu^2 + 8\phi 1(5\phi 1$$
$$- \phi 2) + 3\mu(-9\phi 1 + \phi 2)) + \alpha(-19\mu^2 - 8\phi 1(3\phi 1 + \phi 2) + \mu(53\phi 1$$
$$+ 7\phi 2)) + 11\mu^3\theta a + 3\mu^2\phi 1\theta a - 8\mu\phi 1^2\theta a - 13\mu^2\phi 2\theta a + 8\mu\phi 1\phi 2\theta a$$
$$+ 19\mu\theta b - 75\mu^2\phi 1\theta b + 40\mu\phi 1^2\theta b + 3\mu^2\phi 2\theta b - 8\mu\phi 1\phi 2\theta b - 11\mu^3\theta m$$
$$+ 19\mu^2\phi 1\theta m - 8\mu\phi 1^2\theta m + 3\mu^2\phi 2\theta m + 8\mu\phi 1\phi 2\theta m))$$

$$\frac{\partial zb^N}{\partial \phi 2} = \frac{1}{\mu\,(19\mu^2 - 90\mu\phi 1 + 88\phi 1^2 + 14\mu\phi 2 - 16\phi 1\phi 2 - 8\phi 2^2)^2}\,((19\mu^2 - 90\mu\phi 1$$
$$+ 88\phi 1^2 + 14\mu\phi 2 - 16\phi 1\phi 2 - 8\phi 2^2)(7\alpha\mu - 5ca\mu + 3cb\mu + 11cm\mu$$
$$- 8a\phi 1 + 8ca\phi 1 - 8cb\phi 1 + 8cm\phi 1 - 13\mu^2\theta a + 8\mu\phi 1\theta a + 3\mu^2\theta b$$
$$- 8\mu\phi 1\theta b + 3\mu^2\theta m + 8\mu\phi 1\theta m) - 2(7\mu - 8(\phi 1 + \phi 2))(-22cm\mu^2$$
$$+ 11ca\mu\phi 1 + 27cm\mu\phi 1 - 8ca\phi 1^2 - 8cm\phi 1^2 - 5ca\mu\phi 2 + 11cm\mu\phi 2$$
$$+ 8ca\phi 1\phi 2 + 8cm\phi 1\phi 2 + cb(4\mu^2 + 8\phi 1(5\phi 1 - \phi 2) + 3\mu(-9\phi 1$$
$$+ \phi 2)) + \alpha(-19\mu^2 - 8\phi 1(3\phi 1 + \phi 2) + \mu(53\phi 1 + 7\phi 2)) + 11\mu^3\theta a$$
$$+ 3\mu^2\phi 1\theta a - 8\mu\phi 1^2\theta a - 13\mu^2\phi 2\theta a + 8\mu\phi 1\phi 2\theta a + 19\mu^3\theta b$$
$$- 75\mu^2\phi 1\theta b + 40\mu\phi 1^2\theta b + 3\mu^2\phi 2\theta b - 8\mu\phi 1\phi 2\theta b - 11\mu^3\theta m$$
$$+ 19\mu^2\phi 1\theta m - 8\mu\phi 1^2\theta m + 3\mu^2\phi 2\theta m + 8\mu\phi 1\phi 2\theta m))$$

$$
\begin{aligned}
\frac{\partial za^{N}}{\partial \mu} = {} & \frac{1}{2\mu^2(19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)^2} - (-\mu(19\mu^2 \\
& - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)(-18cb\mu - 110cm\mu \\
& + 33cb\phi1 + 43cm\phi1 - 13cb\phi2 + 11cm\phi2 + ca(38\mu - 53\phi1 + 11\phi2) \\
& + \alpha(-76\mu + 97\phi1 + 15\phi2) + 168\mu^2\theta a - 202\mu\phi1\theta a + 40\phi1^2\theta a \\
& + 22\mu\phi2\theta a - 8\phi1\phi2\theta a + 18\mu\phi1\theta b - 24\phi1^2\theta b - 74\mu\phi2\theta b \\
& + 24\phi1\phi2\theta b - 54\mu^2\theta m - 10\mu\phi1\theta m + 40\phi1^2\theta m + 22\mu\phi2\theta m \\
& - 8\phi1\phi2\theta m) + \mu(38\mu - 90\phi1 + 14\phi2)(-9cb\mu^2 - 55cm\mu^2 + 33cb\mu\phi1 \\
& + 43cm\mu\phi1 - 24cb\phi1^2 + 40cm\phi1^2 - 13cb\mu\phi2 + 11cm\mu\phi2 \\
& + 24cb\phi1\phi2 - 8cm\phi1\phi2 + ca(19\mu^2 - 53\mu\phi1 + 40\phi1^2 + 11\mu\phi2 \\
& - 8\phi1\phi2) + \alpha(-38\mu^2 - 8\phi1(7\phi1 + \phi2) + \mu(97\phi1 + 15\phi2)) + 56\mu\theta a \\
& - 101\mu^2\phi1\theta a + 40\mu\phi1^2\theta a + 11\mu^2\phi2\theta a - 8\mu\phi1\phi2\theta a + 9\mu^2\phi1\theta b \\
& - 24\mu\phi1^2\theta b - 37\mu^2\phi2\theta b + 24\mu\phi1\phi2\theta b - 18\mu^3\theta m - 5\mu^2\phi1\theta m \\
& + 40\mu\phi1^2\theta m + 11\mu^2\phi2\theta m - 8\mu\phi1\phi2\theta m) + (19\mu^2 - 90\mu\phi1 + 88\phi1^2 \\
& + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)(-9cb\mu^2 - 55cm\mu^2 + 33cb\mu\phi1 \\
& + 43cm\mu\phi1 - 24cb\phi1^2 + 40cm\phi1^2 - 13cb\mu\phi2 + 11cm\mu\phi2 \\
& + 24cb\phi1\phi2 - 8cm\phi1\phi2 + ca(19\mu^2 - 53\mu\phi1 + 40\phi1^2 + 11\mu\phi2 \\
& - 8\phi1\phi2) + \alpha(-38\mu^2 - 8\phi1(7\phi1 + \phi2) + \mu(97\phi1 + 15\phi2)) \\
& + 56\mu^3\theta a - 101\mu^2\phi1\theta a + 40\mu\phi1^2\theta a + 11\mu^2\phi2\theta a - 8\mu\phi1\phi2\theta a \\
& + 9\mu^2\phi1\theta b - 24\mu\phi1^2\theta b - 37\mu^2\phi2\theta b + 24\mu\phi1\phi2\theta b - 18\mu^3\theta m \\
& - 5\mu^2\phi1\theta m + 40\mu\phi1^2\theta m + 11\mu^2\phi2\theta m - 8\mu\phi1\phi2\theta m))
\end{aligned}
$$

$$\frac{\partial zb^{N}}{\partial \mu} = \frac{1}{\mu^2(19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)^2}\,(\mu(19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)(-44cm\mu + 11ca\phi1 + 27cm\phi1 - 5ca\phi2 + 11cm\phi2 + cb(8\mu - 27\phi1 + 3\phi2) + \alpha(-38\mu + 53\phi1 + 7\phi2) + 33\mu^2\theta a + 6\mu\phi1\theta a - 8\phi1^2\theta a - 26\mu\phi2\theta a + 8\phi1\phi2\theta a + 57\mu^2\theta b - 150\mu\phi1\theta b + 40\phi1^2\theta b + 6\mu\phi2\theta b - 8\phi1\phi2\theta b - 33\mu^2\theta m + 38\mu\phi1\theta m - 8\phi1^2\theta m + 6\mu\phi2\theta m + 8\phi1\phi2\theta m) - \mu(38\mu - 90\phi1 + 14\phi2)(-22cm\mu^2 + 11ca\mu\phi1 + 27cm\mu\phi1 - 8ca\phi1^2 - 8cm\phi1^2 - 5ca\mu\phi2 + 11cm\mu\phi2 + 8ca\phi1\phi2 + 8cm\phi1\phi2 + cb(4\mu + 8\phi1(5\phi1 - \phi2) + 3\mu(-9\phi1 + \phi2)) + \alpha(-19\mu^2 - 8\phi1(3\phi1 + \phi2) + \mu(53\phi1 + 7\phi2)) + 11\mu^3\theta a + 3\mu^2\phi1\theta a - 8\mu\phi1^2\theta a - 13\mu^2\phi2\theta a + 8\mu\phi1\phi2\theta a + 19\mu^3\theta b - 75\mu^2\phi1\theta b + 40\mu\phi1^2\theta b + 3\mu^2\phi2\theta b - 8\mu\phi1\phi2\theta b - 11\mu^3\theta m + 19\mu^2\phi1\theta m - 8\mu\phi1^2\theta m + 3\mu^2\phi2\theta m + 8\mu\phi1\phi2\theta m) - (19\mu^2 - 90\mu\phi1 + 88\phi1^2 + 14\mu\phi2 - 16\phi1\phi2 - 8\phi2^2)(-22cm\mu^2 + 11ca\mu\phi1 + 27cm\mu\phi1 - 8ca\phi1^2 - 8cm\phi1^2 - 5ca\mu\phi2 + 11cm\mu\phi2 + 8ca\phi1\phi2 + 8cm\phi1\phi2 + cb(4\mu^2 + 8\phi1(5\phi1 - \phi2) + 3\mu(-9\phi1 + \phi2)) + \alpha(-19\mu^2 - 8\phi1(3\phi1 + \phi2) + \mu(53\phi1 + 7\phi2)) + 11\mu^3\theta a + 3\mu^2\phi1\theta a - 8\mu\phi1^2\theta a - 13\mu^2\phi2\theta a + 8\mu\phi1\phi2\theta a + 19\mu^3\theta b - 75\mu^2\phi1\theta b + 40\mu\phi1^2\theta b + 3\mu^2\phi2\theta b - 8\mu\phi1\phi2\theta b - 11\mu^3\theta m + 19\mu^2\phi1Tm - 8\mu\phi1^2Tm + 3\mu^2\phi2\theta m + 8\mu\phi1\phi2\theta m))$$

Cooperative solutions

$$\frac{\partial za^{C}}{\partial \alpha} = -\,\frac{-\mu + \phi1 + \phi2}{\mu.(2.(\phi1 + \phi2) - \mu)}$$

$$\frac{\partial zb^{C}}{\partial \alpha} = \frac{-7\mu^2 + 16\mu.(\phi1 + \phi2) - 8.(\phi1 + \phi2)^2}{\mu.(8.(\phi1 + \phi2) - 7\mu).(2.(\phi1 + \phi2) - \mu)}$$

$$\frac{\partial za^{C}}{\partial ca} = \frac{-\mu + \phi1 + \phi2}{2\mu.(2.(\phi1 + \phi2) - \mu)}$$

$$\frac{\partial zb^{C}}{\partial cb} = \frac{-3\mu + 4(\phi1 + \phi2)}{\mu(8.(\phi1 + \phi2) - 7\mu)}$$

$$\frac{\partial zb^{C}}{\partial ca} = \frac{\phi1 + \phi2}{(8.(\phi1 + \phi2) - 7\mu).(2.(\phi1 + \phi2) - \mu)}$$

$$\frac{\partial za^{C}}{\partial cm} = \frac{\mu + \phi1 + \phi2}{2\mu.(2.(\phi1 + \phi2) - \mu)}$$

$$\frac{\partial zb^C}{\partial cm} = \frac{-2\mu + \phi1 + \phi2}{(8.(\phi1 + \phi2) - 7\mu).(2.(\phi1 + \phi2) - \mu)}$$

$$\frac{\partial za^C}{\partial \theta a} = \frac{-2\mu + \phi1 + \phi2}{2.(2.(\phi1 + \phi2) - \mu)}$$

$$\frac{\partial zb^C}{\partial \theta b} = -\frac{7\mu - 4.(\phi1 + \phi2)}{8.(\phi1 + \phi2) - 7\mu}$$

$$\frac{\partial zb^C}{\partial \theta a} = \frac{\mu.(\mu + \phi1 + \phi2)}{(8.(\phi1 + \phi2) - 7\mu).(2.(\phi1 + \phi2) - \mu)}$$

$$\frac{\partial za^C}{\partial \theta m} = \frac{\phi1 + \phi2}{2.(2.(\phi1 + \phi2) - \mu)}$$

$$\frac{\partial zb^C}{\partial \theta m} = \frac{\mu.(-\mu + \phi1 + \phi2)}{(8.(\phi1 + \phi2) - 7\mu).(2.(\phi1 + \phi2) - \mu)}$$

$$\begin{aligned}\frac{\partial za^C}{\partial \mu} = \frac{1}{2\mu^2.(\mu - 2.(\phi1 + \phi2))^2}\ & 2\alpha\,(\mu^2 - 2\mu(\phi1 + \phi2) + 2(\phi1 + \phi2)^2) \\ & + ca\,(-\mu^2 + 2\mu(\phi1 + \phi2) - 2(\phi1 + \phi2)^2) \\ & + cm\,(\mu^2 + 2\mu\phi1 - 2\phi1^2 + 2\mu\phi2 - 4\phi1\phi2 - 2\phi2^2) \\ & + \theta a\,(-3\mu^2\phi1 - 3\mu^2\phi2) + \theta m\,(\mu^2\phi1 + \mu^2\phi2)\end{aligned}$$

$$\begin{aligned}\frac{\partial zb^C}{\partial \mu} = \frac{1}{\mu^2.(7\mu^2 - 22\mu.(\phi1 + \phi2) + 16.(\phi1 + \phi2)^2)^2}\ & \alpha\,(49\mu^4 - 224\mu^3(\phi1 + \phi2) \\ & + 408\mu^2(\phi1 + \phi2)^2 - 352\mu(\phi1 + \phi2)^3 + 128(\phi1 + \phi2)^4) \\ & + ca\mu^2(\phi1 + \phi2)\big(-14\mu + 22(\phi1 + \phi2)\big) \\ & - cb\,\big(\mu - 2(\phi1 + \phi2)\big)^2(21\mu^2 - 56\mu(\phi1 + \phi2) + 32(\phi1 + \phi2)^2) \\ & + 2cm\mu\,(7\mu^2 - 7\mu(\phi1 + \phi2) - 5(\phi1 + \phi2)^2) \\ & + \theta a\,(-29\mu^4(\phi1 + \phi2) + 32\mu^3(\phi1 + \phi2)^2 + 16\mu^2(\phi1 + \phi2)^3) \\ & + \theta b\,(-28\mu^4(\phi1 + \phi2) + 112\mu^3(\phi1 + \phi2)^2 - 112\mu^2(\phi1 + \phi2)^3) \\ & + \theta m\,(15\mu^4(\phi1 + \phi2) - 32\mu^3(\phi1 + \phi2)^2 + 16\mu^2(\phi1 + \phi2)^3)\end{aligned}$$

Uniform solutions

$$\frac{\partial z^U}{\partial ca} = \frac{\partial z^U}{\partial cb} = -\frac{3\mu - 4(\phi1 + \phi2)}{\mu.(24.(\phi1 + \phi2) - 13\mu)}$$

$$\frac{\partial z^U}{\partial cm} = \frac{5\mu + 4(\phi1 + \phi2)}{\mu.(24.(\phi1 + \phi2) - 13\mu)}$$

$$\frac{\partial z^U}{\partial \theta a} = \frac{\partial z^U}{\partial \theta b} = -\frac{7\mu - 4(\phi1 + \phi2)}{24.(\phi1 + \phi2) - 13\mu}$$

$$\frac{\partial z^{U}}{\partial \theta m} = \frac{\mu + 4(\phi 1 + \phi 2)}{24.(\phi 1 + \phi 2) - 13\mu}$$

$$\frac{\partial z^{U}}{\partial \phi 1} = \frac{\partial z^{U}}{\partial \phi 2} = \frac{4.(-39\alpha + 5.(ca + cb) - 43cm + 29\mu.(\theta a + \theta b) - 19\mu.\theta m)}{(24.(\phi 1 + \phi 2) - 13\mu)^2}$$

$$\begin{aligned}\frac{\partial z^{U}}{\partial \mu} = \frac{1}{\mu^2(24.(\phi 1 + \phi 2) - 13\mu)^2}\ & \alpha\,(169\mu^2 - 312\mu(\phi 1 + \phi 2) + 288(\phi 1 + \phi 2)^2) \\ & + ca\,(-39\mu^2 + 104\mu(\phi 1 + \phi 2) - 96(\phi 1 + \phi 2)^2) \\ & - cb\,(39\mu^2 - 104\mu(\phi 1 + \phi 2) + 96(\phi 1 + \phi 2)^2) \\ & + cm\,(65\mu^2 + 104\mu(\phi 1 + \phi 2) - 96(\phi 1 + \phi 2)^2) \\ & + \theta a\,(-116\mu^2\phi 1 - 116\mu^2\phi 2)\ + \theta b\,(-116\mu^2\phi 1 - 116\mu^2\phi 2) \\ & + 76\theta m\mu^2(\phi 1 + \phi 2)\end{aligned}$$

CURRICULUM VITAE

Name Surname: Merve Kumaş

Place and Date of Birth: 05.04.1990, Kocaeli/Izmit

Address: Emniyetevler Mah., 34400, 4.LEVENT, ISTANBUL/TURKEY

E-Mail: kumas@itu.edu.tr

B.Sc.: 2007-2012 Management Engineering / Istanbul Technical University

Professional Experience and Rewards:

05.2013 - …	YANDEX TURKEY - Assessor Team
03.2014 - 07.2014	Istanbul Technical University- Part-time student assistant
07.2011 - 08.2011	IZAYDAŞ - Integrated management systems intern
08.2010 - 09.2010	TUPRAŞ - Production planning intern