Analyzing the Twin Effects of Trade and Population Ageing on the Environment

Chahreddine Abbes

Thesis submitted to
the Faculty of Graduate and Postdoctoral Studies
in partial fulfillment of the requirements for
the PhD degree in Economics

Department of Economics
Faculty of Social Science
University of Ottawa

Acknowledgement

I am heartily thankful to my supervisor, Professor Marcel Mérette, whose guidance, encouragement, and support from the beginning to the end helped me to explore different topics in various fields, and enhanced my knowledge in constructing and using CGE models. This thesis would have not been possible without the inspiring ideas generated through my fruitful discussions with Professor Marcel Mérette. I simply cannot thank him enough.

It is also a great pleasure to thank those who made this thesis possible, all the members of my committee. I owe my deepest gratitude to Professor Yazid Dissou, Professor Patrick Georges, Professor Zhiqi Chen, and Professor Randal Wigle for their constant support and the time they dedicated to help me see my ideas clearly and to provide me with valuable comments and suggestions. Also, I would like to show my gratitude to Professor Rose Anne Devlin for all her encouragements and great advice. I am so fortunate to have such a dedicated committee. I am grateful to each and every member.

I am indebted to many of my colleagues and friends from the University of Ottawa and Industry Canada who supported me and took time to discuss my research papers. My special thanks go to Mme. Meda-Cristina Horacsek, my director at industry Canada, for giving me the time to focus on my research and finish my thesis, as well as to my manager, Dr. Teodora Cosac, for her advice and suggestions. Also, I would like to express my thanks to my friends Ibtihel Gharbi, Faisal and Rizwana Arif, Catherine Milot, Carlene Belford, Asma Heptulla, and Gloria Tubman for their comments and useful discussions.

Finalement, je veux exprimer ma grande gratitude à ma chère mère pour son support inconditionnel et ses encouragements continuels qui n'a jamais cessé de croire en moi et qui a toujours voulu que je réussisse mon doctorat. Je veux bien lui dédier ce modeste travail pour tous ses sacrifices et ses efforts à prendre soin de la famille, ainsi qu'à ma petite sœur, Wafa, pour l'encourager à continuer de l'avant et à bien réussir ses études.

Ottawa, Canada, March 2011

ABSTRACTS

Chapter One: When is Free Trade Good for the Environment? This paper provides the conditions under which free trade reduces the emission of pollution. In this paper, we construct a computable general equilibrium model of free trade and environment. Using data from different countries with different characteristics with respect to the stringency of their environmental and trade policies and factor endowments, we simulate a reduction on import tariffs and measure the impact on the volume of emission.

Our main findings show that, for a combination of relatively high capital to labour ratio and low level of protectionism, if a country exports the polluting good then, trade liberalization increases the level of emission. Whereas if the country exports the clean good, then the effect of an import tariff reduction on the emission level is positively related to the variation in the producer's price of the polluting good. Furthermore, we find that under a relatively low level of capital endowment for a country that exports the polluting good, the impact of free trade on the environment depends on the degree of protectionism.

Chapter Two: Ageing and the Environment in an Overlapping Generations Model. We empirically investigate the impact of population ageing on the environment using an overlapping generations model. We decompose the impact into scale, composition, and cohort effects. Using data from the Canadian economy, we simulate the impact of demographic shock on the volume of emission.

Population ageing results mostly from a baby bust that follows a baby boom. The demographic transition is characterized by an increase then a decline in the population growth rate. Under the first part of the transition, we find that the scale effect generates more pollution. However, if young generations are more concerned about the environment, an increase in the population growth rate may improve the environment via the composition effects. On the other hand, a decline in the population growth rate (population ageing) creates the opposite results. We further find that cohort effect is positively related to the environment when there is a higher degree of awareness towards a cleaner environment. By comparing

scale to both composition and cohort effects, we find that scale dominates both effects, so population ageing causes the level of pollution to fall.

Chapter Three: Does Population Ageing in the North Leads to More Pollution in the South? We construct a two-country model: a rich country (the North) with relatively high level of capital endowment and stringent environmental policy and a poor country (the South) with less stringent environmental policy. Both countries produce a clean and a polluting good and both have access to an exogenous abatement technology. The paper has three main foci. First, it provides an empirical test for the pollution haven and the factor endowment hypotheses. Second, it introduces the issue of population ageing in the North into the question of trade liberalisation and the environment. Finally, it investigates the impact of demographic and trade shocks on the level of emissions in both countries.

Results from simulations suggest that an increase in the population growth rate increases the volume of emission in the long run. However, population-ageing generates an opposite effect. In the short term, the scale dominates the composition effect. Empirical evidences show that the level of emission is positively related to the size of population. With respect to trade, pollution increases in the North and falls in the South. Also, we find that demographic changes dominate trade liberalization. Finally, worldwide free trade is bad for the environment, but its effect is marginal.

CONTENTS

Introduction……………………………………………………………………....1

1 When is Free Trade Good for the Environment? 5

1.1 Introduction ………………………………………………………………….5

1.2 Literature Review ……………………………………………………..…7

1.2.1 Complexity of the Relationship between Free Trade, Economic Growth and the Environment ……………………………………………………….……...7

1.2.2 Environmental Kuznet Curve: A Development-Environment Relationship…………………………………………………………………...9

1.2.3 The Debate Free Trade/Environment ……………………………………..11

1.2.4 The Decomposition Approach..…………………………………………...12

1.3 The ACT Model of Free Trade and Environment …………………….........14

1.3.1 Description of the ACT (2001) Model ……………………………………....14

1.3.2 Main Findings of the ACT Model …………………………………………...17

1.4 Computable General Equilibrium Version of the ACT Model ………………....18

1.4.1 Assumptions and Structural Equations ……………………………………...19

1.4.2 Analytical Equations ………………………………………………………...21

1.4.2.1 The Producer Problem ……………………………………………....22

1.4.2.2 The Domestic Consumption ………………………………………....24

1.4.2.3 Equilibrium Conditions ……………………………………………...26

1.5 Data and Calibration of the CGE Model ……………………………………....26

1.5.1 The Social Accounting Matrix ………………………………………………....27

1.5.2 Calibration …………………………………………………………………...32

1.6 Simulations and Main Findings …………………………………………………..32

1.6.1 Main Findings under Less Stringent Environmental Policy ………………...34

1.6.2 Main Findings under Stringent Environmental Policy ……………………...40

1.7 Conclusion ……………………………………………………………….........43

Appendix ……………………………………………………………………………45

2 Ageing and the Environment in an Overlapping Generations Model …………………………………………………………………………..56

2.1 Introduction …………………………………………………………………...56

2.2 Literature Review on Age versus Environmental Concern ………….…………58

2.2.1 The Ageing Effect ……………………………………………………..…….59
2.2.2 The Cohort Effect ……………………………………………………….....62
2.2.3 Empirical Assumptions ……………………………………………….....63

2.3 A Computable General Equilibrium Model of Population Ageing and Environment (EOLG Model) ………………………………………………....66
2.3.1 Assumptions …………………………………………………………..…..66
2.3.2 The EOLG Model …………………………………………………………..68
2.3.2.1 The Domestic Consumption Problem ………………………….....68
2.3.2.2 The Producer Problem ……………………………………………...74
2.3.2.3 Equilibrium Conditions ……………………………………………..77

2.4 Empirical Analysis of the EOLG Model: Data and Calibration ……………..…80

2.5 Simulations and Main Results …………………………………………….....83

2.5.1 Scenario 1: Homogenous Preferences ……………………………..……..85
2.5.2 Scenario 2: Heterogeneous Preferences ……………………..……………89
2.5.3 Scenario 3: The Cohort Preferences …………………………...……………92
2.5.4 Sensitivity Analysis ……………………………………….....…………..95

2.6 Conclusion ……………………………………………………………...………...98

Appendix …………………………………………………………………..………100

3 Does Population Ageing in the North Leads to More Pollution in the South?...111

3.1 Introduction ……………………………………………………………..…...111
3.2 Literature Review ……………………………………………………..…….114
3.2.1 Population Growth and the Environment ………………………..……...114
3.2.2 Relationship Between Trade Liberalization and the Environment: Ambiguity/lack of Empirical Evidence on the PHH/FEH ……………..…..118
3.2.3 The North-South Model and the Need to Include the Demographic Composition Dimension ……………………………………………..….121

3.3 Dynamic Model of Trade North-South (OLG-NS) ……………………….………124
3.3.1 Assumptions ……………………………………………………….………124
3.3.2 The OLG-NS Model ………………………………………..………...125
3.3.2.1 The Consumer Problem ……………………………..………..127
3.3.2.2 The Producer Problem …………………………………..……130
3.3.2.3 Saving Decisions and Current Account ……………………..……..131

3.3.2.4 Investment …………………………………………………..………...132
3.3.2.5 Trade Balance …………………………………..……………133
3.3.2.6 Market Clearing ……………………………………………..……..134

3.4 Data and Model Parameterization ………………………………………………135
3.4.1 Social Accounting Matrix (SAM) …………………………………………135
3.4.2 Calibration ……………………………………………………………………137

3.5 Simulations and Main Findings ……………………………………..………...139
3.5.1 Population Ageing and the Environment ………………………..………139
3.5.2 Free Trade in a Context of Demographic Transition ……………………..…..147
3.5.2.1 Impact of Import Tariff Reduction in the South …………………..….147
3.5.2.2 Impact of Import Tariff Reduction in the North …………………..….149
3.5.3 Sensitivity Analysis ………………………………………………..……151

3.6 Conclusion ……………………………………………………………...…….154

Appendix ……………………………………………………………………...………156

References ……………………………………………………..…………164

Introduction

After decades of extensive research aimed at exploring the relationship between trade liberalization and environment, a consensus remained unachievable. In fact, although most economists support the idea that trade liberalization leads to economic growth by expanding the scale of the economic activity, a heated debate takes place when assessing its impact on the environment. Many economists argue that by becoming richer, countries will turn to clean production and implement a more restrictive environmental policy. However, for the environmentalists, international trade constitutes a threat to the environment as it promotes long distance transport, alters the composition of the world production towards the most traded goods, and encourages polluting industries to gravitate towards the developing countries to take advantage of their lack of stringent environmental policy. Survey of the relevant economic literature reveals the existence of two opposing theories describing the impacts of free trade on the environment: the pollution haven hypothesis and the factor endowment hypothesis. By empirically testing these two theories, Antweiler et al. (2001) reach the conclusion that the relationship between free trade and environment depends on the distribution of comparative advantages among countries. Furthermore, survey of the empirical literature shows the extent of the approach developed by Grossman and Krueger (1991) that decomposes the impacts of free trade on the emission levels into scale, composition and technique effects.

Mostly ignored in the economic literature is the impact of population ageing on the quality of the environment. As the proportion of seniors increases over time in most of the developed countries, a new challenge for researchers has emerged: how to address/assess the potential impacts of population ageing on the social preference for environmental quality? Despite the existence of few studies that investigate the change in the perception of the quality of environment through age, a consensus was forged among researchers. In fact, although clear and direct estimate of the valuation of environment by different age groups is not available, theoretical and empirical reviews of the literature and observations from survey indicate that seniors care less about the environment compared to young generations. Furthermore, a decomposition of the impacts of the demographic structure on the quality of the environment into scale, composition and cohort effect presents the potential to provide clear understanding of the relationship between population ageing and the environment.

Trade liberalization and population ageing constitute two issues that play central role in shaping the emission levels in rich and poor countries. To help preserving the environment, it is quintessential that policymakers examine the twin effects of trade and population ageing on the environment within a unified framework. According to the United Nations Population Fund Report (2009), it is essential that climate policies take people into consideration to be able to mitigate climate change. This lies at the core of our thesis. The fundamental questions explored in this thesis include: when is free trade good for the environment? Is population ageing good for the environment? Does population ageing in the North lead to more pollution in the South?

First, being inspired by the originality of Antweiler et al. (2001) methodology and results in using the decomposition approach to assess the impact of free trade on the environment, we attempt to extend their model by constructing a static computable general equilibrium model. Our objective is to identify conditions and situations under which free trade may improve the environment without limiting our analysis to an average country of a specific sample. The use of computable general equilibrium models helps us find a compromise across the different views expressed in the literature. Second, by turning our focus to the issue of population ageing, we attempt to assess its potential impact on the environment - an issue that is becoming more pressing as the weight of seniors increases over time in the developed countries. By constructing a dynamic computable overlapping generations model we simulate the effect of scale, composition and cohort effects on the emission levels. This model constitutes a first attempt to introduce the issue of population ageing into the discussion surrounding the environment by using overlapping generations structure. Finally, we combine the first two models, and consolidate the issues further by developing the third model that assess the impacts of demographic and trade shocks on the emission levels in poor and rich countries. The main objective is to explore to what extent population ageing in rich countries can be responsible for making poor countries dirtier through trade by taking advantage of their lack of stringent environmental policy.

More specifically, in chapter one, we numerically investigate the impact of trade liberalization on the quality of environment. We construct a computable general equilibrium model based on Antweiler et al. (2001) decomposition model of free trade and environment. Our model is based on an open economy producing a clean and a polluting good using capital and labour. We use the model to run a set of simulations using different country profiles. In total we construct four profiles based on the stringency of the environmental policy, the characteristics of the trade policy, and the level of capital and labour endowments. Furthermore, following Antweiler et al. (2001), we assume that trade patterns are mainly determined by the interaction between factor endowment and income differences. Our main findings show that for a combination of relatively high capital to labour ratio and low level of protectionism if a country exports the polluting good, then trade liberalization increases the level of emission. However, if the country exports the clean good, then the effect of an import tariff reduction on the emission levels is positively related to the variation in the producer’s price of the polluting good. Finally, under a relatively low level of capital endowment for a country that exports the polluting good, the impact of free trade on the environment depends on the degree of protectionism.

In chapter 2, we turned our focus to investigate the link between population ageing and the quality of the environment. We construct a dynamic overlapping generations model based on a closed economy producing a set of clean and polluting goods. By assuming that agents are utility maximizers, we simulate different scenarios to assess the impacts of a demographic shock on the emission levels. Application of the decomposition approach allowed us to provide separate estimations of the scale, composition and cohort effect and provide a comprehensive answer to the following question: is ageing good for the environment? We show that the scale effect is positively related to the size of the population. In addition, both the composition effect generated by an increase in the population growth rate and the cohort effect are positively related to the environment. We further find that the cohort effect can be high enough to offset the composition effect associated with population ageing when there is a high degree of awareness towards a clean environment. Finally, we find that scale effect dominates both composition and cohort effect. All these led us to arrive to a logical yet surprising conclusion: population ageing is good for the environment.

Finally in chapter 3 we construct a dynamic two-country model of trade liberalization, population ageing and environment, by combining the first two models. The North is characterised with relatively high level of capital endowment and stringent environmental policy, while the South is considered as a poor country with less stringent environmental policy. Both countries produce a clean and a polluting good and both have access to an exogenous abatement technology. The model is used to run two sets of simulations. In the first set we assess the impact of demographic shock on the emission levels in both countries, while in the second set we simulate an import tariff reduction. Our main findings show a negative impact of population ageing in the North on the global emission levels and the dominance of the demographic effect to the trade effect. These results seem to find more support in the United Nations Population Fund report, which states that population growth is one of the main responsible causes of pollution. Since most countries seem to reach a highly advanced level in liberalizing their economies, only little can be done to help protect and preserve the environment from trade liberalization perspective. On the other hand, however, population ageing in rich countries and population growth in poor countries constitute a serious issue affecting the environment.

It is worth mentioning that our findings on trade, population ageing, and the environment constitute a first step to explore more in detail the means and ways to help protect and preserve the environment. In fact, one of the main obstacles we faced was the lack of many accurate data including consumers' consumption profiles per age group and consumers reactions to changes in the environmental quality as they grow old. More research especially on the evolution of consumers' preferences towards the environment over age is crucial to have clear understanding of the impact of ageing on the environment. Furthermore, a possible extension can be done by modeling an endogenous environmental policy. Such policy will take into consideration the role played by income in tightening the environmental policy, and reduce the emission levels. Such effect can be significant enough to offset the impact of scale effect on the environment.

Chapter One

When is Free Trade Good for the Environment?

1.1 Introduction

The relationship between Free trade and the environment has been the subject of extensive debates that were aimed to explore the impact of openness on the quality of the environment. Two theories provide opposite conclusions.[1] According to the pollution haven hypothesis ("PHH"), countries with relatively weak environmental regulation and low income will specialize in the production of the polluting goods. Multinational companies will reallocate their polluting industries to developing countries with less stringent environmental regulation. As a consequence, poor countries will become havens for polluters by exploiting their comparative advantage in pollution-intensive industries. Rich countries benefit environmentally from free trade, while poor countries become dirtier. The alternative theory to the PHH is the factor endowment hypothesis ("FEH"). It predicts that capital abundant countries will specialize in the production of the capital-intensive goods without any consideration given to the environmental policy. Therefore, trade liberalization leads to more pollution in rich countries. Poor countries will specialize in the production of the clean goods, which is labour intensive and hence become cleaner with free trade. Overall, the relationship between free trade and environment depends on the distribution of comparative advantages among countries.

The main purpose of this paper is to numerically investigate the impact of trade liberalization on the quality of the environment. First, we elaborate a computable general equilibrium model based on the Antweiler, Copland and Taylor (2001) decomposition model of free trade and environment ("ACT" model). The originality of their results consists of showing that a trade liberalization which raises the Gross Domestic Product per person by 1% reduces the pollution by the same proportion via three channels: composition, scale and technological

[1] For more details about the PHH and the FEH see Brian R. Copeland; M. Scott Taylor, (2004), "Trade, Growth, and the Environment", *Journal of Economic Literature*, Volume 42, Issue 1, pages 7-71.

effects.[2] This statement is in contrast to many of the findings of environmentalists, who claim that economic growth and international trade constitute a threat to the environment (Daly 1977, Meadows et al 1972, and Georgescu-Roegen 1971).

Second, we construct four different country profiles based on their characteristics with respect to their trade policy, stringency of their environmental policy, and their endowment expressed in term of capital to labour ratio. Furthermore, following ACT (2001), we assume that trade patterns are mainly determined by the interaction between factor endowment and income differences. Therefore, calibration of the computable general equilibrium model is based on the type of the exported good (clean versus polluting good) that depends on a country comparative advantage.

Finally, we attempt to numerically answer the question -When is free trade good for the environment? - Our objective is to identify conditions, circumstances, and situations under which free trade may improve the environment. In fact, instead of providing an estimation of the impact of trade on the environment for an average country (ACT, 2001), we attempt to explore the role played by countries' characteristics other than differences in income and capital endowment to preserve the environment. Such characteristics include for instance the type of exported good, the stringency of the environmental policy, the level of protectionism, and the size of the country. By using a static general equilibrium model in which the tax on pollution, the intensity of abatement, and the coefficient of emissions are endogenous, we conduct a set of simulations to test the impact of import tariff reduction on the volume of emission.

Our main findings show that, for a combination of a relatively high capital to labour ratio and a low level of protectionism, if a country exports the polluting good then, trade liberalization increases the level of emission. Whereas if the country exports the clean good, then the pollution effect of an import tariff reduction is positively related to the variation in the producer's price of the polluting good and hence the environment deteriorates.

[2] For more details about the composition, technique and scale effects, see subsection 1.2.4.

Furthermore, we find that under a relatively low level of capital endowment for a country that exports the polluting good, the impact of free trade on the environment depends on the degree of protectionism. Under a relatively high level of protectionism, trade liberalization generates more pollution in the economy. However, with relatively low level of protectionism, free trade may improve the environment.

The remainder of the paper is organized as follows. A detailed study of the literature linking free trade and economic growth to the environment is presented in the second section of this paper. In the third section, we summarize ACT (2001) findings on free trade and environment. In Section 4, we develop a numerical version of the ACT model. The purpose of this model is to quantify the impact of trade liberalization on the quality of the environment. In Section 5, we present the data and the calibration procedures. Section 6 presents the results and in Section 7 we provide some concluding remarks.

1.2 Literature Review

1.2.1 Complexity of the Relationship between Free Trade, Economic Growth and the Environment

The complexity of the debate on free trade and environment and the necessity to link each other make many economists like Cooper (1994) and Bhagwati (1999) believe that it is better to keep pollution control and natural resource management issues out of the trade policy-making process. However for Runge (1994), Rodrik (1997) and Summers (2000),[3] building a kind of environmental sensitivity into the international trading system is a better approach in order to analyze the link between environment and trade. The fundamental problem involves the role of trade on economic growth and the interaction between growth and the degradation of the quality of the environment. As put forward by Panayotou (2003), the crucial questions are:

"*Will the world be able to sustain economic growth indefinitely without running into resource constraints or despoiling the environment beyond repair? What is the relationship*

---

[3] Quoted by Daniel C. Esty (2001), "Bridging the Trade-Environment Divide", *The Journal of Economic Perspectives*, Volume 15, Issue. 3, page 113.

between a steady increase in incomes and environmental quality? Are there trade-offs between the goals of achieving high and sustainable rates of economic growth and attaining high standards of environmental quality?" [4]

Anderson (1998) and Panayotou (1993) claim that an appropriate environmental policy would correct the price of resources. Resources are mis-priced by not taking into consideration the full amount of the social cost, which includes pollution. According to Stiglitz (2008), economic growth, which is based on environmental degradation and the exploitation of scare natural resources, cannot be sustainable if the proceeds have not been reinvested to compensate for the harm caused to the environment.[5] Free trade increases the volume of resources exchanged at prices that do not compensate for the harm to the environment. Furthermore, Nordstrom and Vaughan (1999) report that even the World Trade Organization acknowledges the negative effect of free trade on the quality of the environment (pollution harms and natural resource management mistakes) in the absence of appropriate environmental policy.

In exploring the relationship between economic growth and the environment, survey of the economic literature reveals the existence of at least three distinct assessments of this relationship. First, by linking environment degradation to resources scarcity, Daly (1977), Georgescu-Roegen (1971), and Meadows et al. (1972), recommend a stop to economic growth and make a transition towards a steady-state economy with no growth.[6] However, in a different assessment, Barlett (1994) and Beckerman (1992) argue that the quality of the environment may become worse if the economic growth declines. In fact, they state that the surest way to improve the quality of the environment is by becoming rich.[7] Finally, the third assessment is reflected in the World Commission on Environment and Development 1987 report, which supports the idea of sustainable economic growth. Many environmentalists continue to believe that economic growth can support environmental improvements if it is

---

[4] Theodore Panayotou, (2003), "Economic growth and the environment", Paper prepared for and presented at the Spring Seminar of the United Nations Economic Commission for Europe, Geneva, page 1.

[5] Joseph E. Stiglitz, (2008), "Turn Left for Sustainable Growth", Economists' Voice, The Berkley Electronic Press, September 2008.

[6] For more details see Panayotou, (2003), "Economic Growth and the Environment", Paper prepared for and presented at the Spring Seminar of the United Nations Economic Commission for Europe, Geneva, page1.

[7] Quoted by Dale S. Rothman, (1998), "Environmental Kuznets Curves - Real Progress or Passing the Buck? A Case for Consumption - based approaches", *Ecological Economics,* Volume 25, Issue 2, pages 177-194.

managed properly. However, there are environmentalists who remain committed to "limits to growth" paradigm and found that trade liberalization increases economic activity, which leads to an accentuation of the pollution problem (see Meadows et al. (1972) and Daly (1993)).

1.2.2 Environmental Kuznets Curve: A Development-Environment Relationship

Shafik and Bandyopadhyay (1992), Panayotou (1993), Grossman and Krueger (1993) and Selden and Song (1994) argue that the relationship between environment and economic growth may change sign from negative to positive as a country becomes rich and people demand more clean goods and high environmental quality. This relationship is similar to the famous "Kuznets curve" that links inequality of income and economic development. In fact, according to Beckerman (1992), even though economic growth usually leads to environmental degradation in the early stages of the process, in the end the best way to improve the quality of the environment in most countries is by becoming rich. In the same trend, the World Bank's World Development Report 1992 (IBRD, 1992) states that: As incomes from trade rise, the demand for improvements in environmental quality will increase, as will the resources available for investment.[8]

The development-environment relationship can be illustrated in the following figure:[9]

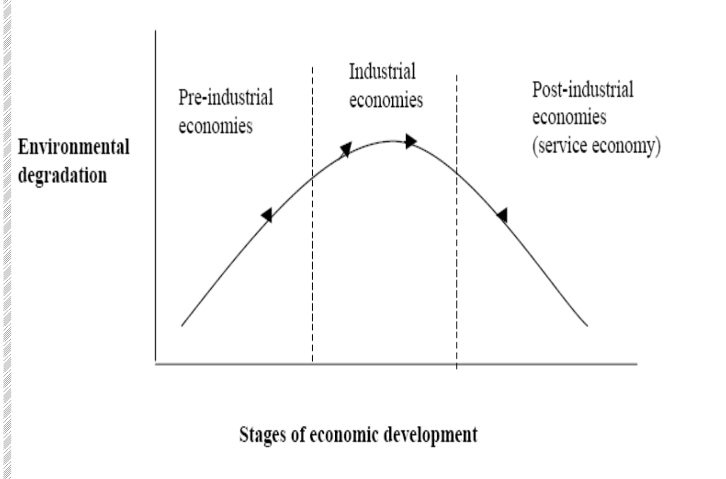


Figure 1: The Environmental Kuznets Curve: a development-environment relationship

[8] Quoted by David I. Stern (2003), "The Environmental Kuznets Curve", International Society for Ecological Economics, International Encyclopaedia of Ecological Economics, June 2003, page 2.

[9] Source of figure 1: Theodore Panayotou, (2003), "Economic Growth and the Environment", Paper prepared for and presented at the Spring Seminar of the United Nations Economic Commission for Europe, Geneva, page3.

The Kuznets curve shows that, in the beginning of economic development, little attention is given to environmental concerns, raising pollution along with industrialization. When basic physical needs are met, interest in a clean environment rises, reversing the trend. In fact as explained by Panayotou (1991) and Stern (2003), when countries reach a higher level of development, they will implement structural change towards information-sensitive industries and services, coupled with increased environmental awareness, enforcement of environmental regulations, better technology and higher environmental expenditures, result in leveling off and gradual decline of environmental degradation.

However, the Environment Kuznets Curve ("EKC") remains a subject of many critiques. From a theoretical perspective, Stern (2003) argues that the EKC has been tested with only some of the known pollutants. He argues that most of the theoretical model developed to show an inverted U shape curve of pollution intensity, come out with results that depend on the hypothesis made and the value of particular parameters.[10] Moreover, Arrow et al. (1995) and Stern et al. (1996) raise the possibility that the EKC may be "partly or largely" affected by trade and its impact on the distribution of polluting industries. In fact with trade liberalization, each country will specialize in the production in which it possesses a comparative advantage. Such specialization may lead to an improvement of the environment in developed countries and a degradation of the environmental level in "middle income" countries. These effects due to trade, according to Stern (2003), may accentuate the decline in pollution intensity as income rises.

From an empirical perspective, Boercherding and Deaton (1972), Bergstrom and Goodman (1973), and Walters (1975) found income elasticities for environmental improvements greater than one, while, Kriström (1995) found income elasticities for environmental quality much less than one. According to Stern (2003)[11] and Panayotou (2003),[12] most of the models

[10] Lopez (1994) and Selden and Song (1995) assume that pollution is generated by production. However John and Pecchenino (1994), John *et al*. (1995), and McConnell (1997) by developing an overlapping generations model, they state that pollution is generated by consumption. Also Stokey (1998) has developed a model with endogenous technical change. (Cited by Panayotou, 2003)

[11] Instead of using a simple quadratic function of the levels of income to estimate the EKC, by running the following regression: $\ln(E/P)_{it} = \alpha_i + \gamma_t + \beta_1 \ln(GDP/P)_{it} + \beta_2 (\ln(GDP/P))^2_{it} + \varepsilon_{it}$, where E is emissions and P is population [Ref: David I. Stern, (2003, page 4), "The Environmental Kuznets Curve", International Society for Ecological Economics, Internet Encyclopaedia of Ecological Economics] ; Stern found that an EKC

investigating the link between the environment and economic growth lack rigorous and systematic decomposition analysis that allows the decomposition of the income-environment relationship into composition, scale and abatement effects. Stern (2003) argues that there are no clear answers on the effect of trade liberalization on pollution from the empirical EKC literature.

1.2.3 The Debate Free Trade/Environment

The arguments supporting the statement that free trade is good for the environment are as follows: Trade liberalization leads to economic growth. When countries become richer, households prefer more clean goods and polluters face a more restrictive environmental policy imposed by the national government. Also, trade liberalization implies a more efficient allocation of resources including environmental ones. It is also the best way to transfer environmental technology to developing countries. Free trade thus permits the convergence to a high level of environmental standards for all countries, which would increase the market for clean goods all over the world. Finally, international trade may encourage international cooperation in environmental issues.

The arguments against free trade underline the negative externality on the environment arising from the increase in economic growth. By promoting long distance transportation, free trade accentuates pollution. Furthermore, since it is based on competition in both prices and costs, free trade may lead to what is called "Race to the bottom" behaviour via competitive deregulation. Also, by promoting the production of the most traded goods rather than the set of commodities that would have been otherwise domestically produced and consumed, international trade accentuates the deterioration of the ecological equilibrium. This increases the degree of exploitation and the size of the land used to produce the traded products by exploiting lands for trade purposes instead of agricultural ends.

---

estimated with fixed effects using only developed country data cannot be used to estimate efficiently the future behaviour of developing countries. In fact Stern (2003), stated that "*…,the fixed effect can be estimated consistently, but the estimated parameters are conditional on the country, and time effects in the selected sample of data (Hsiao, 1986). Therefore, they cannot be used to extrapolate to other samples of data. This means that an EKC estimated with fixed effects using only developed country data might say little about the future behaviour of developing countries.*"

[12] A summary of empirical studies investigating the EKC theory is provided by Panayotou (2003), "Economic Growth and the Environment", Paper prepared for and presented at the Spring Seminar of the United Nations Economic Commission for Europe, Geneva, page 44.

According to free trade theory, developing countries detain a comparative advantage in labour and natural resources. However, developed countries would specialize in manufactured capital-intensive activities. It is argued by Lucas *et al*. (1992) that, stringent environmental regulation in developed countries, might lead polluting activities to gravitate towards the developing countries.[13]

Panayotou (2003) states that, as developed countries become richer, they may start getting rid of polluting industries through trade or direct investment delocalization in poorest countries with lower income and lower environmental standards. A new set of evidences coming from many recent researches shows that open economies tend to be cleaner than closed economies. In fact, according to Panayotou (2003), the best strategy to reduce the negative externality on the environment caused by the economic growth, is by removing environmentally harmful subsidies for example on energy and transport, by well define and enforce property rights, by a full cost pricing of resources to reflect the growing scarcities, and by internalizing the environmental cost.

1.2.4 The Decomposition Approach

One way to further investigate the relationship between free trade and quality of the environment is by using an approach based on the decomposition of emissions. According to Grossman and Krueger (1991) and ACT (2001), it is possible to decompose the effect of economic growth into "technique effect", "composition effect" and "scale effect". The technique effect (referred to also as technological effect) means that when wealth increases and trade expands, firms become more willing to improve their technology and use what is called "environmental best practices." The composition effect reflects the shift in production toward cleaner or polluter goods.[14] Finally, the scale effect refers to the increase in pollution due to expanded economic activity (Grossman and Krueger 1993; Lopez, 1994). To explain

[13] Quoted by David I. Stern (2003), "The Environmental Kuznets Curve", International Society for Ecological Economics, International Encyclopaedia of Ecological Economics, June 2003, page 7.

[14] According to ACT (2001), the trade induced composition effect increases emission for an exporter of the polluting good and reduces the volume of pollution for an importer of dirty good. Grossman and Krueger (1991, page 4) argue that "*If competitive advantage derives largely from differences in environmental regulation, then the composition effect of trade liberalization will be damaging to the environment…. On the other hand, if the sources of international comparative advantage are the more traditional ones, namely cross-country differences in factor abundance and technology, then implications of the composition effect for the state of the environment are ambiguous*".

the impact of free trade as a source of economic growth on the quality of the environment, ACT (2001) show that, above a certain level of per capita income, the technological effect becomes high enough to offset the summation of the scale and the composition effects,[15] in case of a dirtier good exporter.

By decomposing the sulphur emission in the Netherlands and Western Germany into scale, composition, and technique effects, De Bruyn (1997) found that, between 1980 and 1990, the Gross Domestic Products grew by 26% for the Netherlands and 28% for Western Germany (scale effect). In addition, the structural change on the output side contributed (-4.5%) to emissions in Western Germany and (+5.7%) in the Netherlands (composition effect). Furthermore, in the two countries, the technique effect contributed all together into a reduction of about 74% in sulphur emissions, that is; the energy efficiency by almost 15 to 20 % and the energy mix and emissions specific technological change by 55% to 60%. Overall, the level of emission had decreased by around 42% in Netherlands and by 50.5% in Western Germany.

Hilton and Levinson (1998) investigate the emission caused by gasoline consumption and conclude the existence of an EKC in 1992, by showing that the lead content per gallon of gasoline was a declining function of income, and the per capita gasoline consumption is positively related to income. In fact, they infer the adoption by high-income countries of technological innovations. Stern (2003) also decomposes sulphur emissions in 64 countries for the period 1973-90 into what he identifies as "scale effect", "output mix" and "input mix" changes, and "state of technology", which can be divided into "production efficiency", and "emission specific changes in process". Stern concludes that the composition effect given by "output mix" and "input mix" effects globally have little impact. The technique effect known as "state of technology" seemed to reduce the increase in emission by 50%. Finally, ACT (2001) using the Global Environment Monitoring System ("GEMS") sulfur dioxide concentration data concludes that free trade is good for the environment for an average country in their sample.

---

[15] ACT (2001, page 886) states, "*For a dirty good exporter, both the trade-induced composition effect and the scale effect are positive.*"

In this paper, our contribution consists of developing a simulation model that will help to assess and quantify the impact of trade liberalization on the volume of emission using the ACT (2001) decomposition approach with respect to preferences and technological parameters. The investigation of the relationship between free trade and environment quality improvement using computable general equilibrium ("CGE") model will help us find a compromise across the different views expressed so far in the literature. Our main goal consists of identifying conditions under which free trade may lead to an improvement of the quality of the environment.

1.3 The ACT Model of Free Trade and Environment

The purpose of this section is to summarize the ACT Model and its main findings in order to develop a computable general equilibrium version of the model.

1.3.1 Description of the ACT (2001) Model

ACT (2001) develop a theoretical model using the decomposition approach described above. The model consists of a small open economy with two factors of production, labour and capital, producing two goods: X the polluting and capital intensive good and Y the clean and labour intensive good. The model also includes an abatement technology to reduce pollution. The intensity of emission is assumed to be negatively related to the amount of output x_a of the polluting good X invested in the abatement process. The polluting industry chooses the optimal level of abatement by taking into consideration the tax on pollution. This tax is endogenously determined by the social planner to optimize social welfare. The social welfare function is composed by the welfare of two groups of households with homogeneous preferences except for their perception of the quality of the environment. One group of consumers is called Green ("g") and prefers a clean environment. The other group is called Brown ("b") and is careless about the environment. The government manages the supply of pollution (volume of emission in the economy) through a tax on emission, which subsequently determines the price for pollution. As the demand side of the volume of emission is generated by the polluting industry, the price of pollution ensures the equalization of demand and supply in the pollution market. It is important to note that ACT (2001) decompose the impacts of trade liberalization on the quality of the environment into scale, technique and composition effects.

Analytically, the producer problem consists of optimizing the following objective function taking into consideration the net of abatement price function:

$$\pi^x = p^N x - wL^x - rK^x \quad ; \; p^N = p(1-\theta) - \tau e(\theta)$$

p^N denotes the domestic price for the producer of the polluting good net of abatement and tax on emission; *x* represents the total volume of polluting good produced in the economy; *w* is the wage; L and *K* are respectively the demand for labour and capital to produce *x*; *r* is the rate of return on capital; *P* is the relative domestic price of good X; θ measures the intensity of abatement and is given by: $\theta = \frac{x_a}{x}$, where x_a refers to the quantity of *x* used for abatement. The term τ represents the tax on emission; finally, $e(\theta)$ is the coefficient of emission.

Producers take as given the tax on pollution and find the optimal level of abatement that maximizes profit. The optimization procedure allows to express the emission coefficient as a function of the price and the tax on pollution. Indeed, by taking the derivative of P^N with respect to θ, the optimal level of abatement can be expressed as: $p = -\tau e'(\theta)$. $e(\theta)$ is assumed to be a decreasing function of θ. Since e' is negative, the level of abatement θ is positively related to the tax on emission.

The government maximizes a weighted sum of "g" and "b" consumers' preferences using the following expression of the indirect utility function:

$$V^i(p, G/N, z) = u\left(\frac{G/N}{\rho(p)}\right) - \delta^i z \;\; ; \; \forall i \in \{g;b\}$$

V is the indirect utility function. G is total income and N the number of individuals in the economy. Consequently, G/N is per capita income; z is the emission of pollution; ρ(p) is a price index of the two consumed goods. Hence, the real per capita income ("I") is given by: $I = \dfrac{G/N}{\rho(p)}$; δ is the disutility coefficient of pollution. Note that $\delta^g > \delta^b \geq 0$. From a social welfare perspective, if the proportion of Green individuals in the economy gets larger, the environmental policy becomes more stringent with a higher tax on pollution. As preferences over consumption are homothetic, marginal utility with respect to income is declining. Consequently an increase in the real income gives room for a higher τ and hence increases the demand for environmental quality. A higher tax on pollution shifts up the pollution supply curve and makes pollution more costly.[16]

The indirect utility function can be transformed as: $V^i(p, G/N, z) = u(I) - \delta^i z$. To find the optimal tax on emission, the government solves the following optimization problem subject to private sector behaviour, production possibilities, world prices, and trade friction.

$$\max_{\tau} N\{\lambda V^g + (1-\lambda)V^b\}$$

By taking the first order condition, the optimal tax on pollution can be given by the following amended Samuelson rule, which can be expressed as:

$$\tau = N[\lambda MD^g(p,I) + (1-\lambda)MD^b(p,I)]$$

$MD^i(p,I) = \delta^i \rho(p)/u'$ $\forall i \in \{g;b\}$ is the marginal damage per person; λ is percentage of "g" customers in the population. One way to express this optimal level tax on pollution consists of using the following form: $\tau = T\phi(p,I)$ where $T = \lambda N\, \delta^g + (1\text{-}\lambda)N\, \delta^b$ defines the "country type" and $T\phi(p,I)$ is the effective marginal damage.[17]

[16] According to ACT (2001, page 882), the total income given by the summation of private sector net revenue "$R(p^N, K, L)$" and rebated taxes and expressed by: $G = R(p^N, K, L) + \tau z$, is a function of τ through two channels p^N and the last component of the expression of *G*. By assuming that world prices are fixed, ACT express the derivative of the real income per capita with respect to τ as: $\dfrac{dI}{d\tau} = \dfrac{\tau}{N\rho(p)} \dfrac{dz}{d\tau}$.

[17] For more details see ACT (2001, page 882), "Is Free trade Good for the Environment?", *The American Economic Review*, Volume 91, Issue 4.

1.3.2 Main findings of the ACT Model

By estimating a logarithmic form taking sulphur dioxide ("SO_2") concentration as the dependant variable across 43 countries spanning the years 1971-1996, ACT (2001) show that "*…if trade liberalization raises GDP per person by 1 percent, then pollution concentrations fall by about 1 percent. Free trade is good for the environment"*[18]

Also by distinguishing between the negative consequence of free trade on the quality of the environment in terms of the scale effect and the positive consequence in terms of the technique effect, they estimate that: *"…a 1 percent increase in the scale of economic activity raises pollution concentrations by 0.25 to 0.5 percent for an average country in our sample, but the accompanying increase in income drives concentrations down by 1.25–1.5 percent via a technique effect."*[19]

It is worth mentioning, that such estimation of both scale and technique effects for an average country seems to provide a general picture describing the impact of openness on the environmental quality. In addition, ACT's estimations seem to put a high weight on the reaction of the environmental policy to change in income considered as the sole motive that drives pollution down by influencing consumers' perception towards clean goods. Also, scale effect seems to be highly impacted by capital endowment. However, such estimations may possibly neglect the possibilities of different reaction to trade, at least in term of magnitude, associated with countries' characteristics other than income and capital endowment, such as the type of exported good, the stringency of the environmental policy, the level of protectionism, and whether the country is small or not. By constructing different profiles based on countries characteristics to investigate the impact of trade liberalization on the environmental quality for specific countries selected based on these profiles, we may end-up having clear answer to when free trade is good for the environment.

Concerning the composition effect, which implies that free trade alters the composition of the production in the national economy, two hypotheses are confronted: the pollution haven

---

[18] For more details see ACT (2001, page 878), "Is Free trade Good for the Environment?*", The American Economic Review*, Volume 91, Issue 4.
[19] Ibid.

hypothesis and the factors endowment hypothesis. By conditioning trade effect on countries characteristics, ACT show that openness to free trade conditioned on country characteristics has a significant but small composition effect on pollution. In fact for an average country, the trade induced composition effect is found to be negative. However as ACT realized, when considering individual countries, it is difficult to evaluate relative strength of pollution haven and factors abundance motives.

By jointly estimating the three effects using data from 43 developed and developing countries, ACT make the distinction between pollution caused by income growth due to trade from pollution caused by capital accumulation or progress in technology. This distinction makes them conclude that, income gained from trade in a case of neutral technological progress reduces pollution. However, income gained from capital accumulation, which intensifies the production of the polluting goods, raises pollution. Therefore, the effect of economic growth on the environment depends on the source of this growth. Furthermore, according to ACT, pollution concentration may rise in the first step due to capital accumulation before it falls through neutral technological progress.

Under few assumptions concerning the technology, the type of goods, the trade friction, and by taking into consideration a very specific kind of abatement policy, ACT show that for an average country of their sample, the scale elasticity is dominated by the technique elasticity, while the composition elasticity is small in magnitude. Therefore, openness to international trade for an average country reduces pollution under the assumption of constant endowments. However, for individual countries, ACT claim that the reaction to trade liberalization will depend on country characteristics.

1.4 Computable General Equilibrium Version of the ACT Model

In this section, we provide a detailed numerical version of the ACT Model. We start by discussing the assumptions of the model, then present a detailed analysis of the producer and the consumer problem, and finally setup the equilibrium conditions for the economy.

1.4.1 Assumptions and Structural Equations

***Technology*:** We assume an open economy made of N consumers and two industries "X1" and "X2", producing respectively two goods, x_1 and x_2, using two factors of production: labour (L) and capital (K). The industry X1 is intensive in capital and x_1 is considered a polluting good. The industry X2 is labour intensive and x_2 is considered a clean good. Both industries are characterized with a constant return to scale technology. The labour and capital markets are competitive, so that the wage and the rate of return on capital are freely determined by the interaction of domestic supply and demand.

Interaction with the rest of the world: By assuming that trade patterns are mainly determined by the interaction between factor endowments and income differences, the small open economy keeps trade balance between exports and imports. Furthermore, domestically produced and imported goods are assumed to be perfectly homogeneous. If the country exports the good x_1, it automatically imports the good x_2.[20] According to both PHH and FEH theories, free trade will alter the composition of national production in a way that depends on a country's comparative advantage. Let $P_i^*; P_i$ denote respectively the world and the domestic prices for the good $x_i \quad \forall i \in \{1,2\}$. Consumers pay the world price for the exported good but imports are subject to a tariff rate τ^m. The local price of the imported good is thus $P_i = (1+\tau^m)P_i^*$. Tariff revenues are redistributed to consumers.

Production of the polluting good: The emission of pollution is generated by the production of good x_1. To compensate for the negative externality caused to the economy, the emission is taxed at τ^e. This tax is determined in an optimal way by the government by maximizing a social welfare objective function subject to the firm's effort to reduce its emission by investing in an abatement process, and the population preferences with respect to the quality of the environment. We assume that the industry X1 uses a part of its production to reduce its emission through a technology of abatement given by e(θ) where e(.) represents the

[20] There is no transfer of capital to or from the rest of the world to offset any variation in the trade balance.

coefficient of emissions.[21] This technology is function of the intensity of abatement $\theta = x_a / x_1$, where x_a is the proportion of x_1 used for the abatement.[22] For the coefficient of emissions, we take the same form as in ACT (2001) by assuming that e(θ) is a decreasing function of θ. However, for the general equilibrium model, we develop below an analytical expression for this coefficient of emissions, which we use to measure the volume of emission. Moreover, we need to determine the optimal level of abatement that maximizes the profit of the polluting industry. Evaluated at the world price, the value of the effort to reduce the emission of pollution is assumed to be given by $\theta x_1 P_1 *$. Also at the pricing level, the following expression relates the domestic price of the polluting good in terms of world price: [23]

$$P_1 = \left[(1-\theta) P_1^* - \tau^e e(\theta) \right]$$

The emission of pollution: We define the emission of pollution by $z = e(\theta) x_1$, where z represents the volume of emission generated by the production of x_1. It is positively related to both the coefficient of emissions e(.) and the volume of production of x_1. Besides, we assume that the coefficient of emissions is given by: $e(\theta) = 1 - \Lambda \theta^\delta$; $\delta \in \left]0,1\right[$ is a share parameter of the abated pollution.[24] If $\theta = 1$, the coefficient of emissions is given by $e(1) = 1 - \Lambda$. The expression $(1 - \Lambda)$ represents the amount of uncompressible emission. Since $e(1) > 0$, therefore $0 < \Lambda < 1$ is country specific. If $\theta = 0$, for each unit of good x_1 produced, the industry X1 generates one unit of pollution, and $z = x_1$.

---

[21] More details concerning the coefficient of emission are provided in the subsection bellow.
[22] ACT (2001, page 881) assume a constant abatement technology.
[23] This expression is given by equation (3) of the ACT Model (2001, page 881), which is appropriate for a small open economy.
[24] The volume of emission of pollution can be expressed as:

$$z = x_1 - \Lambda x_a^\delta x_1^{1-\delta} = x_1 \left[\frac{x_1}{x_1} - \Lambda \frac{x_a^\delta x_1 x_1^{-\delta}}{x_1} \right] = x_1 \left[1 - \Lambda \left(\frac{x_a}{x_1} \right)^\delta \right] = x_1 \left[1 - \Lambda \theta^\delta \right] = x_1 e(\theta)$$

Trade balance: Trade is balanced trade as $P_1^* TRD_1 + P_2^* TRD_2 = 0$, where $TRD_i \; \forall i \in \{1,2\}$ denotes the quantity of traded good x_i with the rest of the world. We can formulate the volume of trade for each commodity as follow:

$TRD_1 = c_1 - x_1(1-\theta)$; $\qquad TRD_2 = c_2 - x_2$;[25]

A positive value of $TRD_i \; \forall i \in \{1,2\}$ is synonym to imports and a negative value means that the country exports the commodity *i*, $\forall i \in \{1,2\}$.

Structural equations: By assuming a Cobb-Douglas production technology, the production function for the industries X1 and X2 is given by: $x_i = A_i K_i^{\alpha_i} L_i^{1-\alpha_i}; \forall i \in \{1,2\}$, where A_i denotes the shift parameter and α_i represents the share parameter of the capital in the production of the polluting good. L_i and K_i denote respectively the labour and the capital demands by the industry Xi, $\forall i \in \{1,2\}$.

Finally we assume a monotonic transformation of a constant elasticity of substitution ("CES") utility function, which can be expressed as follows:[26]

$$u^j(c_1, c_2) = \frac{\sigma_c}{\sigma_c - 1} \ln \left[\alpha_c c_1^{\sigma_c - 1/\sigma_c} + (1-\alpha_c) c_2^{\sigma_c - 1/\sigma_c} \right] - \delta^j z \; ; \; \forall j \in \{g; b\}$$

Where σ_c denotes the elasticity of substitution and α_c represents the share parameter of c_1 in the CES utility function.

1.4.2 Analytical Equations

In this section we first solve the producers' problem. Then we express the optimal level of domestic consumption from each consumed good. Finally we establish the equilibrium

---

[25] $c_i \forall i \in \{1,2\}$ denotes the level of domestic consumption of good x_i.

[26] The utility function has to respect the assumption of homothetic preferences over consumption goods. A CES utility function is homogeneous of degree 1. The logarithm function ("ln") is monotonic. ln(CES) is a monotonic transformation of a homogeneous function of degree 1. ln(CES) is a homothetic function.

conditions in all markets involved in the economy, which include markets for the clean and the polluting goods, labour, capital, and trade with the rest of the world.

1.4.2.1 The Producer Problem

Domestic production of the polluting good: For a country that exports the polluting good, we can express the profit function facing the polluting industry X1 as:[27]

$$\Pi^1 = x_1 P_1^* - c(x_1) - \theta x_1 P_1^* - \tau^e e(\theta) x_1 ; \tag{1}$$

where $c(x_1)$ represents the cost function for producing x_1, which is given by: $c(x_1) = wL_1 + rK_1$. By the zero profit condition, equation (1) can be expressed as:

$$x_1 P_1^* = c(x_1) + P_1^* \theta x_1 + \tau^e e(\theta) x_1 \tag{2}$$

By manipulating equation (2), we can define the producer domestic price as a function of the world price:[28] [29]

$$P_1 = \left[(1-\theta) P_1 * - \tau^e e(\theta) \right] \tag{3}$$

Based on this expression we can formulate the world price as $P_1^* = \dfrac{P_1 + \tau^e e(\theta)}{(1-\theta)}$. From equation (3), the firm receives a domestic price below the world price ($P_1 < P_1^*$) as it is penalized for its emission of pollution through two channels: the abatement (θ) and the tax on emission $\tau^e e(\theta)$.

As $x_1 \left[(1-\theta) P_1^* - \tau^e e(\theta) \right] = wL_1 + rK_1$, the domestic production for the polluting X1 sector can be formulated as $x_1 P_1 = wL_1 + rK_1$. Then by calculating the first-order condition with respect to x_1, the domestic price is found to be equal to the marginal cost, $P_1 = C_{x_1}(x_1)$, where $C_x(x_1)$ is the marginal cost with respect to x_1.

---

[27] If the country imports the polluting good, the profit function of the polluting industry can be expressed as: $\Pi^1 = x_1 P_1^* (1+\tau^m) - c(x_1) - P_1^* (1+\tau^m) \theta x_1 - \tau^e e(\theta) x_1$. This expression show that domestic producers of the polluting good benefit from a protection against foreign producers, given by the tariff on imports.

[28] For more details see Appendix 1.

[29] If the country imports the polluting good, the producer of the polluting good domestic price is given by: $P_1 = \left[(1+\tau^m)(1-\theta) P_1^* - \tau^e e(\theta) \right]$

To maximize its profit, the polluting industry in a country that exports the dirty good determines the optimal level of abatement, taking as given the tax on pollution. Its objective function to find the optimal level of θ subject to the tax on pollution that can be expressed as:[30]

$$\max_{\theta}(\Pi^1) = x_1 P_1^* - c(x_1) - P_1^* \theta x_1 - \tau^e e(\theta) x_1 \tag{4}$$

Knowing that the coefficient of emission is given by:

$$e(\theta) = 1 - \Lambda\theta^{\delta} \tag{5}$$

and by taking the first order condition with respect to θ, we get:

$$\frac{d\Pi^1}{d\theta} = 0 \Rightarrow -x_1 P_1^* - \tau^e x_1 \frac{de(\theta)}{d\theta} = 0 \Rightarrow -P_1^* + \tau^e \Lambda\delta\theta^{\delta-1} = 0 \Rightarrow \theta^{\alpha-1} = \frac{P_1^*}{\tau^e \Lambda\delta}$$

The optimal level of θ that maximizes the firm profit is given by:[31]

$$\theta^* = \left(\tau^e \Lambda\delta / P_1^*\right)^{1/1-\delta} \tag{6}$$

Based on equation (6), The optimal level of abatement θ^* is positively related to the tax on pollution. Since $\frac{d\theta^*}{d\tau^e} > 0$, abatement increases as the tax on pollution raises.

Domestic production of the clean good: If a country imports the clean good, the profit function facing the industry X2 producing the clean good is:[32]

$$\Pi^2 = x_2 P_2^* (1+\tau^m) - c(x_2); \tag{7}$$

$c(x_2)$ represents the cost function for the industry X2.

Concerning the price at the producer level for this commodity, since the problem of abatement and tax on emission do not apply to this industry, the price is given by:

---

[30] For a country that imports the polluting good, the objective function to find the optimal level of θ subject to the tax on pollution is given by: $\max_{\theta}(\Pi^1) = x_1 P_1^*(1+\tau^m) - c(x_1) - P_1^*(1+\tau^m)\theta x_1 - \tau^e e(\theta) x_1$

[31] For importer of the polluting good the optimal level of θ is given by: $\theta^* = \left(\tau^e \Lambda\delta / \left(P_1^*(1+\tau^m)\right)\right)^{1/1-\delta}$

[32] If a country exports the clean good, then the profit function of the industry X2 is given by:
$\Pi^2 = x_2 P_2^* - c(x_2)$

$$P_2 = P_2^*(1+\tau^m);^{33} \tag{8}$$

Finally, when maximizing its profit, both industries X1 and X2 set their labour and capital demands as follow: $\forall i \in \{1,2\}$

$$L_i = (1-\alpha_i)P_i x_i / w; \tag{9}$$
$$K_i = \alpha_i P_i x_i / r; \tag{10}$$

Using equation (2), equation (7) and the structural equations of both industries, we can formulate the condition of null profit for both industries as:

$$P_i A_i K_i^{\alpha_i} L_i^{1-\alpha_i} = wK_i + rL_i; \tag{11}$$

1.4.2.2 The Domestic Consumption

By maximizing their utility function with respect to their budget constraint, the consumers chose the optimal quantities of the domestic demands for x_1 and x_2 expressed by c_1 and c_2 respectively. The objective function is given by:[34]

$$u^j(c_1,c_2) = \left(\frac{\sigma_c}{\sigma_c - 1}\right)\ln\left[\alpha_c c_1^{\sigma_c - 1/\sigma_c} + (1-\alpha_c)c_2^{\sigma_c - 1/\sigma_c}\right] - \delta^j z \tag{12}$$

Subject to $PC_1 c_1 + PC_2 c_2 \le w\sum_1^2 LD_i + r\sum_1^2 K_i + \sum_1^2 (P_i^* \tau^m TRD_i) + \tau^e e(\theta) x_1$

PC_1 is the consumption price of the polluting good; PC_2 is the consumption price of the clean good; $w\sum_{i=1}^{2} LD_i$ is the total wage paid to consumers by both industries X1 and X2; $r\sum_{i=1}^{2} K_i$ is the total return on capital gained by consumers by lending their capital to both industries X1 and X2; $TRD_i \forall i \in \{1;2\}$ when larger than zero is the volume of imports of commodity *i*.

---

[33] τ^m >0 if the good x_2 is imported from the rest of the world and $\tau^m = 0$ if the good x_2 is exported to the rest of the world.
[34] When maximizing their utility function, consumers treat pollution as given.

$\sum_{1}^{2}(P_i^* \tau^m TRD_i)$ is the total tax on imports,[35] which is simply redistributed to consumers; and finally $\tau^e e(\theta)x_1$ is the total amount of tax on emission from producing x_1 unit of polluting good, which is redistributed to consumers.

By taking the first order-conditions with respect to the consumption of x_1 and x_2, we can express the domestic consumption as follows:

$$c_2 / c_1 = \left\{\left[(1-\alpha_c)/\alpha_c\right]\left(PC_1 / PC_2\right)\right\}^{\sigma_c} \tag{13}$$

Using the equation (13) we can elaborate an expression for the share parameter αc which can be expressed as:

$$\alpha_c = 1/\left[1+\left(PC_2 / PC_1\right)\left(c_2 / c_1\right)^{1/\sigma_c}\right] \tag{14}$$

Let R denoting the revenue of the household, we have:

$$R = w\sum_{1}^{2} LD_i + r\sum_{1}^{2} K_i + \sum_{i=1}^{2} P_i^* \tau^m TRD_i + \tau^e e(\theta)x_1 \tag{15}$$

By optimizing utility, household's revenue equals its consumption expenditure:

$$R = PC_1 c_1 + PC_2 c_2 \tag{16}$$

By solving the consumer problem analytically, we can express the optimal level of consumption form each commodity c_1 and c_2 as follows:[36]

$$c_1 = R\alpha_c^{\sigma_c} / PC_1^{\sigma_c}\{PC_1^{1-\sigma_c}\alpha_c^{\sigma_c} + PC_2^{1-\sigma_c}(1-\alpha_c)^{\sigma_c}\} \tag{17}$$

$$c_2 = R(1-\alpha_c)^{\sigma_c} / PC_2^{\sigma_c}\{PC_1^{1-\sigma_c}\alpha_c^{\sigma_c} + PC_2^{1-\sigma_c}(1-\alpha_c)^{\sigma_c}\} \tag{18}$$

---

[35] τ^m is zero if $TRD_i < 0$.

[36] For more details see Appendix 2.

Finally, with respect to the consumption price for both the exported and imported goods, if the country exports the good x_i, then price at the consumer level is given by

$$PC_i = P_i^* \ \forall i \in \{1,2\}; \tag{19}$$

However if the country imports the good x_i, then the consumers pay the following price:

$$PC_i = P_i^*(1+\tau^m) \ \ \forall i \in \{1,2\}; \tag{20}$$

1.4.2.3 Equilibrium Conditions

Market Clearing: In order to build a computable general equilibrium model, and run simulation to test the impact of trade liberalization on the quality of the environment, we need to ensure that at least all minus one market are in equilibrium. The two equilibrium conditions for capital and labour markets are:

$K_1^d + K_2^d = K^s$, where K^s denotes the capital endowment in the economy. (21)

$L_1^d + L_2^d = L^s$, where L^s denotes the capital endowment in the economy. (22)

The equilibrium between demand and supply for both commodities x_1 and x_2 need to be verified through the following conditions:[37]

$$x_1(1-\theta) = c_1 - TRD_1; \tag{23}$$

$$x_2 = c_2 - TRD_2; \tag{24}$$

1.5 Data and Calibration of the CGE Model

As a preliminary step, we provide a brief discussion of the role of the social accounting matrix ("SAM") and how to apply it to specific countries. Second, for each country selected, we calibrate the parameters of our model using data available from the SAM.

[37] A summary of the analytical equation describing the adjusted version of the ACT Model is provided in Appendix 3.

1.5.1 The Social Accounting Matrix

By recording all the transactions that take place in one particular year in a specific economy, the SAM represents a picture of the economy at a specific period of time.[38] [39] In the last 30 years a large number of researchers have extended the CGE model in many relevant applications (see for example Ginsburgh and Waelbroeck (1981); Jorgenson (1984); Scarf and Shoven (1984); Manne (1985); Srinivasan and Whalley (1986); Taylor (1990); Bergman, Jorgenson, and Zalai (1990); Don, van de Klundent, and van Sinderen (1991); Mercenier and Srinivasan (1994); Timothy, 1996; Mérette and Fougère (1998), Mérette, Mercenier, Beausejour and Hsueh (2001); Dissou (2005)).

To investigate the impact of trade liberalization on the environment we gather information about four selection criteria: capital endowment, real domestic income per capita, degree of protectionism, and type of exported good. Using these selection criteria, we construct four country profiles. A first profile is a country that exports the polluting good, has a relatively high capital to labour ratio, a relatively high level of real income per capita, and a relatively low level of protectionism. A second profile is a country that exports the polluting good, has relatively low levels of capital endowment and real income per capita, and a low level of protectionism. A third profile is a country that exports the polluting good, has relatively low levels of capital to labour ratio and real income per capita, and a relatively high level of protectionism. A fourth country that exports the clean good. Such country has relatively high levels of capital endowment and real income per capita and a relatively low level of protectionism. For each case, we select the stringency of the environmental policy (high versus low level) that is mainly associated with the level of real income per capita.[40]

---

[38] Historically, the SAM was used at least since 1759 under a French appellation "Tableau économique" (Studenski, 1958; Stone's, 1986; Timothy, 1996). Over time, the SAM has evolved under the work of Kuznets (1937), Leontief (1941), Meade and Stone (1941), and Stone (1947). A complete set of double-entry national income accounts were born and adopted by the United Nations (1953-1968) under the name of System of National Accounts, which has currently a worldwide use.

[39] Harberger (1962) and Johansen (1960) were among the first to develop a SAM in order to construct an applied general equilibrium model. Scarf (1967, 1973) also made important contributions in the literature by making a connection between empirical and theoretical research.

[40] According to ACT (2001), low-income countries typically have both low incomes per capita and low capital to labour ratio. Since the stringency of the environmental policy is mainly determined by differences in income, we expect such policy to be stringent in rich countries and less stringent in poor countries.

For illustration purposes, the four profiles refer to four countries.[41] Degrees of protectionism are limited to tariffs.[42] The volumes of emission are based on Sulfur Dioxide Emissions between 1990 and 2000 according to the World Resources Institute.[43]

According to ACT (2001), sulfur dioxide can be a useful pollutant to assess the impact of free trade on the environment as it is generated from production activity in some industries. It is subject to regulations with well known abatement technologies. Sulfur dioxide (SO2) is a primary contributor to acid deposition, or acid rain, a proven detriment to the health of ecosystems. High concentrations of sulfur dioxide also affect breathing and may aggravate existing respiratory and cardiovascular disease. Sulfur dioxide forms when fuel containing sulfur, such as coal and oil, is burned, when gasoline is extracted from oil, or metals are extracted from ore. Petroleum refineries, cement manufacturing, and metal processing facilities, as well as locomotives, large ships, and some non-road diesel equipment burn high sulfur fuel and release SO2 emissions to the air in large quantities. Using the Emission Database for Global Atmospheric Research (EDGAR) 3.2, we summarize the evolution in the level of SO2 emissions in the world between 1990 and 1995.[44] (see Table 1)

Table 1: Trend in regional SO2 emissions 1990-1995 (Unit: Tg SO2)

Region / Year	1990	1991	1992	1993	1994	1995
01: CANADA	2.5	2.5	2.5	2.5	2.7	2.8
02: USA	22.5	20.9	20.1	20.1	19.3	18.1
03: OECD EUROPE	23.5	21.8	20.1	18.3	17.4	16.5
05: JAPAN	2.1	2.1	2.1	2.1	2.1	2.2
06: EASTERN EUROPE	12.5	11.9	12.2	10.8	10.4	10.5
07: FORMER USSR	29.0	25.9	21.4	19.3	16.4	16.0
08: LATIN AMERICA	8.8	8.9	9.5	9.4	9.7	10.1
09: AFRICA	7.7	7.0	7.0	6.9	6.8	6.9
10: MIDDLE EAST	4.9	4.9	5.3	5.3	5.5	5.7
11: SOUTH ASIA	5.8	6.2	6.5	6.7	7.1	7.5

[41] To determine the volume and the $ value of the imports and exports for each countries, we use data provided by the World Trade Organization report titled "International Trade Statistics 2001", which is available at: www.wto.org

[42] For the tariff on imports, we use average tariff provided by the World Trade Organization Report on Tariff Profiles available at:
http://www.wto.org/english/tratop_e/tariffs_e/tariff_profiles_2001_e/tariff_profiles_2001_e.pdf

[43] http://earthtrends.wri.org/text/climate-atmosphere/variable-812.htm

[44] Data on SO2 emissions is made available by the Netherlands National Institute for Public Health and the Environment, the Netherlands Environmental Assessment Agency and the Netherlands Organization for Applied Scientific Research via EDGAR 3.2.

12: EAST ASIA	30.3	31.4	32.5	36.3	37.9	40.2
13: SOUTH EAST ASIA	3.0	3.2	3.3	3.6	3.7	3.8
Total	**154.3**	**148.4**	**144.3**	**143.1**	**140.8**	**141.9**
Source: EDGAR 3.2, 2002						

For each country, we construct a SAM based on year 2000 aggregated data that respects the ACT assumptions.[45] Both primary and secondary sectors constitute the polluting industry as defined in the ACT Model and the tertiary sector represents the clean industry.

Based on their 2000 level of emission as first and second highest polluter in the world, China and USA constitute the perfect candidates for the following two profiles. In one hand, the United States (USA) is a country with relatively high capital to labour ratio, high level of income per capita, and relatively low level of protectionism with an average imports tariff of 3.5%. The USA exports the clean good. In the other hand, China is a country with relatively low capital to labour ratio, low level of income per capita, and low imports tariff. China exports the polluting good. For the remaining two profiles, we select Germany and Brazil. First, Germany is a relatively rich country with relatively high level of income per capita and low level of protectionism with an average imports tariff of 5.4%. Second, Brazil is a country with relatively low capital to labour ratio, low level of income per capita, and relatively high level of protectionism where the imports tariff exceeds 31%. Both Germany and Brazil export the polluting good. The following table provides a detailed description of the four countries.

Table 2: Country characteristics based on year 2000 Data

	Brazil	**China**	**Germany**	**USA**
Real Gross Domestic Income[46]	8396	4173	29030	39377
K/L($1000/worker)[47]	3.17	0.47	16.06	24.35
Tax on Pollution[48]	1.12%	1.17%	11.15%	11.57%
Intensity of Abatment	1%	1%	10%	10%
Import Tarif	31.40%	10%	5.40%	3.50%
Exports	Polluting Good	Polluting Good	Polluting Good	Clean Good

[45] SAMs are constructed based on input-output tables made available in the "THE OECD INPUT-OUTPUT DATABASE: 2006 EDITION", STI WORKING PAPER 2006/8.

[46] Real Gross Domestic Income (unit: I$ terms of trade in 2005 Constant Prices), Source: Alan Heston, Robert Summers and Bettina Aten, Penn World Table Version 6.3, Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania, August 2009.

[47] Capita to labour ratio is calculated based on the stock of capital available in the input-output tables divided by the labour force available in the World Bank Report at the following address: http://siteresources.worldbank.org/INTPOVERTY/Resources/WDR/English-Full-Text-Report/ch12a.pdf

[48] Tax on pollution at the benchmark situation is calibrated based on the intensity of abatement.

With respect to world total emission, the sum of USA and China share had increased from 31% in 1990 to 35% in 2000, mainly due to an increase in the Chinese emissions by more than 35%. It is worth mentioning that, during the same period, China's annual economic growth rate had exceeded 10%. For Brazil, with a share of 1.9% of total world emission in 2000, its emission share had increased by 54% between 1990 and 2000. During this period, Brazilian economy had increased at a rate of 6.03%. Finally, Germany had its share out of total world emission declined from 4.72% in 1990 to 1.6 % in 2000. Table 3 summarizes the evolution of SO2 emission between 1990 and 2000 in the four countries selected.[49]

Table 3: Emission of SO2 in the Four Countries Over Time

		SO2 Emission (Thousand metric Tons)	Share of World Total Emission	Percentage of Change
Brazil	1990	1892.9	1.23%	
	1995	2050.1	1.45%	8%
	2000	2852.7	1.90%	39%
China	1990	25375.6	16.45%	
	1995	34359.5	24.22%	35%
	2000	34204.7	22.75%	-0.45%
Germany	1990	7285.4	4.72%	
	1995	3604.2	2.54%	-51%
	2000	2402.1	1.60%	-33%
USA	1990	22455.4	14.55%	
	1995	18142.2	12.79%	-19%
	2000	17866	11.88%	-2%

From Table 3, we notice that between 1995 and 2000, the level of SO2 emission had decreased in all countries except for Brazil where its share of world total emission had increased by more than 39%. The following graph describes the evolution in the level of emission of SO2 in the four countries selected between 1990 and 2000.

[49] It is worth mentioning that more recent data, mainly for Canada and USA, is available from various sources. However, for consistency purposes we rely on the Emission Database for Global Atmospheric Research (EDGAR 3.2).

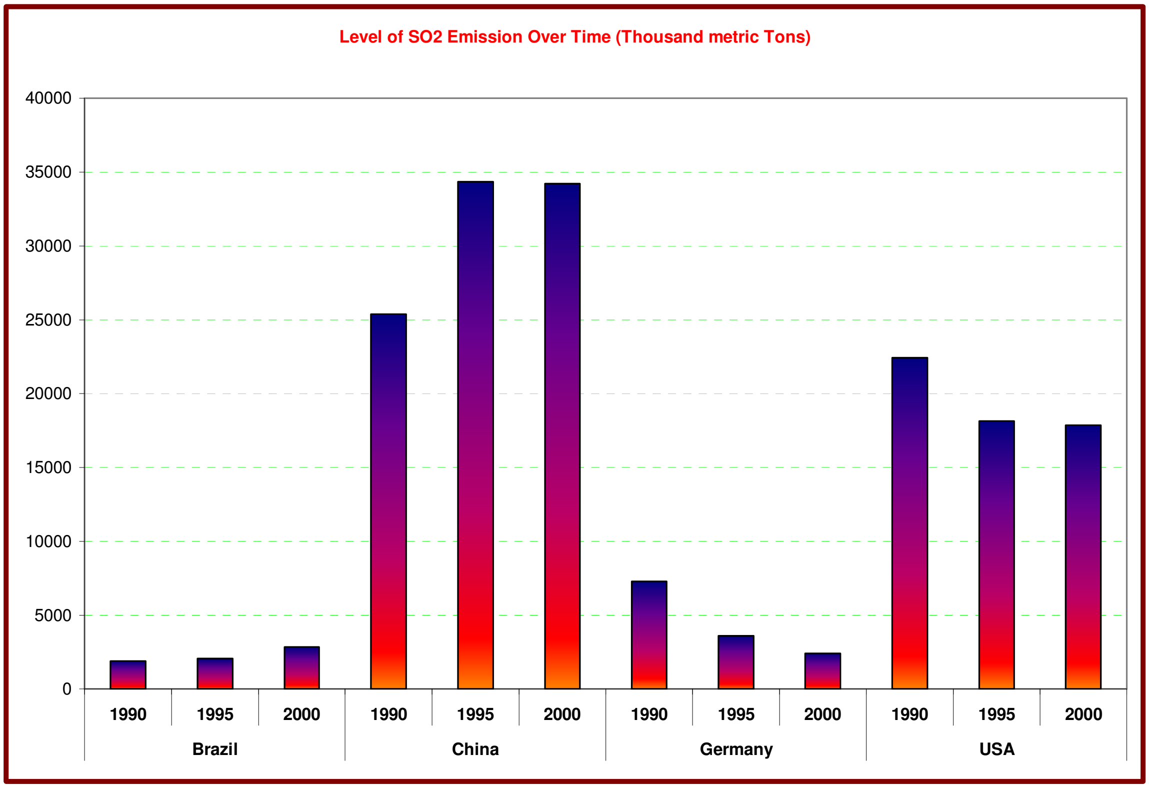


Figure 2: Evolution of the Level of SO2 over Time

With respect to the stringency of the environmental policy, we assume two states: A stricter environmental policy featuring a high tax on pollution and a high intensity of abatement, and a loose environmental policy that is characterized by a relatively low tax on pollution and a low level of abatement. We assume that USA and Germany have stringent environmental policy, whereas China and Brazil have loose policy. Due to the lack of information on abatement costs and tax on pollution, we make the following assumptions: First, we assume two levels of intensity of abatement at the benchmark situation: A high level of abatement in rich countries and a low level in poor countries. [50] Second, we assume that the pollution tax is set at its optimal level at the benchmark situation. By using the level of emission data and information enclosed in the SAM, we indirectly calibrate the level of tax on pollution and the coefficient of emission at the benchmark situation for each state of the environmental policy.[51]

[50] Jaffe et al. (1995) assume that total cost of pollution control in USA represents 7% of US GNP in 1993.
[51] The SAMs for the four countries are available in the appendix 4.

1.5.2 Calibration

Numerical values of the parameters reflecting the behaviour of consumers and producers need to be calibrated in order to reproduce the initial equilibrium reported in the SAM (Annabi, Cockburn and Decaluwe, 2003).[52]

The calibration of the ACT Model consists of findings values for the share and the shift parameters characterizing the two production functions, the share parameter of the CES utility function, the rate of tax on pollution and the coefficient of emission at the benchmark situation. In table 4, we provide analytical expression for these calibrated parameters. We set the elasticity of substitution between the two goods, x_1 and x_2 to be equal to 1.5.

Table 4: Main Results of the Calibration Process

Calibrated Parameters		**Expression**
Industry X1	**Shift Parameter**	$A_1 = x_1 / (K_1^{\alpha_1} L_1^{1-\alpha_1})$
	Share Parameter	$\alpha_1 = r.K_1 / (P_1 x_1)$
Industry X2	**Shift Parameter**	$A_2 = x_2 / (K_2^{\alpha_2} L_2^{1-\alpha_2})$
	Share Parameter	$\beta = r.K_2^{\beta} / (P_2.x_2)$
Consumers	**Share Parameter of the CES Utility Function**	$\alpha_c = 1/\left[1 + (PC_2 / PC_1)(C_2 / C_1)^{1/\sigma_c}\right]$
	Elasticity of Substitution	Based on empirical literature
Coefficient of Emission[53]		$e(\theta) = 1 - \Lambda \theta^{\delta}$
Tax on Pollution at the Benchmark Situation[54]		$\tau^e = P_1^* \theta^{1-\delta} / \Lambda \delta$

1.6 Simulations and Main Findings

This section numerically investigates the impact of import tariffs reduction on the volume of emission in the four countries selected. Based on the stringency of the environmental policy, we conduct two sets of simulation. First, under less tighter environmental policy, we report

[52] The calibration consists of determining the parameters describing the behaviors of different economic agents in such a way that we reproduce the information contained in the initial SAM.
[53] The calibration of the parameter Λ is provided in Appendix 5.
[54] Formulation of the optimal tax on pollution is provided in Appendix 6.

our main findings on Brazil and China. Our purpose here is to investigate the role played by the gap in trade policy (degree of protectionism) on the level of emission from trade. Second, by allowing countries to export different type of goods (clean versus polluting good), under stringent environmental policy, we analyse the key results associated with Germany and the USA. This analysis will shed more light on the interaction between the PHH versus the FEH to determine trade patterns. Furthermore, it will provide a detailed discussion of the connection between income, tax on pollution, intensity of abatement, and coefficient and level of emission as they evolve as a result of trade liberalization. In fact, it is important to highlight that, in our model, the tax on pollution is kept endogenous. It is set to be positively related to the level of income.

Our model suggests that, if free trade leads to a higher tax on pollution, producers of the polluting good will invest more to abate their emissions. Consequently, the coefficient of emissions falls. However, the total impact of an import tariffs reduction on pollution will also depend on the change in domestic production of the polluting good. For example, for an exporter of the polluting good, trade liberalization reduces domestic protection of the clean industry.[55] With respect to the polluting good, trade liberalization affects producer price through three channels: the intensity of abatement, the tax on pollution, and the coefficient of emissions (equation 3). Therefore, assessment of the impact of trade liberalization on the composition of the domestic production will depend on the variation in the relative price of domestic producers.[56]

For an exporter of the clean good, trade liberalization has no direct impact on domestic producer price of the clean good. However, producer price of the polluting good, the intensity of abatement, the tax on pollution, and the coefficient of emissions will be affected by the import tariff reduction. In such a context, we expect both scale and composition effects to reduce the volume of emission.

[55] Since by assumption, domestic producers benefit from a protection against foreign industries given by the import tariffs (equation 8).
[56] The magnitude of the change in the composition of output due to a decrease in the producer price of the polluting good caused by higher pollution tax depends on the importance of the pollution tax in the net price and the elasticity of the composition effect with respect to change in the producer price.

Finally, with respect to the trade induced composition effect, our model suggests that, for an exporter of the polluting good, free trade will increase the relative price of the polluting good. More resources will be diverted to the production of such product. Also, abatement becomes more expensive and hence reduces the incentives to reduce emissions. In addition, because of the pure substitution effect of the goods price increase,[57] the tax on pollution increases. Overall, the increase in the tax on emission may not be high enough to offset the increase in pollution due to change in the relative price. Consequently, the total emission from the composition effect may increase. For an importer of the polluting good, free trade augments the relative price of the clean good, causing the level of emission to fall.[58]

1.6.1 Main Findings under Less Stringent Environmental Policy

Characterized with relatively low capital to labour ratio and low level of income per capita in comparison to rich countries, both China and Brazil are found to be polluting good exporter. The following factors spell out the reasons behind such classification:

- lack of stricter environmental policy caused by relatively low level of income,
- difference in the level of technological progress and qualification of the labour force in comparison to rich countries, and
- heterogeneity of capital.

However, it is important to emphasize the differences between China and Brazil. First, Brazil has the highest import tariffs (31.4%) among the four countries selected, while China imports tariff is equal to 10%. Second, Brazil is more capital endowed and has higher income per capita relative to China. In addition, between 1995 and 2000, Brazilian world share of total SO_2 emission had increased by 39%. However, Chinese share had decreased by 0.45% for the same period.

[57] Pure substitution effect take place when the world relative price of the polluting good increases in such a way that consumption of market goods becomes more expensive in comparison to environmental protection. The government intervenes by increasing the tax on pollution.

[58] It is important to mention that the free trade induced composition effect does not take into consideration the impact of change in the trade friction on the scale of the economy and the income. Also it does not explain the determinant of trade patterns.

To assess the impact imports tariff reduction on the volume of emission, we conduct a set of simulations for each country, which consist of reducing the imports tariffs starting from a benchmark situation described in the following table.

Table 5: Benchmark Situation under Less Stringent Environmental Policy

	Tax on Pollution	Intensity of Abatement	Coefficient of Emission	Level of SO2 Emission (thousand metric tons)	Import Tariff
Brazil	1.12%	1%	0.047	2852.7	31.40%
China	1.17%	1%	0.004	34204.7	10%

Based on the information presented in Table 2, we notice that, the intensity of abatement at the benchmark situation is positively related to the tax on pollution. In addition, as suggested by equation (5), the coefficient of emission is negatively related to the intensity of abatement. Table 5 suggests that, for the same level of abatement at the benchmark situation, the tax on pollution is lower in Brazil than in China leading to a higher coefficient of emission in Brazil. A potential explanation can be derived from the gaps in capital endowment and income per capita between these two countries at the benchmark situation. In fact, although capital to labour ratio and income per capital are higher in Brazil relative to China, it seems that the gap in capital endowment is relatively more significant than the gap in income.[59]

By reducing the imports tariff, Brazil reduces its protection that benefits its clean industry. Producer's price of the clean good decreases leading to a reduction in the domestic production of such commodity. More resources are diverted to the production of the polluting good, and more pollution is generated. Furthermore, with respect to the environmental policy reaction, the tax on pollution decreases. Less resource is allocated to reduce pollution, and the coefficient of emission increases. In fact, by removing its protection to the clean industry, Brazil chooses to reduce the cost of its environmental policy to improve the competitiveness of its polluting industry. All three effects (scale, composition, and technique effect) create a negative impact on the environment. Moreover, results derived from simulations show a decrease in the disposable income as expressed by equation (15), which is mainly due to a

[59] Income per capita is two times higher in Brazil than in China and Capital to labour ratio is almost seven times higher in Brazil. This may explain the reason why the FEH seems to dominate the PHH when comparing Brazil to China.

reduction in the amount of tax on imports that is redistributed to consumers. The following table summarizes the main findings form a reduction in the import tariff in Brazil.

Table 6: Impact of Import Tariff Reduction on Emission Under Less Stringent Environmental Policy						
Percentage of Variation		Δ	2Δ	3Δ	4Δ	5Δ
Brazil	COEFFICIENT OF EMISSION	3.01	6.05	9.13	12.24	15.38
	VOLUME OF EMISSION	3.04	6.13	9.27	12.47	15.71
	TAX ON POLLUTION	-0.02	-0.04	-0.06	-0.08	-0.10
	INTENSITY OF ABATMENT	-0.20	-0.40	-0.60	-0.81	-1.01
	DISPOSABLE INCOME	-0.04	-0.08	-0.12	-0.16	-0.20
	CONSUMPTION OF X	-0.09	-0.18	-0.28	-0.37	-0.46
	CONSUMPTION OF Y	0.27	0.54	0.81	1.08	1.35
	DEMAND FOR CAPITAL BY X1	0.02	0.04	0.05	0.07	0.09
	DEMAND FOR CAPITAL BY X2	-0.81	-1.63	-2.44	-3.24	-4.05
	DEMAND FOR LABOUR BY X1	0.50	1.01	1.52	2.03	2.55
	DEMAND FOR LABOUR BY X2	-0.33	-0.67	-1.01	-1.35	-1.70
	PRODUCTION OF Y	-0.34	-0.69	-1.03	-1.38	-1.73
	PRODCUTION OF X	0.25	0.51	0.77	1.02	1.28
	WELFARE	0.005	0.010	0.015	0.020	0.024
	Percentage of Import Tariff Reduction (Δ =5%)					

Table 6 shows that trade liberalization has a positive impact on the production of the polluting good (scale effect)[60], and as well as a positive impact on the weight of the production of the polluting good (composition effect).[61] In addition, a reduction in tariffs reduces the tax on pollution, leading to a reduction in abatement effort and consequently, the coefficient of emissions increases (technique effect).[62] The total impact of trade liberalization on the volume of emissions is significantly positive. In fact, under 25% of imports tariff reduction, the production of the polluting good increases by 1.3%, while the production of the clean good decreases by 1.7%. In addition, due to an increase in the coefficient of emission by 15.38%, the level of emission of SO_2 increases by 15.71%.

---

[60] As expected, free trade generates more activity and production of the polluting good increases. If the composition of the total output and the coefficient of emission remain constant, then we expect the volume of emissions to increase.

[61] Free trade changes the composition of total output towards the production of more polluting good as compared to the clean good. This composition effect causes the level of emission to increase in the economy.

[62] An increase in the coefficient of emissions due to a reduction in the imports tariff constitutes a deterioration in the abatement technology, which leads to more emission generated in the economy.

To summarize the main findings from the simulations conducted using data from Brazil, if the country exports the polluting good then:

- trade liberalization reduces the tax on pollution, the intensity of abatement, the producer's and consumers' prices of the clean good, the wage, and the production of the clean good. On the other hand, free trade increases the production of the polluting good, the rate of return on capital, and the coefficient of emission, which leads to more pollution generated in the economy.
- with respect to the decomposition approach, we find that all three effects scale, composition and technique effects contribute to the increase of pollution. In fact, free trade increases the production of the polluting good, alters the domestic production towards more capital intensive production, and increases the coefficient of emission to generate more pollution in the economy using the same level of output.
- due to the fact that Brazilian imports tariff is relatively high (31.4%), free trade reduces the amount of tax collected from imports and distributed to consumers. Such decrease dominates the impact of free trade on tax from pollution and real income.
- under less stringent environmental policy and being more capital endowed than China, free trade seems to create more incentives for Brazil to produce more of its polluting good for both the domestic and the international markets.
- free trade seems to have positive impact on total welfare.[63] However, such effect is very small in magnitude.

With respect to China, an emerging–global economy with a low capital to labour ratio, low level of per capita income, and low level of protectionism in comparison to Brazil, by exporting the polluting good, China's level of emission is the highest in the world. Following the same set of simulations as for Brazil to investigate the impact of openness on environmental quality, Table 7 provides a detailed description of the main results.

[63] With respect to variation in total welfare, note that the percentage welfare changes are computed as equivalent variations as a proportion of benchmark total income.

Table 7: Impact of Import Tariff Reduction on Emission Under Less Stringent Environmental Policy						
Percentage of Variation		Δ	2Δ	3Δ	4Δ	5Δ
China	COEFFICIENT OF EMISSION	-1.69	-3.38	-5.08	-6.79	-8.51
	VOLUME OF EMISSION	-1.44	-2.98	-4.64	-6.41	-8.29
	TAX ON POLLUTION	0.09	0.18	0.28	0.37	0.46
	INTENSITY OF ABATMENT	0.93	1.86	2.79	3.73	4.68
	DISPOSABLE INCOME	0.19	0.38	0.56	0.75	0.93
	CONSUMPTION OF X	0.18	0.36	0.54	0.72	0.90
	CONSUMPTION OF Y	0.26	0.53	0.79	1.05	1.31
	DEMAND FOR CAPITAL BY X1	0.25	0.5	0.75	0.997	1.24
	DEMAND FOR CAPITAL BY X2	-0.96	-1.91	-2.86	-3.8	-4.74
	DEMAND FOR LABOUR BY X1	0.33	0.66	0.99	1.32	1.66
	DEMAND FOR LABOUR BY X2	-0.89	-1.79	-2.7	-3.62	-4.54
	PRODUCTION OF Y	-0.91	-1.83	-2.76	-3.68	-4.6
	PRODCUTION OF X	0.298	0.596	0.895	1.195	1.496
	WELFARE	0.015	0.031	0.046	0.061	0.076
	Percentage of Import Tariff Reduction (Δ =5%)					

As for Brazil, a reduction in the import tariff reduces the production of the clean good. More resources are diverted to the production of the polluting good. However, in contrast to Brazil, free trade generates more income in China that increases the tax on pollution. According to equation (6), the intensity of abatement follows and the coefficient of emission decreases as shown by equation (5).

The results reported in Table 7 suggest the existence of a positive relationship between the intensity of abatement and the environmental quality. For instance, if the intensity of abatement at the benchmark situation is set at 1%, a 25% drop in the imports tariff increases the tax on pollution by 0.46%. This will lead to an increase in the effort of abatement by 4.68%, and the coefficient of emission drops by 8.51%. Thus, despite the increase in the production of the polluting good by 1.5%, the volume of emission falls by 8.29%. Free trade improves the quality of the environment.

Based on the information provided in Table 7, trade liberalization leads to more production of the polluting good. For example, as a result of a 25% decrease in the imports tariff, production of the polluting good increases by 1.5% from the scale effect. In addition, import tariff reduction alters the composition of the domestic production towards more polluting production by reducing the production of the clean good by 4.6% compared to 1.5% increase for the polluting good due to the composition effect. The coefficient of emission decreases by 8.51% thanks to the technique effect. In total, the volume of emission decreases by 8.29%. The technique effect dominates both the scale and composition effects.

At the producer level, free trade leads to a reduction in the price of the clean product. The economy converges towards the production of more polluting goods to serve both domestic and foreign markets. This will increase the level of pollution in the absence of environmental policy response. To compensate for that, the tax on pollution increases. More resources are invested to reduce emission and the coefficient of emission falls. Moreover, due to the expansion of the production of the polluting good, the demand for capital increases relative to labour, leading the rate of return on capital to increase in the detriment of wage.

From the consumers' perspective, trade liberalization impacts consumers via two channels: lower price for the clean commodity relative to polluting one and higher level of income in comparison with the benchmark situation. The latter became possible thanks to the increase in the production of the polluting good and the opportunity to trade with the rest of the word that offset the impact of trade liberalization on wage and the reduction in the import tariff. Results form simulations suggest that, as a result of more openness to trade, more income is used to increase domestic consumption of domestically produced and imported commodities.

To conclude, by running a set of simulations based on less stricter environmental policy, we show that if China exports the polluting good, then trade liberalization reduces the producer's price of the clean good. The production of such commodity decreases and the production of the polluting good expands. In addition, the tax on pollution and the intensity of abatement increases, leading to a decrease in the coefficient of emission. In contrast to Brazil which has a high level of protectionism, free trade generates more income in China and domestic consumption of both products increases. Moreover, the results derived from simulation show the existence of a positive relationship between free trade, environment, and total welfare. The impact on welfare is, however, very small.

1.6.2 Main Findings under Stringent Environmental Policy

Characterized with relatively high capital to labour ratio and high level of per capita income, both Germany and USA are assumed to have a stringent environmental policy. Furthermore, both countries have a low level of protectionism. However, by assuming that trade patterns are mainly determined by the interaction between factors endowments and differences in income, the type of exported good in these two countries constitutes a perfect example of such interaction. For instance, ACT (2001) affirm that,[64] if the country is sufficiently capital abundant, it must export the capital intensive good. Germany in our model is a perfect manifestation of such statement. The USA is considered in our model a rich country exporting the labour intensive good because its level of income is high enough to impose a more stringent policy.[65]

To measure the impact of imports tariff reduction on the volume of emission, we conduct a set of simulations for each country, which consist of reducing the imports tariff starting from a benchmark situation described in the following table.

Table 8: Benchmark Situation under Stringent Environmental Policy

	Tax on Pollution	Intensity of Abatement	Coefficient of Emission	Level of SO2 Emission (thousand metric tons)	Import Tariff
Germany	11.15%	10%	0.006	2402.1	5.40%
USA	11.57%	10%	0.006	17866	3.50%

Based on the information reported in Table 8, Germany imposes an import tariff of 5.4% on its imports of the clean good. Import tariff reduction will have a direct impact on the production of the clean product. According to equation (8), producer's price of clean good will decrease with free trade, causing the production of such commodity to fall. Based on equation (11), less resource will be required by the clean industry and more resources are diverted to the production of the polluting good. In addition, due to the increase in the

[64] For more details see ACT (2001, P887), Proposition 3. "Suppose the world price p^w is fixed. Then, for a given level of real income I, there exists $\underline{k}$ such that if $k > \underline{k}$, then Home exports X (capital intensive good). Moreover, for such a country, the trade-induced composition effect will be positive."

[65] For more details see ACT (2001, P. 888), Proposition 4. "When countries differ in factor endowments and income levels, we can show that if the country is *sufficiently* rich, it must export the labour-intensive (clean) good."

domestic and foreign demand for the polluting good generated by free trade, domestic production of such product increases, creating more pollution.

The following table provided detailed description of the main results form import tariff reduction in Germany.

Table 9: Impact of Import Tariff Reduction on Emission Under Stringent Environmental Policy

	Percentage of Variation	Δ	2Δ	3Δ	4Δ	5Δ
Germany	COEFFICIENT OF EMISSION	0.47	0.97	1.50	2.06	2.66
	VOLUME OF EMISSION	0.62	1.28	1.99	2.74	3.55
	TAX ON POLLUTION	0.00	0.00	-0.01	-0.01	-0.01
	INTENSITY OF ABATMENT	-0.02	-0.04	-0.06	-0.08	-0.10
	DISPOSABLE INCOME	0.00	-0.01	-0.01	-0.02	-0.02
	DEMAND FOR CAPITAL BY X1	0.17	0.33	0.5	0.66	0.83
	DEMAND FOR CAPITAL BY X2	-0.06	-0.13	-0.2	-0.26	-0.32
	DEMAND FOR LABOUR BY X1	0.13	0.26	0.4	0.52	0.65
	DEMAND FOR LABOUR BY X2	-0.1	-0.2	-0.29	-0.39	-0.49
	PRODUCTION OF Y	-0.08	-0.17	-0.25	-0.33	-0.41
	PRODCUTION OF X	0.14	0.28	0.42	0.56	0.7
	WELFARE	0.002	0.004	0.006	0.009	0.011

Percentage of Import Tariff Reduction (Δ =5%)

Table 9 suggests that, as a result of a 25% reduction in the imports tariff, production of the clean good falls by 0.41%, while production of the polluting good increases by 0.7%. Moreover, the tax on pollution declines by 0.01%, causing the coefficient of emission to increase by 2.66%. The overall impact of tariff reduction is an increase in the volume of emission by 3.55%. All three effects (scale, composition and technique effects) seem to work together to increase the level of SO2 emission in Germany. Free trade is positively related to the volume of emission. In fact, trade liberalization seems to accelerate Germany specialization in the production of the polluting good.

To conclude, for a country with relatively high capital endowment and low level of protectionism, if the FEH dominates the PHH allowing the country to export the polluting good, then free trade leads to more specialization in the production of the polluting good. Hence, despite the stringency of the environmental policy, we find that all three effects (scale, technique, and composition effects) are positively related to the level of emission.

Turning to the USA, the income effect seems to dominate the factor endowment effect and the country exports the clean good. For the same level of intensity of abatement at the benchmark situation in comparison with Germany, USA has the highest tax on pollution. Following the same set of simulations that is conducted for Germany; we attempt to assess the impact of import tariff reduction on the level of emission in the USA.

Results from simulation suggest that the tax on pollution is positively related to the intensity of abatement and negatively related to the coefficient of emission. By reducing the imports tariff, domestic producers of the polluting good loose their protection against foreign competition. Two possible scenarios are worthy of particular attention: an increase versus a decrease in the disposable income as a result of trade liberalization.

First, if free trade reduces the level of disposable income, then we expect the tax on pollution to fall. Assessment of the impact of import tariff reduction on the intensity of abatement using equation (6) given by $\theta^* = \left(\tau^e \Lambda \delta / \left(P_1^*(1+\tau^m)\right)\right)^{1/1-\delta}$ shows that, if the tax on pollution effect dominates the tariff effect, the intensity of abatement declines and the coefficient of emission increases.[66] Based on the following expression of the producer's price of the polluting good $P_1 = \left[(1+\tau^m)(1-\theta)P_1^*\right] - \tau^e e(\theta)$, the producer price of the polluting good increases. More resources are diverted to the production of the polluting good and the volume of emission increases.

Second, if free trade leads to an increase in the disposable income, both the intensity of abatement and the tax on pollution will follow the same path. As a result, the coefficient of emission falls. Overall, trade liberalization leads to a reduction in the producer's price of the polluting good. The domestic production converges towards more specialization in the production of the clean good and the volume of emission falls.[67] In fact, both scale and

[66] However, in the opposite situation, the intensity of abatement increases, causing the coefficient of emission to fall. Overall, the producer's price of the polluting good decreases, causing the level of production and emission to fall.

[67] According to equation (6) trade liberalization creates two effects that impact the intensity of the abatement: the tax on pollution and the import tariff effects as shown in the following expression: $\theta^* = \left(\tau^e \Lambda \delta / \left(P_1^*(1+\tau^m)\right)\right)^{1/1-\delta}$. Both effects seem to have similar impact on the intensity of abatement that varies in the same direction as the tax on pollution.

technique effects work together to reduce the volume of pollution. The following table summarizes the impact of import tariff reduction on the volume of emission in the USA.

Table 10: Impact of Import Tariff Reduction on Emission Under Stringent Environmental Policy

	Percentage of Variation	Δ	2Δ	3Δ	4Δ	5Δ
USA	COEFFICIENT OF EMISSION	-1.73	-3.47	-5.23	-6.99	-8.77
	VOLUME OF EMISSION	-1.93	-3.79	-5.58	-7.29	-8.92
	TAX ON POLLUTION	0.01	0.02	0.02	0.03	0.04
	INTENSITY OF ABATMENT	0.12	0.23	0.35	0.47	0.59
	DISPOSABLE INCOME	0.02	0.04	0.06	0.08	0.10
	CONSUMPTION OF X	0.02	0.05	0.07	0.10	0.12
	CONSUMPTION OF Y	0.02	0.04	0.06	0.08	0.10
	DEMAND FOR CAPITAL BY X1	-0.24	-0.48	-0.72	-0.96	-1.2
	DEMAND FOR CAPITAL BY X2	0.11	0.23	0.34	0.46	0.57
	DEMAND FOR LABOUR BY X1	-0.25	-0.5	-0.75	-1	-1.25
	DEMAND FOR LABOUR BY X2	0.10	0.21	0.31	0.41	0.52
	PRODUCTION OF Y	0.11	0.21	0.32	0.43	0.53
	PRODCUTION OF X	-0.25	-0.49	-0.74	-0.98	-1.23
	WELFARE	0.001	0.003	0.004	0.006	0.007
						Percentage of Import Tariff Reduction (Δ =5%)

Table 10 shows that under stringent environmental policy, if a rich country exports the clean good, then free trade creates a positive variation in the disposable income leading to an increase in the intensity of abatement and the tax on pollution. Under 25% of import tariff reduction, the coefficient of emission falls by 8.77%, the production of the polluting good falls by 1.23%, the volume of emission shrinks by 8.92%, and the total welfare shows positive but very small improvement. These results are coherent with ACT (2001) finding stating that, the full effect of free trade on a country that exports the clean good is to lower pollution emission.[68]

[68] For more details see Act (2001, P886), *Proposition 2*. “if the small open economy exports the clean good, the full effect of this trade liberalization is to lower pollution emission.”

1.7 Conclusion

In the context where trade patterns are mainly determined by the interaction between factor endowments and income differences, we have attempted to create four country profiles to provide computational assessment of the effect of trade liberalization on the volume of emission. This paper investigates numerically the conditions and circumstances in which free trade is good for the environment.

First, we analytically solved the model by assigning specific forms to the producer and consumer problem, to the coefficient of emission, to trade, and to the tax on pollution. Second, we elaborate four different country profiles based on their characteristics with respect to their trade and environmental policies, their endowments and wealth, and the type of good they export. Third, we select four countries with respect to these profiles. For each country, we calibrate the parameters of the model based on the stringency of the environmental policy. Fourth we conduct series of simulation to assess the impact of import tariff reduction on the volume of emission.

Our main findings show that for a combination of relatively high capital to labour ratio, polluting exports, and low level of protectionism, trade liberalization increases the level of emission. However, if the country exports the clean good, then the impact of tariff reduction is positive on the environment when income increases (Case of USA).

Under a relatively low level of capital endowment for a country that exports the polluting good, the impact of free trade on the environment depends on the degree of protectionism. With a high level of protectionism, trade liberalization generates more pollution. However, with relatively low level of protectionism, free trade can improve the environment.

One possible extension to this paper consists of introducing the impact of changes in the demographic structure of the economy on the level of emission using a dynamic framework. Under such a model, it is possible to take into consideration changes in preferences towards the consumption of clean versus polluting good as they grow older. A potential question would be: is ageing good for the environment?

Appendix

Appendix 1: Expressing the Domestic Price as a Function of the World Price

- If the country exports the polluting good:

Using equation (2) $x_1 P_1^* = c(x_1) + P_1^* \theta x_1 + \tau^e e(\theta) x_1$, we can process the following manipulations:

$$x_1 P_1^* = c(x_1) + P_1^* \theta x_1 + \tau^e e(\theta) x_1 \Rightarrow x_1 P_1^* = w * L_1 + r * K_1 + P_1^* \theta x_1 + \tau^e e(\theta) x_1$$

$$x_1 (1-\theta) P_1^* = w * L_1 + r * K_1 + \tau^e e(\theta) x_1 \Rightarrow x_1 \left[(1-\theta) P_1^* - \tau^e e(\theta) \right] = w * L_1 + r * K_1$$

The domestic price of the polluting good for the producer is thus given by: $P_1 = \left[(1-\theta) P_1^* - \tau^e e(\theta) \right]$

- If the country imports the polluting good:

Using equation (2) $x_1 (1+\tau^m) P_1^* = c(x_1) + P_1^* (1+\tau^m) \theta x_1 + \tau^e e(\theta) x_1$, we can process the following manipulations:

$$x_1 (1+\tau^m) P_1^* = c(x_1) + P_1^* (1+\tau^m) \theta x_1 + \tau^e e(\theta) x_1 \Rightarrow$$
$$x_1 (1+\tau^m) P_1^* = w * L_1 + r * K_1 + P_1^* (1+\tau^m) \theta x_1 + \tau^e e(\theta) x_1$$

$$x_1 (1+\tau^m)(1-\theta) P_1^* = w * L_1 + r * K_1 + \tau^e e(\theta) x_1 \Rightarrow$$
$$x_1 \left[(1-\theta)(1+\tau^m) P_1^* - \tau^e e(\theta) \right] = w * L_1 + r * K_1$$

The domestic price of the polluting good for the producer is thus given by: $P_1 = \left[(1-\theta)(1+\tau^m) P_1^* - \tau^e e(\theta) \right]$

Appendix 2: Optimal Level of Consumption

Using equation (16), we can proceed as follow:

$$\frac{c_2}{c_1} = \left[\frac{1-\alpha c}{\alpha c} * \frac{PC_1}{PC_2}\right]^{\sigma c} \Rightarrow \frac{c_2}{c_1} = \left[\frac{PC_1}{PC_2}\right]^{\sigma c} \left[\frac{1-\alpha c}{\alpha c}\right]^{\sigma c} \Rightarrow c_2 = c_1 \left[\frac{PC_1}{PC_2}\right]^{\sigma c} \left[\frac{1-\alpha c}{\alpha c}\right]^{\sigma c}$$

Also using the equation (19), we have:

$$R = PC_1 * c_1 + PC_2 * c_2 \Rightarrow R = PC_1 * c_1 + PC_2 * c_1 \left[\frac{PC_1}{PC_2}\right]^{\sigma c} \left[\frac{1-\alpha c}{\alpha c}\right]^{\sigma c}$$

$$R = c_1 \left\{ PC_1 + PC_2 \left[\frac{PC_1}{PC_2}\right]^{\sigma c} \left[\frac{1-\alpha c}{\alpha c}\right]^{\sigma c} \right\}$$

$$c_1 = R / \left\{ PC_1 + PC_2 \left(\left[\frac{PC_1}{PC_2}\right]\right)^{\sigma c} \left(\left[\frac{1-\alpha c}{\alpha c}\right]\right)^{\sigma c} \right\}$$

$$c_1 = R / \{PC_1 + PC_2^{1-\sigma c} PC_1^{\sigma c} (1-\alpha c)^{\sigma c} \alpha c^{-\sigma c}\}$$

$$c_1 = R / PC_1^{\sigma c} \alpha c^{-\sigma c} \{PC_1^{1-\sigma c} \alpha c^{\sigma c} + PC_2^{1-\sigma c} (1-\alpha c)^{\sigma c}\}$$

Then we can express the optimal level of c_1 as:

$$c_1 = R * \alpha c^{\sigma c} / PC_1^{\sigma c} \{PC_1^{1-\sigma c} \alpha c^{\sigma c} + PC_2^{1-\sigma c} (1-\alpha c)^{\sigma c}\}$$

By analogy we can express the consumption of the good x_2 given by c_2:

$$c_2 = R * (1-\alpha c)^{\sigma c} / PC_2^{\sigma c} \{PC_1^{1-\sigma c} \alpha c^{\sigma c} + PC_2^{1-\sigma c} (1-\alpha c)^{\sigma c}\}$$

Appendix 3: Main Equations Describing an Adjusted Version of the ACT Model Applied to a Country that Exports the Polluting Good

The Producer Problem	**Industry**	
	Good x_1	**Good x_2**
Production Function	$x_1 = A_1 K_1^{\alpha_1} L_1^{1-\alpha_1}$	$x_2 = A_2 K_2^{\alpha_2} L_2^{1-\alpha_2}$
Optimal Level of Labor Demand	$L_1 = \frac{(1-\alpha_1)P_1 x_1}{w}$	$L_2 = \frac{(1-\alpha_2)P_2 x_2}{w}$
Optimal Level of Capital Demand	$K_1 = \frac{\alpha_1 P_1 x_1}{r}$	$K_2 = \frac{\alpha_2 P_2 x_2}{r}$
Condition of Null Profit	$P_1 A_1 K_1^{\alpha_1} L_1^{1-\alpha_1} = wK_1 + rL_1$	$P_2 A_2 K_2^{\alpha_2} L_2^{1-\alpha_2} = wK_2 + rL_2$
Domestic Prices	$P_1 = \left[(1-\theta)P_1^* - \tau^e e(\theta)\right]$	$P_2 = P_2^*(1+\tau^m)$
Intensity of Abatement	$\theta^* = \left(\tau^e \Lambda \delta / P_1^*\right)^{1/1-\delta}$	
Coefficient of Emission	$e(\theta) = 1 - \Lambda\theta^{\delta}$	
Total Emission	$z = e(\theta)x_1$	
The Consumer Problem	**Consumption of Each Commodity**	
	Good x_1	**Good x_2**
Consumption function	$u(c_1, c_2) = [\alpha c * c_1^{\sigma c-1/\sigma c} + (1-\alpha c) * c_2^{\sigma c-1/\sigma c}]^{\sigma c/\sigma c-1}$	
Optimal level of consumption	$c_1 = R*\alpha c^{\sigma c} / PC_1^{\sigma c}\{PC_1^{1-\sigma c}\alpha c^{\sigma c} + PC_2^{1-\sigma c}(1-\alpha c)^{\sigma c}\}$	$c_2 = R*(1-\alpha c)^{\sigma c} / PC_2^{\sigma c}\{PC_1^{1-\sigma c}\alpha c^{\sigma c} + PC_2^{1-\sigma c}(1-\alpha c)^{\sigma c}\}$
Consumption Prices	$PC_1 = P_1^*$	$PC_2 = P_2^*(1+\tau^m)$
International Trade	**Commodity**	
	Good x_1	**Good x_2**
Trade Balance	$P_1^*.TRD_1 + P_2^*.TRD_2 = 0$	
Volume of Trade	$x_1(1-\theta) + TRD_1 = c_1$	$x_2 + TRD_2 = c_2$
World Prices	$P_1^* = 1$	$P_2^* = 1$
Rate of Tax on Imports	The rate of tax on imports is equal to τ^m in case of imports and 0 for exports	
Labour and Capital Markets Clearing		
Labour Market	$L_1 + L_2 = L_s$	
Capital Market	$K_1 + K_2 = K_s$	

Appendix 4: Aggregated SAM (year 2004) Used to Run Simulations

SAM (USA)

	L	K	H	X	Y	ABT	ROW	MTAX	TPL
L				1682177	4078103				
K				1088184	2296250				
H	5760280	3384433						24632.48	2067
X			3500845			308047.5			
Y			5670567				703785		
ABT				308047.5					
ROW				703785					
MTAX				24632.48					
TPL				2067					

SAM (Germany)

	L	K	H	X	Y	ABT	ROW	MTAX	TPL
L				432856.4	580206.8				
K				183951.7	474476.9				
H	1013063	658428.6						1177.51	267.84
X			595270.2			68563.99	21805.67		
Y			1077667						
ABT				68563.99					
ROW					21805.67				
MTAX					1177.51				
TPL				267.84					

SAM (China)

	L	K	H	X	Y	ABT	ROW	MTAX	TPL
L				441612	161331.8				
K				277543.7	72794.98				
H	602943.8	350338.7						1541.53	398.82
X			704139.3			7268.23	15415.3		
Y			251083.6						
ABT				7268.23					
ROW					15415.3				
MTAX					1541.53				
TPL				398.82					

SAM (Brazil)[69]

	L	K	H	X	Y	ABT	ROW	MTAX	TPL
L				233606.8	350410.2				
K				244773.2	5519.8				
H	584017	250293						963.35	31.88
X			475343.9			4832.44	3068		
Y			359961.4						
ABT				4832.44					
ROW					3068				
MTAX					963.35				
TPL				31.88					

[69] Data is available through the "Instituto Brasileiro de Geografia e Estatística" through the following address: http://www.ibge.gov.br/home/estatistica/economia/contasnacionais/referencia2000/2004_2005/defaulttab.shtm

Appendix 5: Calibration of the Parameter Λ in the Expression of the Coefficient of Emission

To calibrate the value of the parameter Λ in the expression of the coefficient of emission given by equation (5) for each value of the intensity of abatement at the benchmark situation, we can proceed as follows:

From the producer objective function problem we know that: $x = \dfrac{c(x)}{P_1^*(1-\theta) - \tau^e e(\theta)}$.

By substituting this expression into the formula of the emission, we get:

$$z = \frac{(1-\Lambda\theta^{\delta})c(x)}{P_1^*(1-\theta) - \tau^e(1-\Lambda\theta^{\delta})} \Rightarrow z\left(P_1^*(1-\theta) - \tau^e(1-\Lambda\theta^{\delta})\right) = (1-\Lambda\theta^{\delta})c(x)$$

$P_1^*(1-\theta)z - \tau^e z + \tau^e \Lambda\theta^{\delta} z = c(x) - c(x)\Lambda\theta^{\delta} \Rightarrow$ By replacing τ^e using its expression provided in table 3, we have:

$$P_1^*(1-\theta)z - \frac{P_1^*\theta^{1-\delta}}{\Lambda\delta}z + \frac{P_1^*\theta}{\delta}z - c(x) + c(x)\Lambda\theta^{\delta} = 0$$

$$\Lambda\delta P_1^*(1-\theta)z - P_1^*\theta^{1-\delta}z + \Lambda P_1^*\theta z - \Lambda\delta c(x) + \Lambda\delta c(x)\Lambda\theta^{\delta} = 0$$

$$\delta c(x)\theta^{\delta}\Lambda^2 + \Lambda\left(\delta P_1^*(1-\theta)z + P_1^*\theta z - \delta c(x)\right) - P_1^*\theta^{1-\delta}z = 0$$

Let:

$a1 = \alpha c(x)\theta^{\delta}$; $a2 = \delta P_1^*(1-\theta)z + P_1^*\theta z - \delta c(x)$, and $a3 = -P_1^*\theta^{1-\delta}z$

$$a1\Lambda^2 + a2\Lambda + a3 = 0$$

It is a polynomial of second degree which can be solved using the following procedures:

$$\Lambda = \frac{-a2 \pm \sqrt{(a2)^2 - 4a1a3}}{2a1}; \qquad (25)$$

<u>Appendix 6: The Tax on Pollution: IS There Any Possible Analytical Solution?</u>

To compensate for the negative externality caused to the economy, the polluting industry has to pay a tax on pollution which is a function of the coefficient of emission. As stated in the previous section, the optimal tax on pollution is estimated endogenously in the ACT Model. To solve analytically the problem of the tax on pollution, we maximize the indirect utility function of the consumers to which we subtract a component representing the disutility caused to the consumers due to the emission of pollution. The disutility term is a function of the consumers' perception of the quality of the environment of the "Greens" who give a high value to the environment and of the "Brown" who care less about the quality of the environment.

Let λ denote the proportion of the Greens in the population. Hence (1-λ) equals the proportion of the Browns. Also, let δ^g and δ^b denote the disutility coefficients respectively associated to the Greens and the Browns. Then we can express the indirect utility function for each consumer in the same way as in ACT (2001):

$$V^i(p, I, Z) = u(I) - \delta^i z; \tag{26}$$

Where $V^i\ \forall i \in \{Green, Brown\}$ is the indirect utility function. p is the price index for consumption. I is per capita income. Z is the emission of pollution from the production of the dirty good. Consumers take the pollution level Z as given. The function $u(.)$ is increasing and concave on income.

To find the optimal rate of tax on pollution, we have to solve the following optimization problem:

$$\max_{\tau^e} N\{\lambda V^g + (1-\lambda)V^b\}; \tag{27}$$

To solve equation (27), we need first to find an expression for the indirect utility function. Second, we have to determine the first order condition with respect to the rate of tax on emission. Finally, using the assumptions related to the properties of the consumers' utility function, and substituting equation (12), (17) and (18) into equation (26), we have:

$$V^i = (\sigma_c / \sigma_c - 1)\ln\left[\alpha_c \left(c_1^*\right)^{\sigma_c - 1/\sigma_c} + (1-\alpha_c)\left(c_2^*\right)^{\sigma_c - 1/\sigma_c}\right]; \quad (28)$$

Where c_1^* and c_2^* represent the optimal levels of good x_1 and x_2 that maximize the consumer utility function. Then via few manipulations we can express the indirect utility function as:[70]

$$V^i = Ln(R) + \frac{1}{\sigma c} Ln\left(\alpha c^{\sigma c} PC_1^{1-\sigma c} + (1-\alpha c)^{\sigma c} PC_2^{1-\sigma c}\right); \quad (29)$$

The optimal rate of tax on pollution is given by maximizing the following equation with respect to the rate of tax on pollution.

$$M\,\mathrm{ax}_{\tau^e}\ SW = Ln(R) + \frac{1}{\sigma c} Ln\left(\alpha c^{\sigma c} PC_1^{1-\sigma c} + (1-\alpha c)^{\sigma c} PC_2^{1-\sigma c}\right) - Z\{\lambda \delta^G + (1-\lambda)\delta^B\};$$

Where:

- $R = w\sum_1^2 LD_i + r\sum_1^2 K_i + \sum_{i=1}^2 P_i^* \tau^m TRD_i + P_1^* \tau^e e(\theta) x_1$
- $e(\theta) = 1 - \Lambda\theta^\delta$
- $z = e(\theta)x_1$

Knowing that firms will chose their optimal level of abatement taking into consideration the rate of tax on pollution as given, we can express the coefficient of emission as:

$$e(\theta) = 1 - \Lambda\theta^\delta = 1 - \Lambda\left(\left(\frac{\tau^e \Lambda\delta}{P_1^*}\right)^{1/1-\delta}\right)^\delta = 1 - \Lambda\left(\frac{\tau^e \Lambda\delta}{P_1^*}\right)^{\delta/1-\delta} = 1 - \Lambda\left(\frac{\Lambda\delta}{P_1^*}\right)^{\delta/1-\delta}\left(\tau^e\right)^{\delta/1-\delta}$$

Knowing that the polluting industry takes the rate of tax on pollution as given to fix the optimal level of abatement, the solution to the maximization problem can be expressed as follow:

$$\frac{dSW}{d\tau^e} = 0 \Rightarrow \frac{dSW}{d\tau^e} = \frac{dLn(R)}{d\tau^e} - \frac{dZ}{d\tau^e}\{\lambda\delta^G + (1-\lambda)\delta^B\} = 0$$

---

[70] For more details on how the equation 28 is derived see Appendix 6a.

$$\Rightarrow \frac{\left[e(\theta)x_1 + \tau^e x_1\left(\frac{de(\theta)}{d\tau^e}\right)\right]}{R} - \left(\frac{de(\theta)}{d\tau^e}\right)x_1\left[\lambda\delta^G + (1-\lambda)\delta^B\right] = 0\,.$$

We have:

$$\frac{de(\theta)}{d\tau^e} == -\frac{\delta}{1-\delta}\Lambda\left(\frac{\Lambda\delta}{P_1^*}\right)^{\delta/1-\delta}\left(\tau^e\right)^{\frac{\delta}{1-\delta}-1} = -\frac{\delta}{1-\delta}\Lambda\left(\frac{\Lambda\delta}{P_1^*}\right)^{\delta/1-\delta}\left(\tau^e\right)^{\frac{\delta-1+\delta}{1-\delta}} = -\frac{\delta}{1-\delta}\Lambda\left(\frac{\Lambda\delta}{P_1^*}\right)^{\delta/1-\delta}\left(\tau^e\right)^{\frac{2\delta-1}{1-\delta}}$$

Let $a = -\frac{\delta}{1-\delta}\Lambda\left(\frac{\Lambda\delta}{P_1^*}\right)^{\frac{\delta}{1-\delta}}$

Then we can express the derivative $\frac{de(\theta)}{d\tau^e}$ as: $\frac{de(\theta)}{d\tau^e} = a\left(\tau^e\right)^{\frac{2\delta-1}{1-\delta}}$

$$\Rightarrow \frac{\left[e(\theta) + \tau^e\left(a\left(\tau^e\right)^{\frac{2\delta-1}{1-\delta}}\right)\right]}{R} - \left(a\left(\tau^e\right)^{\frac{2\delta-1}{1-\delta}}\right)\left[\lambda\delta^G + (1-\lambda)\delta^B\right] = 0$$

$$e(\theta) + a\tau^e\left(\tau^e\right)^{\frac{2\delta-1}{1-\delta}} - a\left(\tau^e\right)^{\frac{2\delta-1}{1-\delta}} R\left[\lambda\delta^G + (1-\lambda)\delta^B\right] = 0\,; \qquad (30)$$

By using mathematical software such as GAMS,[71] a numerical solution to equation (30) can be calculated.

[71] GAMS stands for "*The General Algebraic Modeling System (GAMS) is a high-level modeling system for mathematical programming and optimization. It consists of a language compiler and a stable of integrated high-performance solvers*" For more information see : www.gams.com

<u>Appendix 6a: Expression of the Indirect Utility Function</u>

Homothetic preferences with respect to the consumed goods, concave on income:

Derivation of the expression of the indirect utility function using a logarithmic transformation of a CES utility function

Using equation (33), we can proceed as follow:

$$V^i = \left(\frac{\sigma c}{\sigma c - 1}\right) Ln \left[\begin{array}{l} \alpha c\left(R.\alpha c^{\sigma c} / PC_1^{\sigma c}\left\{PC_1^{1-\sigma c}\alpha c^{\sigma c} + PC_2^{1-\sigma c}(1-\alpha c)^{\sigma c}\right\}\right)^{\sigma c - 1/\sigma c} + \\ (1-\alpha c)\left(R(1-\alpha c^{\sigma c}) / PC_2^{\sigma c}\left\{PC_1^{1-\sigma c}\alpha c^{\sigma c} + PC_2^{1-\sigma c}(1-\alpha c)^{\sigma c}\right\}\right)^{\sigma c - 1/\sigma c} \end{array} \right]$$

$$V^i = \left(\frac{\sigma c}{\sigma c - 1}\right) Ln \left(\begin{array}{l} \alpha c\left(\dfrac{R.\alpha c^{\sigma c}}{PC_1^{\sigma c}\left[PC_1^{1-\sigma c}\alpha c^{\sigma c} + PC_2^{1-\sigma c}(1-\alpha c)^{\sigma c}\right]}\right)^{\sigma c - 1/\sigma c} + \\ (1-\alpha c)\left(\dfrac{R(1-\alpha c^{\sigma c})}{PC_2^{\sigma c}\left[PC_1^{1-\sigma c}\alpha c^{\sigma c} + PC_2^{1-\sigma c}(1-\alpha c)^{\sigma c}\right]}\right)^{\sigma c - 1/\sigma c} \end{array} \right)$$

$$V^i = \left(\frac{\sigma c}{\sigma c - 1}\right) Ln \left(\begin{array}{l} \alpha c\left(\dfrac{R^{\sigma c - 1/\sigma c}\left(\alpha c / PC_1\right)^{\sigma c - 1}}{\left[PC_1^{1-\sigma c}\alpha c^{\sigma c} + PC_2^{1-\sigma c}(1-\alpha c)^{\sigma c}\right]^{\sigma c - 1/\sigma c}}\right) + \\ +(1-\alpha c)\left(\dfrac{R^{\sigma c - 1/\sigma c}\left((1-\alpha c) / PC_2\right)^{\sigma c - 1}}{\left[PC_1^{1-\sigma c}\alpha c^{\sigma c} + PC_2^{1-\sigma c}(1-\alpha c)^{\sigma c}\right]^{\sigma c - 1/\sigma c}}\right) \end{array} \right)$$

$$V^i = \left(\frac{\sigma c}{\sigma c - 1}\right) Ln \left(\begin{array}{l} \dfrac{R^{\sigma c - 1/\sigma c}\alpha c\left(\alpha c / PC_1\right)^{\sigma c - 1}}{\left[PC_1^{1-\sigma c}\alpha c^{\sigma c} + PC_2^{1-\sigma c}(1-\alpha c)^{\sigma c}\right]^{\sigma c - 1/\sigma c}} \\ + \dfrac{R^{\sigma c - 1/\sigma c}(1-\alpha c)\left((1-\alpha c) / PC_2\right)^{\sigma c - 1}}{\left[PC_1^{1-\sigma c}\alpha c^{\sigma c} + PC_2^{1-\sigma c}(1-\alpha c)^{\sigma c}\right]^{\sigma c - 1/\sigma c}} \end{array} \right)$$

$$V^i = Ln\left(R\right) + \left(\frac{\sigma c}{\sigma c - 1}\right) Ln\left(\frac{\alpha c^{\sigma c} / PC_1^{\ \sigma c-1} + (1-\alpha c)^{\sigma c} / PC_2^{\ \sigma c-1}}{\left[PC_1^{\ 1-\sigma c}\alpha c^{\sigma c} + PC_2^{\ 1-\sigma c}(1-\alpha c)^{\sigma c}\right]^{\sigma c-1/\sigma c}}\right)$$

$$V^i = Ln\left(R\right) + \left(\frac{\sigma c}{\sigma c - 1}\right) Ln\left(\frac{\alpha c^{\sigma c} PC_1^{\ 1-\sigma c} + (1-\alpha c)^{\sigma c} PC_2^{\ 1-\sigma c}}{\left[PC_1^{\ 1-\sigma c}\alpha c^{\sigma c} + PC_2^{\ 1-\sigma c}(1-\alpha c)^{\sigma c}\right]^{\sigma c-1/\sigma c}}\right)$$

$$V^i = Ln\left(R\right) + \frac{1}{\sigma c} Ln\left(\alpha c^{\sigma c} PC_1^{\ 1-\sigma c} + (1-\alpha c)^{\sigma c} PC_2^{\ 1-\sigma c}\right)$$

Chapter Two
Ageing and the Environment in an Overlapping Generations Model

2.1 Introduction

Despite a world characterized by growing economic activities and hence more production and consumption of polluting goods, certain economists believe that, once countries reach a certain level of economic growth, they will turn to cleaner goods. According to Shafik and Bandyopadhyay (1992), Panayotou (1993), Grossman and Krueger (1993), and Selden and Song (1994), as income increases, countries start adopting pro-environmental regulations. This is the fundamental statement behind the Environmental Kuznets Curve ("EKC"). However, population ageing in the OECD countries and its impact on the age profile may increase the rate of time preference of the median voter. In such a case, the social preference towards a cleaner environment may decline in the upcoming demographic transition. This avenue of research seems to be ignored in the economic literature. How sensitive are households vis-à-vis the quality of the environment? Is there any change in the perception of the environment through age? Is there any trade-off between wealth and environment protection over time and through generations? How significant are the cohort and the ageing effect in reflecting changes in environment quality preferences? Only few studies have investigated the change in the perception of the quality of the environment through age. The main consensus was that young households are more sensitive and seemed to be more concerned about the quality of the environment than older households.[72]

The main purpose of this paper is to quantify the impact of a change in the demographic structure of the population on the quality of the environment. As the proportion of seniors increases over time in most of the OECD countries,[73] including Canada,[74] this may have a

[72] More specifically, we list the work done by Buttel (1979), Dunlap (1975), Malkis and Grasmick (1977), Mohai and Twight (1987), Vlosky et al. (1999), and Magnani and Tubb (2007).
[73] See Jones (1998) and Kohl and O'Brien (1998) for OECD countries and Mérette (2002) for Canada.

direct impact on the quality of the environment. Our main goal is to simulate the impact of a demographic shock on the level of emission using data from the Canadian economy. Furthermore, we attempt to decompose such impact into scale, cohort, and composition effects. Assessment of the composition effect is based on the assumption that seniors care less about the environment than young households. This assumption is supported by theoretical and empirical work.

This paper constitutes an attempt to introduce population ageing issue into the question of the environment. The overlapping generations ("OLG") structure permits us to test the impact of a change in the demographic structure of the population on the quality of the environment. By referring to the economic literature related to ageing and its impact on households' perception of the quality of the environment, we first construct a general equilibrium model with an overlapping generations ("EOLG") structure. Secondly, using data from the Canadian economy, we elaborate and calibrate a numerical version of the EOLG model. The benchmark situation is based on 2000 data projected over 30-period time horizon. Thirdly, we run a set of simulations to address the impact of a demographic ageing transition.

One main result suggests that an increase in the weight of young generations in the economy may improve the quality of the environment through the composition effect. This is consistent with evidence supporting the existence of direct age effect on the environment, as suggested by Buttel and Flinn (1978) and Mohai and Twight (1987).

With respect to the cohort effect, we find that a higher level of consumers' awareness about the environment and the need to preserve it can lead to higher demand for clean goods. As a result, the level of emission in both the short and the long run falls. The cohort effect improves the quality of the environment.

The scale effect is associated with an increase in the size of the population. The level of emission is expected to rise as a result of an increase in aggregated demand for consumed goods leading to a higher level of production. However, under a scenario of Population

---

[74] Based on demographic projections by the United Nations and data collected by statistics Canada. For more details see appendix 1.

Ageing,[75] the scale effect positively impacts the environment. In the long run, the impact of the scale effect on the environment depends on the total number of individuals in the economy in comparison with the benchmark situation.

To assess the overall effect of the impact of demographic shock on the environment we compare all three effects: scale, composition, and cohort effects. We find that scale dominates both effects. The level of emission falls in the context of population ageing and increases as a result of an increase in population growth rate. Further, we find that, once associated with higher level of awareness towards the preservation of the environment, the cohort effect can dominate the composition effect in the context of Population Ageing, and prevent the level of emission from rising.

The remainder of the paper is structured as follow: Section 2 emphasizes the relationship between age and environmental concern at the theoretical and empirical levels. Section 3 describes the computable general equilibrium model of population ageing and environment. Section 4 calibrates the model and describes the data. Section 5 discusses the simulations and reports the main results. Section 6 concludes.

2.2 Literature Review on Age versus Environmental Concern

In describing the relationship between age and the environment, two factors are found in the literature: the ageing and the cohort effect. By ageing effect, we refer to the possibility that preferences towards environmental policy change when a person gets older. By cohort effect, we mean the extent to which historical conditions within each cohort is born and raised play a role with respect to environmental concerns.[76] We now discuss in more detail the ageing and cohort effect in turn. After that, we report the findings of empirical studies.

---

[75] Population Ageing refers to the second part of the demographic transition, in which the population growth rate declines.

[76] It is worth mentioning that this paper to a certain extent uses a different approach to explore the question of population ageing and the environment in comparison with the work pioneered by Tetsuo et al (2001). In fact, Tetsuo *et al.* show that a higher proportion of seniors in the industrialized country might improve the quality of the environment. When consumers expect to live longer, they start caring more about the quality of the environment toward the future. Moreover, a lower rate of population growth accompanying population ageing lessens aggregate consumption and hence waste and pollution. However, Population Ageing results mostly from dramatic change in the birth rate. The improvement in life expectancy is a second order factor. Also, it is

2.2.1 The Ageing Effect

The age effect is the change in attitudes and preferences accompanying the ageing process.[77] Mohai and Twight (1987) explain this effect by the biological, psychological, or social changes that naturally occur when individuals become older. Hornback (1974) argues that older individuals are more likely to adhere to religious, political, economic and social subsystems. They are less likely to benefit from social innovations. However, young individuals are more receptive to new ideas and hence to new social systems that are more environmentally friendly. Hornback states that youth are characterized generally with low commitment to existing value system and institutions, and they are more willing to endorse new values and innovative ideas. Further, age is found to be positively related to wealth accumulation and relative political power. According to Cutler and Kaufman (1974) and Glenm (1980), by becoming wealthier, older individuals become conservative, more cautious, and more protective of their social status, and hence become less willing to take risks and adopt new policies on the environment.

Using a multivariate analysis based on a survey of Minneapolis area residents, Malkis and Grasmick (1977) discover a strong relationship between age and environmental concern, showing that the youngest age groups are the most sensitive about the environment.[78] In the same trend, Buttel and Flinn (1978) applied a multivariate statistical analysis to state wide data in Wisconsin. They show that age is the most significantly correlated with environmental concerns of all the social variables. Empirical results suggest that preferences towards a clean environment declines with age. Moreover, Lowe and Pinhey (1982) reach the same conclusion using national surveys.[79]

Magnani and Tubb (2007) acknowledge the potential impact of population ageing on the environment as micro based surveys reveal that demographic structure variation could have a

---

important to highlight that Tetsuo et al. focus on the changing age composition of the population but assume no change in the perception of the quality of the environment through age. Their analysis of the pollution is based on the waste from consumption, ignoring the emission from production. Tetsuo (2004) recognizes the possibility that in democracies, a larger proportion of elderly may induce a decline in the rate of politically determined environmental tax, as they will not fully enjoy the positive environment outcome of such a measure.

[77] In explaining the ageing effect, Buttel (1979, page 240) states that: "The second facet is the phenomenon of aging in which the sociobiological features of advancing age result in differential opinions on social issues."

[78] Quoted in Mohai and Twight, 1987.

[79] ibid

significant impact on social preferences about the environment. Magnani and Tubb claim that an older population increases emission of pollution, as a tighter government budget constraint would divert expenditure away from the environment protection. Furthermore, ageing may lead to change consumption patterns of older individuals towards more polluting goods. Magnani and Tubb argue that empirical studies in the finance literature demonstrate that age is a key determinant of the individual rate of time preference. By growing older, seniors prefer a shorter time span of investment returns. Seniors are more willing to invest in less risky assets with short-term returns, rather than investing in "risky" environmentally friendly technologies. Thus, an increase in the precautionary saving due to a higher proportion of seniors in the economy leads to less investment related to the preservation of the environment. Finally, higher proportion of seniors my create a political power that supports short-term growth rather than having a long run policy oriented to preserve the environment.

Buttel (1979) develops a path analytical model in an attempt to explain the relationship between age and the environment concern. Using a summary of major survey studies in the US on both age and education as independent variables in a bivariate relationship with respect to the environment concern, Buttel finds that age is more related to environment concern than education. Other variables such as the place of residence and political liberalism seem to be significantly related to age, and consequently may have an indirect impact on shaping individuals' environmental concern.[80] Following Alwin and Hauser (1975), Buttel decomposes the effects of age on the environmental concern into direct and indirect effects mediated through education and political liberalism. Buttel (1979) explores two hypotheses, whether age is more strongly related to environmental concern than education and whether the direct effect of age on the perception of the environment is higher than its indirect effect.[81] He finds that age and not education is the major socioeconomic correlate of environmental perception. By treating age and residence as exogenous variables, Buttel also finds that the major effect of age on the environment is direct (not due to the impact of age on education and political liberalism) rather than indirect (where education and political liberalism play a major role).

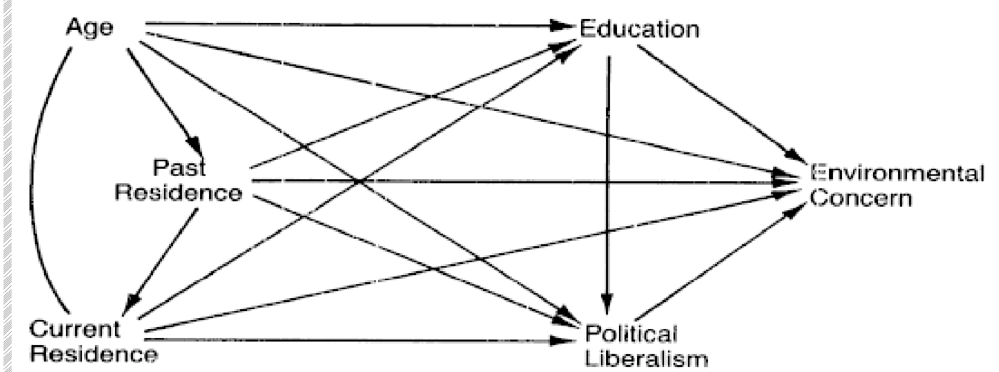
---

[80] Summary of studies of the relationship of age and educational is provided in Appendix 2.
[81] Buttel (1979) used data from a statewide survey of Wisconsin in 1974, based on 548 personal interviews. (Ref: Buttel 1979, page 245)

Controlling for education, political liberalism, and size of place of current residence Mohai and Twight (1987) extended Buttel's model using United States national surveys. Their results confirm Buttel's 1979 findings on age and environmental concern. The model is given by the following graph. (Mohai and Twight 1987, pp. 802)

FIGURE 1

Causal Model Showing Direct and Indirect Linkages of Variables with Environmental Concern



Mohai and Twight (1987) test two hypotheses: whether the independent effect of age on the environmental perception is larger than the indirect effect; and whether the independent effect of age is greater than the independent effects of the intervening variables.[82] In addition to the Buttel (1979) variables, Mohai and Twight (1987) add past residence as a causal factor that may have some influences on environmental preferences. In fact, Lowe and Pinhey (1982) and Lowe, Pinhey, and Grimes (1980) find a stronger causality of past than current residence on environmental concern.

Using evidences from a national survey, Mohai and Twight (1987) find that age is the strongest and most consistent predictor of the perception of the environment; its effect is substantially independent of intervening variables. The autonomous effect of age is stronger than the effect of education or current or past place of residence, and the direct effect of age on the environment is larger than its indirect effect through education, place of residence and political liberalism.

[82] The intervening variables include: education, political liberalism, and size of place of current residence.

To what extent individuals are willing to pay to preserve the environment? Hersch and Viscusi (2005) use a 1999 Eurobarometer survey of European citizens by interviewing 16000 respondents from 15 countries. The authors find a steady decline with age in the willingness to pay for the environmental preservation. For example, seniors are less likely to support a high price of gas if such a measure is designed to protect the environment.[83]

2.2.2 The Cohort Effect

To explain the trend towards greater conservatism, Berelson and Steiner (1964) and Coale (1964)[84] rely on ageing as the main mechanism leading to a shift to more conservative political attitudes. This line of thought is based on two assumptions. First, older people are more likely than younger persons to express conservative political opinions. Second, by growing older (over age) a person is more risk averse. However, Cutler and Kaufman (1974) show that such political conservatism hypothesis associated with ageing has been derived from single cross-sectional studies. Therefore, cohort effect (generational effect) has been ignored. In addition, certain researchers such as Robinson, Rusk and Head (1968) find that, with respect to certain issues, “contemporary” cohorts of older persons express social attitudes that are less conservative than those of younger cohorts.[85]

In assessing the relationship between age and environmental concern, Buttel (1979) makes a distinction between cohort and age effects. The cohort effect is the differences in the attitudes resulting from different life experiences and socialization. Cutler and Kaufman (1974), Glenm (1980) and Palmore (1978) argue that the differences in cohort attitudes can be explained by differences in historical and economic conditions within which each cohort is born and raised.[86] In fact, it is understandable that people of a similar age who lived under similar historical and economic conditions would have the same pattern of attitudes with respect to certain issues but different reactions than those from another age-cohort. Mitchell (1980) and Mohai (1985) postulate that cohort effect may play a significant role in assessing the impact of age on environmental concern.

---

[83] More detail about Hersch and Viscusi (2005) results is provided in section 2.3.
[84] Quoted in Cutler and Kaufman (1975).
[85] ibid
[86] Quoted in Mohai and Twight (1987).

When addressing the generational conflict in the environmental movement in the late 1960's, Buttel (1979) postulated that environmental concern by relatively younger people was a reflection and a result of the cohort effect. By coming of age during a period of intense generational conflict (conflict on civil rights, Indochina war), this exposure could explain their greater concern over environmental problem. However, although Buttel recognizes that the aging and the cohort effects are difficult to decompose using cross-sectional data, he stated that: "‥, *age-environmental concern correlations, to the extent they exist, may well be largely due to features attendant to the aging process, rather than portending the continuity and pervasiveness of sociopolitical generational conflict in the sense employed by Mannheim.*" (Buttel 1979, page 241)

2.2.3 Empirical Assumptions

To empirically assess the impact of age on households' willingness to preserve the environment, we refer to surveys which provide some insights about the nature of such a relationship. The 1999 Eurobarometer survey provides observations on over 16000 European citizens from 15 countries. The interviewees indicate "whether they are willing to pay more for gas if a higher price will reduce the harm to the environment". Hersch and Viscusi (2005) explored three main ideas. First, whether consumers are willing to pay more for gas. Second, what will be the percentage increase that is considered acceptable by the respondents? Third, what is the absolute monetary cost of such an increase?

Hersch and Viscusi find that slightly under one-fifth of the overall sample were willing to pay more for gas if a higher price would reduce harm to the environment. In addition, risk perception, income, information, age, and education are found to have strong effects on consumers' willingness to pay ("WTP") to preserve the environment. However, older individuals were found to be less supportive of environmental policies that impose immediate cost to them. Their support to such policies is conditional to the extent they are altruistic towards future generations. The relationship between age and willingness to pay for gas so as to preserve the environment is thus negative.

By estimating equations of a general form such as: WTP=f(risk perception, income, price, other characteristics),[87] Hersch and Viscusi derive three measures of WTP higher prices for gas if this will reduce the harm to the environment:

- Variable =1 if the individual is willing to pay more for gas, and 0 if not
- As measure of WTP Hersch and Viscusi use "the percentage more" the individual would be willing to pay.
- The implied price increase per liter derived from the "percentage more" that the individual is willing to pay and the actual price per liter in the respondents country.

Results from Tobit[88] and Probit[89] estimations show that, with respect to age, individuals in all age group categories have significantly greater willingness to pay more than those belonging to 65 years and older age group. In addition, the age category coefficients for the included groups display a steady downward trend. The coefficients associated with the age group 15-24 and 25-34 are roughly doubled the values of those in the age group 55-64. More details about Hersch and Viscusi estimations are provided in the table below:

Table 1: Results from Tobit and Probit Estimations of the Impact of Age on the Willingness to Pay for gas Less Harmful to the Environment

	Tobit: Percent More Willing to Pay	Probit: Willing to Pay More (0 – 1)	Tobit: Cents More Willing to Pay
Age 15 - 24	1.277**	0.098**	1.326**
Age 25 - 34	1.206**	0.086**	1.273**
Age 35 - 44	0.912**	0.068**	0.982**
Age 45 - 54	0.758**	0.055**	0.752**
Age 55 - 64	0.628**	0.050**	0.620**

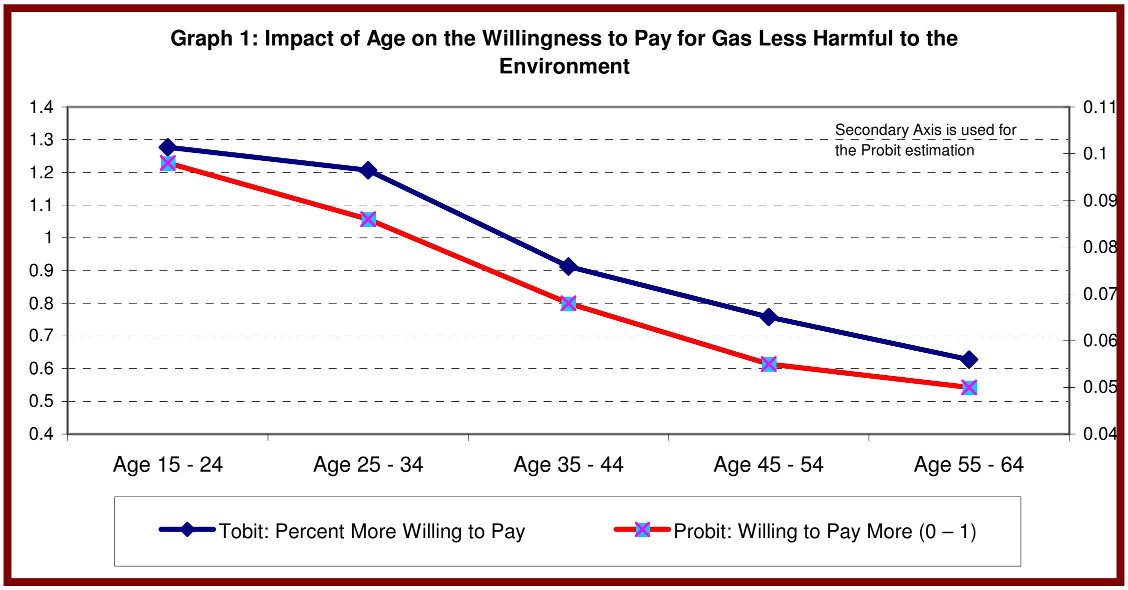
** significant at 1% Source: Hersch and Viscusi (2005, page27)

Probit estimation shows that consumers belonging to age group 15-24 are on average 9.8 percentage point more likely to be willing to raise the price of gas in comparison to those 65 years old and above. Also, Tobit estimation for the same age groups shows that young consumers are 1.277 percent more willing to pay than seniors.[90] The following graph

---

[87] A detailed description of the explanatory variables is provided in Appendix 3.
[88] Tobit estimation of the following variables: "the percentage more to pay" and "the dollars amount more implied by the within country gas prices and percentage more willingness to pay".
[89] Probit estimation of the binary decision "To pay more".
[90] More details about the results from simulation are provided in Appendix 4.

provides details about the results from Tobit and Probit estimations of the Impact of Age on the Willingness to Pay for gas Less Harmful to the Environment.



In Canada, the Survey of Household Spending (SHS) by Statistics Canada constitutes an annual survey of household expenditures on products and services that is based on a sample of more than 20,000 households across Canada. By comparing 1982 "Family Expenditure Survey" to 2003 "Survey of Household Spending", we notice that the share of consumption of goods that are likely to generate pollution such as food, shelter, furnishing, and equipment increases with age. Furthermore, in comparing 2003 to 1982 survey of household spending, we notice the increase in the share of transportation to reach almost 20% in 2003 compared to 17% in 1982. Although limited, evidence in Canada suggests consumers behave as in Hersh and Viscusi (2005).

Even though clear and direct estimate about the valuation of the environment across different age groups is not available, theoretical and empirical reviews of the literature and observations from surveys indicate that seniors care less about the environment compared to younger generations.

In this paper, we use Hersch and Viscusi estimations of consumers' willingness to pay higher gas prices to preserve the environment across different age groups. We assume that young consumers are more willing to protect the environment than seniors. It is by allocating a lower proportion of their disposable income to consume polluting good relative to seniors that young consumers express more willingness to preserve the environment.

It is worth mentioning, that the simulations conducted in this paper provide a quantitative estimation of the scale, composition, and cohort effects.

2.3 A Computable General Equilibrium Model of Population Ageing and Environment (EOLG Model)

This section provides a comprehensive analytical description of the EOGL model. First, we list the assumptions of the model. Second, we analytically solve both the consumer and the producer problem. Finally, we setup the main equations describing the equilibrium conditions for the entire economy.

2.3.1 Assumptions

Since our goal is to investigate the impact of demographic shock on the volume of emission, for simplicity, we used a closed economy with N ($N = N^i + N^j$; N > 2) industries including N^i producing polluting composite goods which are capital ("K") intensive and N^j industries producing clean composite goods intensive in labour ("L").[91] All industries are characterized with a constant return to scale technology. The markets for labour and capital are kept competitive, so that the wage ("w") and the rate of return on capital ("r") are freely determined by the interaction of supply and demand.

In the model, the household sector is characterized by three-generation overlapping generations framework. Each individual lives three periods of time. Hence, in each period, the economy is made of three types of consumers (generations). The first generation "G1" is made of young consumers. They are assumed to enter their first period of life with no initial wealth. They participate in the labour market and allocate their wage between consumption

[91] The purpose of having a multi-sectors model is to have a representative model of the economy that includes different sectors with different level of emission. The total number of industries included in the model depends mainly on the availability of the data. For Canada we used 11 sectors: 7 polluting industries with different levels of emission and 4 clean ones.

and saving. They start their second period of life as “G2” with a positive amount of wealth, which is equal to their saving in the previous period. They participate in the labour market and save a part of their wage. Finally, the generation G3 is the generation of seniors or retired consumers. They do not participate in the labour market, and they exhibit a negative saving as they spend their entire wealth before exiting the economy. Agents are assumed to be rational, utility maximizers, who cannot leave debt at the end of their life.

Each representative consumer has to respect an inter-temporal budget constraint in allocating his wealth over his lifetime to smooth his consumption. Moreover, the capital stock is assumed to be depreciating over time at a rate ψ. Therefore, under zero population growth, the total saving in the economy is assumed to be equal to total domestic investment needed to keep the stock of capital constant over time. In steady state with a positive population growth rate, domestic saving is equal to domestic investment necessary to keep the stock of capital per household constant over time.

Based on the empirical literature, we assume that the concern about the quality of the environment is negatively related to age. In the current model, this takes the form of a very low proportion of disposable income allocated by young generations to consume polluting goods. This proportion increases with age so as to reflect that seniors are allocating a higher proportion of their resources to consume such commodities relative to younger generations. With these preferences, seniors’ relative consumption of the polluting goods is the highest among all households, while young consumers’ relative consumption of such goods is the lowest.

One of the basic premises of the paper is that individuals' age is positively related to the share of disposable income allocated to consume polluting goods. Another basic assumption is that all individuals in the model are rational utility maximizers implying that while exiting the economy, they spend all their savings (that is, they leave no bequest). Interplay between these two assumptions in the case of seniors essentially lead to the fact that not only seniors consume more of dirty goods as they grow older, they also end up consuming more of clean good in terms of dollar-value relative to other generations. It is the magnitude of the disposable income (income effect) that can justify such allocation of aggregate consumption across different age groups.

2.3.2 The EOLG Model

2.3.2.1 The Domestic Consumption Problem

In a context of overlapping generations, one can solve the consumption problem for a representative consumer through multiple stages. First, we solve for the successive budget constraints over the lifetime. Second, we setup the inter-temporal budget constraint. Third, we maximize the utility function and express the optimal composite consumption at each level of age. Finally, we minimize each representative agent expenditure function, to find his optimal consumption in terms of consumed goods.

- **<u>Solving for the Intertemporal Budget Constraint</u>**

To solve the consumer problem, we start first by constructing a dynamic budget constraint for a representative consumer. As the agent ages, his participation in wealth creation, and his allocation of his resources vary. Therefore, it is necessary to analytically describe the evolution of his dynamic budget constraint as he grows older. Let $cons_g(t)$ and $PXY_g(t)$ represent respectively the volume and the price of a composite good consumed by a representative consumer from generation g at period t $\forall g \in \{G1;G2;G3\}$. We can express the dynamic budget constraints facing a representative consumer as follow:

For G1 at period t, the dynamic budget constraint is given by:

$$PXY_{G1}(t)cons_{G1}(t) + sav_{G1}(t+1) = w(t)L_{G1}(t) + TAX_{G1}(t); \qquad (1)$$

Where $sav_g(t); \forall g \in \{G1;G2;G3\}$ denotes the level of saving by a representative consumer from the generation g at the period t. $L_g(t)$ is the supply of productive labour by the generation g. $TAX_{G1}(t)$ is the representative agent's share of tax collected from taxing the polluting industries.

When G1 becomes G2 at t+1, the budget constraint becomes:

$$PXY_{G2}(t+1)cons_{G2}(t+1)+sav_{G2}(t+2)=w(t+1)L_{G2}(t+1)+$$
$$sav_{G1}(t+1)\left[1+r(t+1)\right]+TAX_{G2}(t+1); \qquad (2)$$

When G2 becomes G3, the budget constraint is given by:

$$PXY_{G3}(t+2)cons_{G3}(t+2)=\left(1+r(t+2)\right)sav_{G2}(t+2)+TAX_{G3}(t+2); \qquad (3)$$

By rewriting the equations (1), (2) and (3), we can formulate the amount of wealth for each generation over time as:

$$\begin{cases} sav_{G1}(t+1)=w(t)L_{G1}(t)+TAX_{G1}(t)-PXY_{G1}(t)cons_{G1}(t) \\ \\ sav_{G2}(t+2)=w(t+1)L_{G2}(t+1)+sav_{G1}(t+1)\left[1+r(t+1)\right]+ \\ TAX_{G2}(t+1)-PXY_{G2}(t+1)cons_{G2}(t+1); \\ \\ 0=\left(1+r(t+2)\right)sav_{G2}(t+2)+TAX_{G3}(t+2)-PXY_{G3}(t+2)cons_{G3}(t+2); \end{cases}$$

❖ **<u>Present Value of the Life-Time Budget Constraint</u>**

Via few substitutions we can express the present value of the time-life budget constraint as:

$$0=TAX_{G3}(t+2)-PXY_{G3}(t+2)cons_{G3}(t+2)+$$
$$\left[1+r(t+2)\right]\left\{w(t+1)L_{G2}(t+1)+TAX_{G2}(t+1)-PXY_{G2}(t+1)cons_{G2}(t+1)\right\}+$$
$$\left[1+r(t+2)\right]\left[1+r(t+1)\right]\left\{w(t)L_{G1}(t)+TAX_{G1}(t)-PXY_{G1}(t)cons_{G1}(t)\right\};$$

By dividing this expression using $[1+r(t+2)][1+r(t+1)]$, we can reformulate the expression of the present value of the life-time budget constraint as:

$$\left[\begin{array}{l} 0=\dfrac{TAX_{G3}(t+2)-PXY_{G3}(t+2)cons_{G3}(t+2)}{[1+r(t+2)][1+r(t+1)]}+ \\ \dfrac{\{w(t+1)L_{G2}(t+1)+TAX_{G2}(t+1)-PXY_{G2}(t+1)cons_{G2}(t+1)\}}{[1+r(t+1)]}+ \\ \{w(t)L_{G1}(t)+TAX_{G1}(t)-PXY_{G1}(t)cons_{G1}(t)\}; \end{array}\right] \qquad (4)$$

Via few manipulations, we can rewrite equation (4) using the following expression:

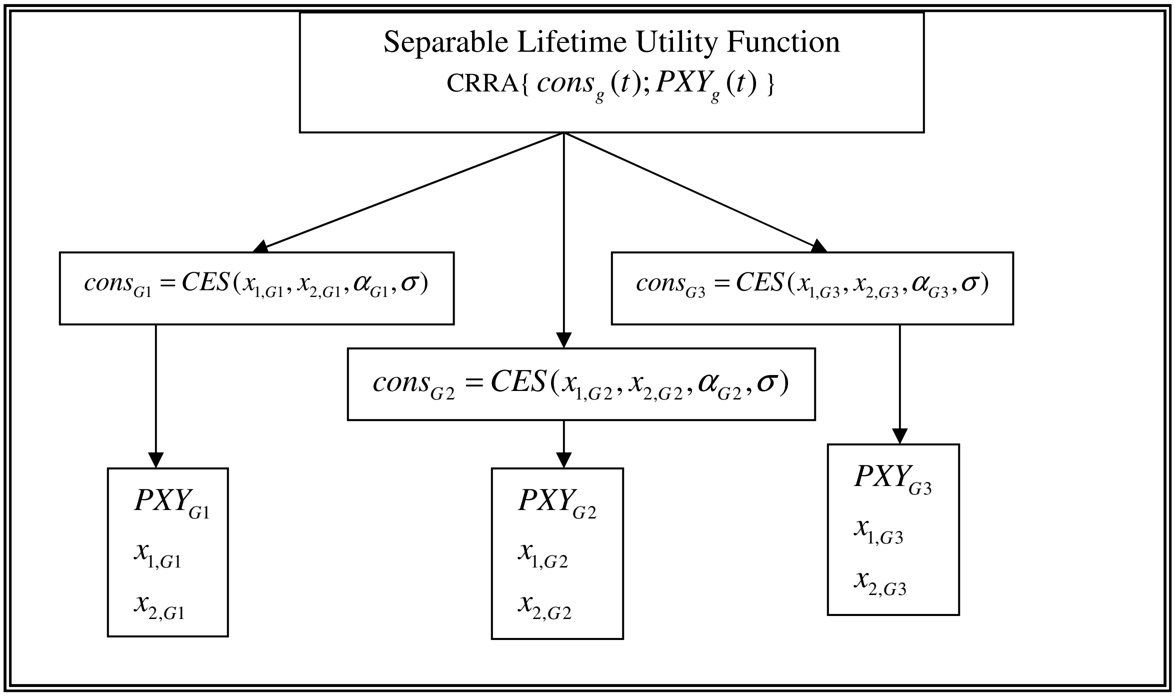
$$\left[\begin{array}{l} \dfrac{PXY_{G3}(t+2)cons_{G3}(t+2)}{[1+r(t+2)][1+r(t+1)]}+\dfrac{PXY_{G2}(t+1)cons_{G2}(t+1)}{[1+r(t+1)]}+PXY_{G1}(t)cons_{G1}(t)= \\ \dfrac{TAX_{G3}(t+2)}{[1+r(t+2)][1+r(t+1)]}+\dfrac{\{w(t+1)L_{G2}(t+1)+TAX_{G2}(t+1)\}}{[1+r(t+1)]}+ \\ \{w(t)L_{G1}(t)+TAX_{G1}(t)\} \end{array}\right]$$

Based on this equation, the present value of the life-time consumption is equal to the present value of the life-time income and transfer from the government.

- **The Consumer Utility Maximization**

When entering in the economy, each consumer has to choose the optimal level of consumption at each stage of his life (G1;G2;G3) taking into consideration his life-time budget constraint and his preferences between current and future consumption, which can be represented by a time separable utility function. Therefore, the life time utility function is given by the summation of periodic utility functions. The following figure illustrates the consumer's problem.

Figure 2: Representative Consumer Utility Maximization



We assume a constant relative risk aversion utility function ("CRRA") describing the relationship between current and future consumption. It can be expressed as:

$$U = \frac{1}{1-\gamma}\left\{\frac{\left(cons_{G1}(t)\right)^{1-\gamma}}{(1+\rho)} + \frac{\left(cons_{G2}(t+1)\right)^{1-\gamma}}{(1+\rho)^2} + \frac{\left(cons_{G3}(t+2)\right)^{1-\gamma}}{(1+\rho)^3}\right\} \tag{5}$$

Where $cons_g$ denotes a composite consumption of both goods x_1 and x_2,[92] $\forall g \in \{G1; G2; G3\}$; and $\gamma = 1/\sigma$ is the inverse of the inter-temporal constant elasticity of substitution between consumption at two periods of time. ρ denotes the rate of time preference. It represents the relevant impatience that consumers express for their current versus their future utility.

Knowing that each household lives three periods of time, each representative consumer maximizes the following objective function:

[92] More details about the structure of $cons_g$ is provided in the subsection: "Decomposition of the Composite Consumption".

$$MaxU = \frac{1}{1-\gamma}\left\{\frac{\left(cons_{G1}(t)\right)^{1-\gamma}}{(1+\rho)} + \frac{\left(cons_{G2}(t+1)\right)^{1-\gamma}}{(1+\rho)^2} + \frac{\left(cons_{G3}(t+2)\right)^{1-\gamma}}{(1+\rho)^3}\right\} \tag{6}$$

Subject to:

$$\left[\begin{array}{l} \frac{PXY_{G3}(t+2)cons_{G3}(t+2)}{[1+r(t+2)][1+r(t+1)]} + \frac{PXY_{G2}(t+1)cons_{G2}(t+1)}{[1+r(t+1)]} + PXY_{G1}(t)cons_{G1}(t) = \\ \frac{TAX_{G3}(t+2)}{[1+r(t+2)][1+r(t+1)]} + \frac{\{w(t+1)L_{G2}(t+1) + TAX_{G2}(t+1)\}}{[1+r(t+1)]} + \\ \{w(t)L_{G1}(t) + TAX_{G1}(t)\} \\ \end{array}\right]$$

The problem can be solved using the Lagrangian.[93] The first-order conditions leads to the following equation:

$$Cons_{g+1}(T+1) = \left\{\frac{1+r(T+1)}{1+\rho}\frac{PXY_g(T)}{PXY_{g+1}(T+1)}\right\}^{\sigma} Cons_g(T) \tag{7}$$

❖ **<u>Decomposition of the Composite Consumption</u>**[94]

Once the optimal level of the composite consumption is determined for each period of time at each age stage, a representative consumer minimizes his expenditure function subject to a level of utility given by a Cobb Douglas ("CD") function. This process allows him to find the optimal levels of individual consumption of $x_z \forall z \in \{1,2,...,N\}$. For each agent belonging to generation $g \in \{G1, G2, G3\}$, the optimization mechanism is given by the following expression:

$$Min\left\{PXY_g cons_g = \sum_z Pc_z x_{z,g}\right\} \text{ Subject to: } cons_g = \Pi_z^N \left(x_{z,g}\right)^{\alpha_{z,g}}; \sum \alpha_z = 1 \tag{8}$$

Where $x_{z,g}$ denotes, the consumption of good $x_z \forall z \in \{1,2,...,N\}$ by a representative consumer from generation g, Pc_z is the consumption price relative to consumption of the good x_z, $\alpha_{z,g}$ is the share parameter of the CD function for a representative consumer from

[93] More details about the optimal solution to the consumer utility maximization problem are provided in Appendix 5.

[94] At this stage, for simplicity we will drop the time dimension, which is added to the final solution of the consumer problem.

generation g associated with the consumption of the commodity z. $\alpha_{z,g}$ constitutes a reflection of consumers perception of emission. A high share parameter associated with polluting goods means that consumers care less about the environment.

By taking the first-order condition with respect to $x_{z,g}$, we get:

$$\frac{dL(x_{1,g};x_{2,g};x_{3,g};x_{4,g};...x_{N,g};\lambda)}{dx_{z,g}}=0; \quad \forall z\in\{1,2,.....N\} \tag{9}$$

Via few manipulations we can analytically express the first-order conditions as:

$$Pc_z x_{z,g}=\alpha_{z,g}PXY_g Cons_g \tag{10}$$

By substituting $x_{z,g} \forall z\in\{1,2,..,N\}$ into the objective function given by equation (8), we can formulate the optimal price for the composite as:

$$PXY_g=\Pi_z^N\left(Pc_z/\alpha_{z,g}\right)^{\alpha_{z,g}} \tag{11}$$

Table 2 describes the main equations characterizing the consumer problem.

Table 2: Main Equations Describing the Consumers' Problem

Expressions	**Consumer Problem**
Intertemporal Consumption	$U=\frac{1}{1-\gamma}\left\{\frac{\left(cons_{G1}(t)\right)^{1-\gamma}}{(1+\rho)}+\frac{\left(cons_{G2}(t+1)\right)^{1-\gamma}}{(1+\rho)^2}+\frac{\left(cons_{G3}(t+2)\right)^{1-\gamma}}{(1+\rho)^3}\right\}$
Consumption of the Composite	$Cons_{g+1}(T+1)=\left\{\frac{1+r(T+1)}{1+\rho}\frac{PXY_g(T)}{PXY_{g+1}(T+1)}\right\}^{\sigma}Cons_g(T)$; $\forall g\in\{g_1,g_2,g_3\}$
Consumption Function	$cons_g=\Pi_z^N\left(x_{z,g}\right)^{\alpha_{z,g}};\sum\alpha_z=1$
Optimal level of Consumption	$Pc_z x_{z,g}=\alpha_{z,g}PXY_g Cons_g; \quad \forall g\in\{g_1,g_2,g_3\}$
Price of the Composite	$PXY_g=\Pi_z^N\left(Pc_z/\alpha_{z,g}\right)^{\alpha_{z,g}}$
Consumption Price	$Pc_z;\forall z\in\{1,2,....,N\}$

2.3.2.2 The Producer Problem

The production sector is disaggregated into N sectors that produce N composite commodities, where N^i industries produce polluting goods and the remaining N^j are considered clean. All firms operate in a competitive environment and have access to a constant return to scale technology. Each industry uses a combination of primary factors such as capital and labour and material inputs to produce its composite output.

Each composite output is a Constant Elasticity of Substitution ("CES") made of a composite of intermediate inputs, which is a Leontief aggregate of the other material inputs and a composite of value added. The latter is a Cobb Douglas aggregate of labour and capital. In addition, with respect to the polluting industries, a part of the production is used for abatement purposes to reduce pollution.

At any period of time, the producers' profit function for any given industry "z" $\forall z \in \{1,2,...,N\}$ is given by the following equation:

$$\Pi^z(t) = x_z(t)P_z(t) - c\left(t, x_z(t)\right) - \theta_z(t)x_z(t)P_z(t) - \tau_z^e(t)e_z\left(t, \theta_z(t)\right)x_z(t) \qquad (12)$$

Where P_z is the sale price of good x_z;[95] $c\left(t, x_z(t)\right)$ represents the cost function for producing $x_z(t)$ at period *t*. It is given by : $c(t, x_z(t)) = PVA_z(t)VA_z(t) + PINT_z(t)INT_z(t)$; $PVA_z(t)$ is the price for a composite Value added $VA_z(t)$ made of capital and labour; $PINT_z(t)$ is the price of a composite $INT_z(t)$ created out of material inputs; $\theta_z(t)$ represents the share of production used for abatement purposes; $\tau_z^e(t)$ is the tax on pollution; $e_z\left(t, \theta_z(t)\right)$ constitutes the coefficient of emission. It is worth mentioning that $\theta_z(t)$, $\tau_z^e(t)$, and $e_z\left(t, \theta_z(t)\right)$ are set to be equal to zero for the clean industries "j" $\forall j \in N^j$. Therefore, the profit function for a clean industry is given by:

$$\Pi^j(t) = x_j(t)P_j(t) - c\left(t, x_j(t)\right) \qquad (13)$$

[95] The sale price is equal to the consumer price for good x_i: $P_z = Pc_z$.

By assuming a perfectly competitive market, the zero profit condition is given by the following expression:

$$x_z(t)P_z(t) = c\left(t, x_z(T)\right) + P_z(T)\theta_z(t)x_z(t) + \tau_z^e(t)e_z\left(t, \theta_z(t)\right)x_z(t) \tag{14}$$

By manipulating equation (14), we can formulate the producer price given by ("$PXTS_z$") as a function of the sale price, and express it as:

$$PXTS_z(t) = \left[\left(1-\theta_z(t)\right)P_z(t) - \tau_z^e(t)e_z\left(t, \theta_z(t)\right)\right] \tag{15}$$

To maximize its profit, the polluting industry calculates the optimal level of abatement, taking as given the tax on pollution. Its objective function can be expressed as: [96]

$$\max_{\theta_z(t)}\left(\Pi^z(t)\right) = x_z(t)P_z(t) - c\left(t, x_z(t)\right) - P_z(t)\theta(t)x_z(t) - \tau_z^e(t)e_z\left(t, \theta_z(t)\right)x_z(t) \tag{16}$$

By maximizing its profit under a CES technology, each industry sets its optimal levels of $VA_z(t)$ and $INT_z(t)$ as:

$$VA_z(t) = \left(A^z\right)^{\sigma_p - 1} x_z(t)\left\{\alpha_z PXTS_z(t) / PVA_z(t)\right\}^{\sigma_p} \tag{17}$$

$$INT_z(t) = \left(A^z\right)^{\sigma_p - 1} x_z(t)\left\{\left(1-\alpha_z\right) PXTS_z(t) / PINT_z(t)\right\}^{\sigma_p} \tag{18}$$

[96] Unlike the first Chapter, the taxes on pollution are kept exogenous in the EOLG model. The model is constructed based on a set of clean and polluting industries with different levels of emissions. Modeling different endogenous taxes on emissions is a very complex procedure both at the analytical and the numerical level that goes beyond the purpose of this paper. Therefore, for simplicity purposes, we calibrate the taxes on pollution at the benchmark using the same approach used in the first paper and treat these taxes as exogenous parameters. We thus assume in this paper that the government is passive with respect to environment policy. The calibrated levels of abatement for each industry given by $\theta_z^*(t) = \left(\tau_z^e(t)\Lambda_z\delta / P_z(t)\right)^{1/1-\delta}$ are derived using the following expression $e_z(t, \theta_z(t)) = 1 - \Lambda_z\theta_z^{\delta}(t)$, where $\left(1-\Lambda_z\right)$ is a parameter associated with the coefficient of emission reflecting the level of incompressible emission; $\delta \in \left]0;1\right[$ is a share parameter of the abated pollution.

Where A^z is a shift parameter in the CES production function and σ_p is the elasticity of substitution between $VA_z(t)$ and $INT_z(t)$.

Once we substitute equations (17) and (18) into the producer objective function we can formulate the producer price using the following expression:

$$PXTS_z(t) = \left(1/A^z\right)\left\{\left(\alpha_z\right)^{\sigma_p}\left(PVA_z(t)\right)^{1-\sigma_p} + \left(1-\alpha_z\right)^{\sigma_p}\left(PINT_z(t)\right)^{1-\sigma_p}\right\}^{1/\left(1-\sigma_p\right)} \tag{19}$$

With respect to the use of capital and labour to produce $VA_z(t)$ using a Cobb Douglas function, we can formulate the optimal level of capital and labour needed to produce the optimal level of $VA_z(t)$ using the following equations:

$$K_z(t) = \left[\beta_z PVA_z(t) VA_z(t)\right] / R(t) \tag{20}$$

$$L_z(t) = \left[(1-\beta_z) PVA_z(t) VA_z(t)\right] / w(t) \tag{21}$$

Where β_z is the share parameter associated with capital in the production of $VA_z(t)$; $w(t)$ denotes the wage, and $R(t)$ represents the rental price of capital at the period *t*. Both variables vary over time. By substituting $K_z(t)$ and $L_z(t)$ expressions into the objective function of $VA_z(t)$ we can formulate the price $PVA_z(t)$ as a function of factors of production prices.

$$PVA_z(t) = \left(1/AV_z\right)\left\{\left(R(t)/\beta_z\right)^{\beta_z}\left(w(t)/\left(1-\beta_z\right)\right)^{1-\beta_z}\right\} \tag{22}$$

Where AV_z is the shift parameter in the $VA_z(t)$ function.

Finally, concerning the optimization of $INT_z(t)$ which is assumed to be a Leontief function of material inputs, we can formulate the optimal level of each input using the following expression:

$$v(z,zz,t) = \varepsilon(z,zz)INT_{zz}(t); \forall z, zz \in \{1,2,...,N\} \tag{23}$$

Where $v(z,zz,t)$ is the fraction of input z used to produce $INT_{zz}(t)$ and $\varepsilon(z,zz)$ is the share parameter associated with this input. By substituting equation (23) into the objective function of $INT_{zz}(t)$ we can express the optimal price of this composite as:

$$PINT_{zz}(t) = \sum_{z} \varepsilon(z,zz)Pc_z(t) \tag{24}$$

Table 3 bellow summarizes the main equation of the producers' problem.

Table 3: Main Equations Describing the Producer Problem in the EOLG Model

Expressions	**Producer Problem at Any Period of Time t**
Value Added	$VA_z(t) = AV_z K_z^{\beta_z}(t) L_z^{1-\beta_z}(t); \forall z \in \{1,2,...,N\}$
Optimal Level of Labor Demand	$L_z(t) = \left[(1-\beta_z)PVA_z(t)VA_z(t)\right]/w(t)$
Optimal Level of Capital Demand	$K_z(t) = \left[\beta_z PVA_z(t)VA_z(t)\right]/R(t)$
Price of the Composite Value Added	$PVA_z(t) = \left(1/AV_z\right)\left\{\left(R(t)/\beta_z\right)^{\beta_z}\left(w(t)/(1-\beta_z)\right)^{1-\beta_z}\right\}$
Composite of Material Inputs	$INT_{zz} = \min\{\varepsilon(z,zz)v(z,zz,t)\} \forall z \in \{1,2,....,N\}$
Optimal Level of Input	$v(z,zz,t) = \varepsilon(z,zz)INT_{zz}(t); \forall z, zz \in \{1,2,...,N\}$
Price of the Composite $INT_{zz}(t)$	$PINT_{zz}(t) = \sum_{z} \varepsilon(z,zz)Pc_z(t)$
Production of the Final Good	$x_z(t) = A^z\left\{\alpha_z\left(VA_z(t)\right)^{(\sigma_p-1)/\sigma_p} + \left(1-\alpha_z\right)\left(INT_z(t)\right)^{(\sigma_p-1)/\sigma_p}\right\}^{\sigma_p/(\sigma_p-1)}$
Optimal Value Added	$VA_z(t) = \left(A^z\right)^{\sigma_p-1} x_z(t)\left\{\alpha_z PXTS_z(t)/PVA_z(t)\right\}^{\sigma_p}$
Optimal Composite of Inputs	$INT_z(t) = \left(A^z\right)^{\sigma_p-1} x_z(t)\left\{\left(1-\alpha_z\right)PXTS_z(t)/PINT_z(t)\right\}^{\sigma_p}$
Optimal Price of the Final Product	$PXTS_z(t) = \left(1/A^z\right)\left\{\left(\alpha_z\right)^{\sigma_p}\left(PVA_z(t)\right)^{1-\sigma_p} + \left(1-\alpha_z\right)^{\sigma_p}\left(PINT_z(t)\right)^{1-\sigma_p}\right\}^{1/(1-\sigma_p)}$

2.3.2.3 Equilibrium Conditions

- ❖ **<u>Capital Accumulation and Saving</u>**

We assume that, at each period of time, the economy's national saving is equals to its domestic investment. Furthermore, the domestic net investment is given by:

$$Ks(t+1) - Ks(t) = \sum_g N_{g+1}(t+1) wealth_{g+1}(t+1) - \sum_g N_g(t) wealth_{g+1}(t) \tag{25}$$

Where K_s denotes the stock of capital in the economy; N_g denotes the number of agent in generation g.

To take into consideration the rate of depreciation of capital, we can reformulate equation (25) and express it as:

$$Ks(t+1) - Ks(t) = inv(t) - \psi K_s(t) \tag{26}$$

Where *Inv(t)* denotes the gross investment at time t.

At the steady state, investment keeps the stock of capital constant, by covering the depreciation rate. Therefore, we can express the domestic investment as:

$$inv(t) = \left[NN(t) + \psi\right] K_s(t) \tag{27}$$

Where *NN(t)* is the population growth rate at period t.

- **Decomposition of the Investment**

Gross investment is a composite of N goods subject to an investment technology. The optimal level of goods purchased for investments can be calculated using the following minimization problem:

$$Min\left\{ Pinv(t) inv(t) = \sum_z Pc_z invx_z(t) \right\} \tag{28}$$

Subject to: $inv(t) = \prod_z^N \left(invx_z(t)\right)^{\alpha_{invx_z}}$

Where *Pinv(t)* is the price of the composite; $invx_z \forall z \in \{1, 2, ..., N\}$ is the individual investment using x_z; α_{invx_z} is the share parameter in the CD investment function.

By taking the first-order condition with respect to $invx_z \forall z \in \{1, 2, ..., N\}$, we get:

$$invx_z(t) = \alpha_{invx_z} inv(t) Pinv(t) / Pc_z(t) \tag{29}$$

By substituting $invx_z$ into the objective function given by equation (28), we can formulate the optimal price for the composite as:

$$Pinv(t) = \prod_{z}^{N} \left(Pc_z(t) / \alpha_{invx_x} \right)^{\alpha_{invx_x}} \tag{30}$$

❖ **Market clearing**

The EOLG model is based on N+2 markets for labour, capital, and composite goods. Each one of these markets needs to be in equilibrium in such a way that total demand equals total supply in the economy. For each commodity x_z, the market equilibrium conditions between demand and supply are given respectively by the following equations:

$$\begin{aligned} & x_z(t)(1-\theta_z(t)) = invx_z(t) + \sum_{g}^{g=G3} \left\{ N_g(t) x_{z,g} \right\} + \sum_{zz}^{N} v(z, zz, t); \forall z \in N^i \\ & And \\ & x_z(t) = invx_z(t) + \sum_{g}^{g=G3} \left\{ N_g(t) x_{z,g} \right\} + \sum_{zz}^{N} v(z, zz, t); \forall z \in N^J \end{aligned} \tag{31}$$

Furthermore, the following two equations describe the equilibrium conditions respectively in capital and labour markets:

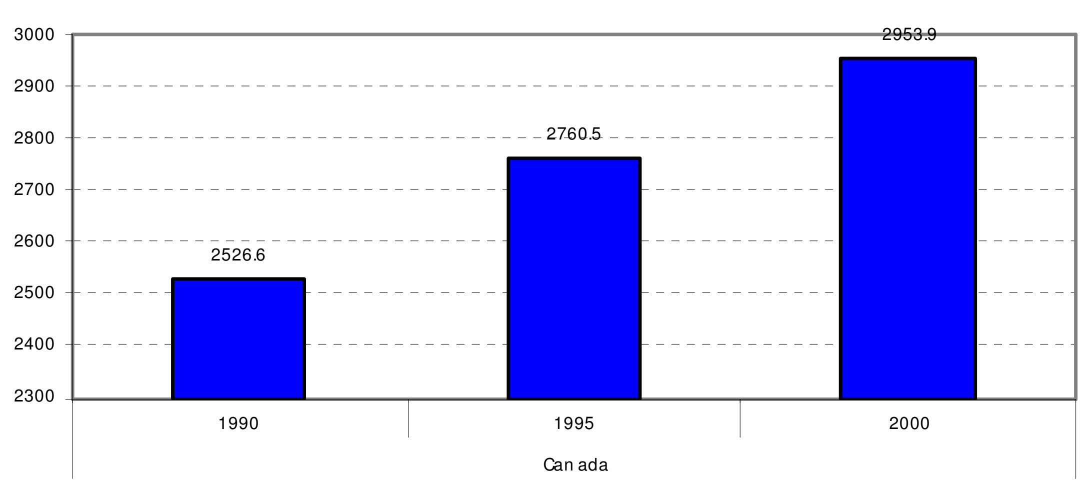
$$K_s(t) = \sum_{z}^{N} K_z(t) \qquad \text{and} \qquad L_s(t) = \sum_{z}^{N} L_z(t) \tag{32}$$

Where, $L_s(t) = \sum_{g}^{G3} N_g(t) L_s(g)$; $L_s(g)$ denotes the effective labour supply by a representative consumer from generation g.

2.4 Empirical Analysis of the EOLG Model: Data and Calibration

In this paper, we used 2000 data for the Canadian economy provided by Statistics Canada. The data include value added for capital and labour,[97] earnings of individual by age and specific industry,[98] saving,[99] and household spending.[100] Furthermore, we relied on the input-output tables made available in the "The OECD INPUT-OUTPUT DATABASE: 2006 EDITION" to construct the Canadian Social Accounting Matrix.[101] Finally the data on the volume of sulfur dioxide ("SO2") emission is extracted from the Emission Database for Global Atmospheric Research (EDGAR) 3.2.[102] The following Figure describes the evolution of the level of SO2 emission in Canada between 1990 and 2000.

Figure 3: SO2 Emission in Canada (Thousand metric Tons)



---

[97] Table 383-0021 - Multifactor productivity, value-added, capital input and labour input in the aggregate business sector and major sub-sectors, by North American Industry Classification System (NAICS), annual (index, 2002=100 unless otherwise noted)(1).

[98] Table 202-0404 - Total income, by economic family type, age group and income source, 2006 constant dollars, annual(1,5). Available at the following address: http://estat.statcan.gc.ca/cgi-win/cnsmcgi.exe?Lang=E&EST-Fi=EStat/English/CII_1-eng.htm

[99] Table 111-0036 - Canadian savers, by savers characteristics, annual (percent unless otherwise noted)(1,2,3,4). Available at the following address: http://estat.statcan.gc.ca/cgi-win/cnsmcgi.exe?Lang=E&EST-Fi=EStat/English/CII_1-eng.htm

[100] For more details about the Household spending as they age, see Chawla (2005), "Shifts in Spending Patterns of Older Canadian", Statistics Canada Catalogue no. 75-001-XIE.

[101] For more details about the input-output tables visit: http://lysander.sourceoecd.org/vl=10976876/cl=17/nw=1/rpsv/cgi-bin/wppdf?file=5l4tpn0275r0.pdf

[102] Data on Sulfur Dioxide emissions is provided by the World Resources Institute, and made available in the following following address: http://earthtrends.wri.org/text/climate-atmosphere/variable-812.htm

The data is first aggregated and then manipulated to respect the EOLG model assumptions and an accounting principle that stipulates the following: for each agent, commodity or industry, the total value of each column (expenditure) has to be equal to the total value of its corresponding row (revenue).[103]

The calibration consists of calculating numerical values for all the EOLG model's parameters using the information contained in the SAM. Such process takes into consideration the assumptions of the model describing the production functions, the emission of pollution, the investment, and the properties of the consumers' preferences in term of consuming clean and polluting goods over their life time.

From the producers' perspective, Table 4 formulates the expressions associated with the shift and share parameters characterizing both polluting and clean industries, in addition to the coefficient of emission and the tax on pollution at the benchmark situation. Estimated values of these parameters are presented in Table 5. It is worth mentioning that estimated coefficient of emission and tax on pollution are only provided for the polluting industries.

Table 4: Parameters Characterizing the Producer Problem and the Pollution Emission

Calibrated Parameters: Production Side		Expression
Production of the Final good: CES($VA_z(t)$, $INT_z(t)$)	Share Parameter	$\alpha_z = 1/\left\{1+\left(PINT_z / PVA_z\right)\left(INT_z / VA_z\right)^{1/\sigma_p}\right\}$
	Shift Parameter	$A^z = x_z / \left\{\alpha_z \left(VA_z\right)^{1-1/\sigma_p} + \left(1-\alpha_z\right)\left(INT_z\right)^{1-1/\sigma_p}\right\}^{\sigma_p(\sigma_p-1)}$
Production of $VA_z(t)$ CD(K,L)	Share Parameter	$\beta_z = K_z R / PVA_z / VA_z$
	Shift Parameter	$AV_z = VA_z / \left\{\left(K_z\right)^{\beta_z}\left(L_z\right)^{1-\beta_z}\right\}$
Production of $INT_z(t)$	Share Parameter	$\varepsilon(z,zz) = v(z,zz) / INT_{zz}$
Coefficient of Emission		$e_z(t,\theta_z(t)) = 1-\Lambda_z \theta_z^{\delta}(t)$
Tax on pollution at the Benchmark Situation		$\tau_z^e = Pc_z \theta_z^{1-\delta} / \Lambda_z \delta$

[103] A copy of the SAM is available from author upon request.

Table 5: Calibrated Parameters (Producer Problem and Emission) [104]

Parameters	α_z	A^z	β_z	AV_z	τ_z^e	$e_z(t,\theta_z(t))$
Polluting Industries						
Primary	0.533	2.21	0.754	0.755	11.117%	0.000559
Other Manufacturing	0.418	2.16	0.461	0.462	11.140%	0.002638
Material Manufacturing	0.416	2.16	0.458	0.458	11.121%	0.000914
Machinery Manufacturing	0.387	2.11	0.488	0.488	11.122%	0.000998
Utility	0.615	2.12	0.749	0.749	11.585%	0.040938
Construction	0.454	2.20	0.124	0.124	11.116%	0.00046
Transport and Communications	0.472	2.21	0.367	0.367	11.137%	0.00228
Clean Industries						
Trade, Hotels and Restaurants	0.547	1.98	0.191	0.191		
Finance, Insurance and Real Estates	0.574	1.95	0.5	0.501		
Business Services	0.544	1.98	0.158	0.159		
Personal Services	0.553	1.97	0.158	0.158		

Concerning the consumer's problem, the calibration consists in expressing and estimating the following parameters using the data contained in the SAM.

Table 6: Consumers' Calibrated Parameters Characterizing the OLGACT Model

Parameters to Be Calibrated	Expression/ Calibrated Value
Share Parameters	$\alpha_{z,g} = \left(Pc_z x_{z,g}\right) / \left(PXY_g Cons_g\right)$
Productivity (G1)	**1.816**
Productivity (G2)	**2.539**

In a dynamic model that involves overlapping generations, the calibration procedure is complex due to the level of aggregation and the need to determine realistic consumption profiles per age group at a specific period of time. We elaborate a decomposition mechanism to distribute consumption among consumers based on Hersch and Viscusi estimations of consumers' willingness to pay higher gas prices to preserve the environment.[105] Estimated values associated with consumers' share parameters are provided in Section 5 below based on different scenarios.

[104] A detailed description about each industry is provided in Appendix6.
[105] Numerical program using GAMS is constructed to estimate the consumer's calibrated parameters. The program is available upon request.

2.5 Simulation and Main Results

This section provides computational economic assessment of three scenarios in order to analyze the aggregate and sectoral impacts of population ageing on the level of SO2 emission.[106] The three scenarios consist of simulating a demographic transition that generates scale, composition, and cohort effects on pollution. The demographic transition is generated by an increase in the population growth rate in the first stage, followed by a declining one, and finally the rate of population growth converges to zero. This is to replicate somewhat a baby boom followed by a baby bust.

The first scenario demonstrates the role played by the size of the population to impact the level of emission via the scale effect.[107] Consumers are assumed here to have homogeneous preferences with respect to the consumed goods regardless of their age.

In the second scenario, consumers from different age groups have different preferences with respect to goods. Young consumers are assumed to be more willing to protect the environment, which is reflected in their resources allocation between clean and polluting commodities. By using Hersch and Vescousi (2005) findings, we model consumers' preferences by allocating young consumers with a lower share parameter associated with polluting goods in comparison to seniors. The share parameters assumed follow the results of Hersch and Vescousi expressed in Table 1. The difference between the levels of emission from the first and second scenarios approximates the impact of the composition of the population on the level of emission.[108]

Finally, in the third scenario, new cohorts become more aware about the risk of SO2 emission and the necessity to protect the environment. Such awareness is reflected by the resources allocation between clean and polluting goods. Therefore, we simulate a change in the share parameters towards more consumption of clean goods for new and future cohorts.

---

[106] It is important to mention that the main objective of this chapter is not to predict or describe the evolution of the SO2 levels over time, but to assess the impact of population ageing on the emission levels and decompose such impact into scale, composition and cohort effects.

[107] The scale effect shows the variation in the level of emission due to a variation in the size of the population, which has direct impact on the supply of capital and labour and the level of consumption.

[108] The demographic composition effect reflects the shift in the production towards cleaner goods as young consumers demand more clean goods.

At the benchmark, the population is simply made out of three equal size generations. Each one represents one third of the living agents at each period of time, and total population remains constant. From the benchmark, we impose an increase in the population growth rate for five successive periods of time, followed by a decrease in the population growth rate for next three periods of time. The long-term trend is characterized by zero population growth rate. (see Figure 3) [109]

Figure 3: Population Growth Rate Over Time

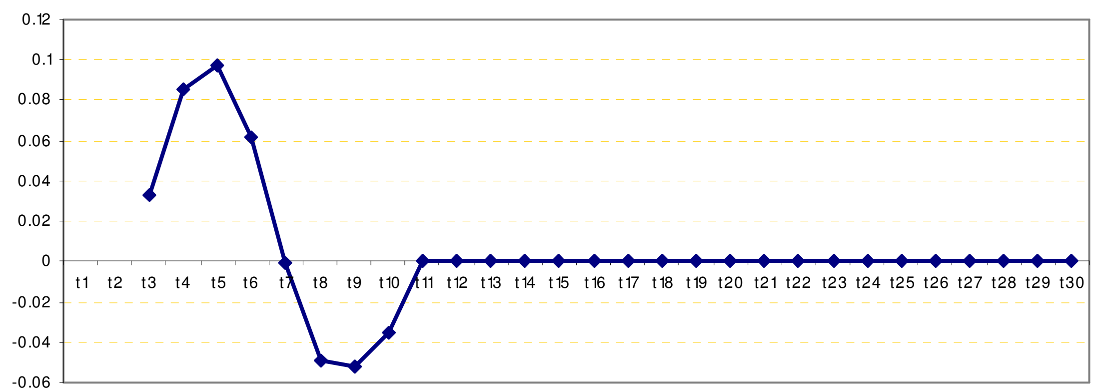
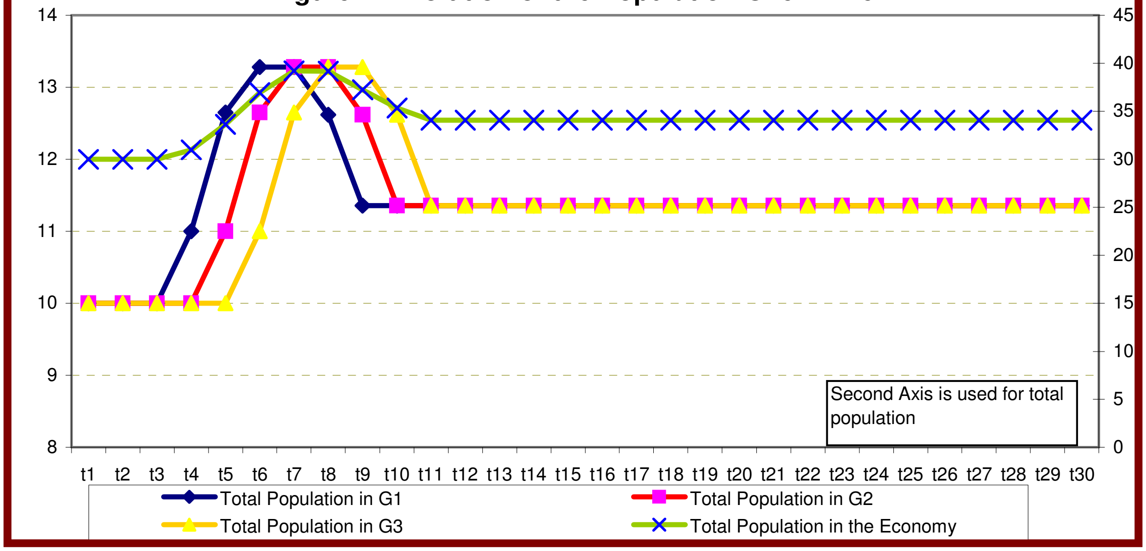


Figure 4 describes the evolution in the number of agents for each generation at each period of time. Notice that total number of individuals in the economy increases over time by 13.6%. Such increase is responsible for the variation in the level of emission related to the scale effect in the long run. During the demographic transition, which starts at period (t4) and ends at period (t10), the total population fluctuates and directly affects the level of emission as a reflection of the scale effect in the short run.

[109] Data about number of agents for each generation at each period of time is provided in Appendix 7.

Figure 4: Evolution of the Population Over Time

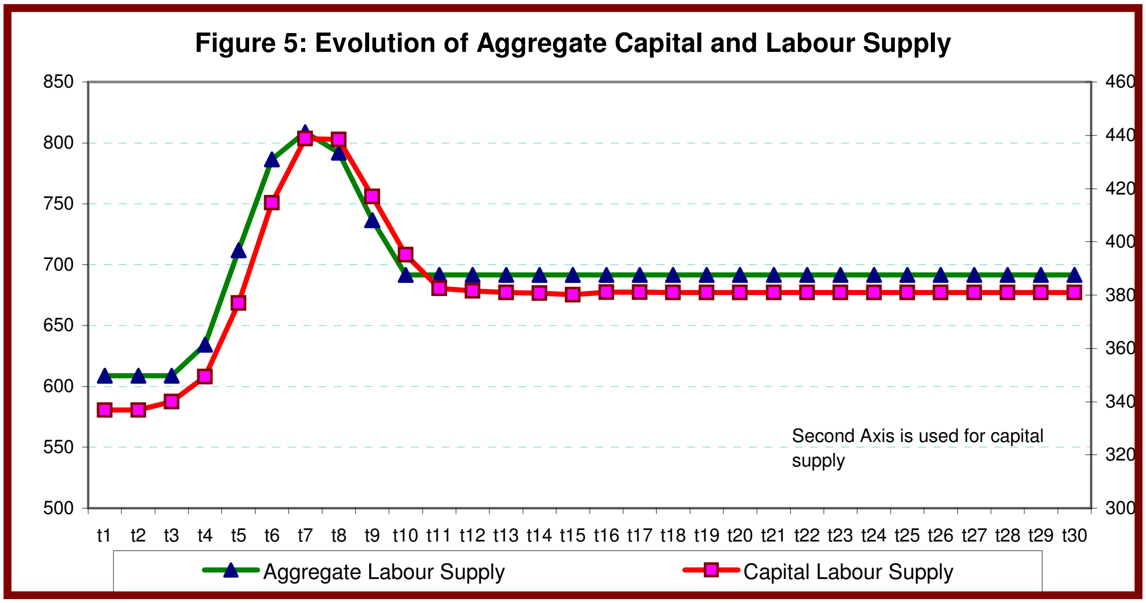


2.5.1 Scenario 1: Homogeneous Preferences

This section assesses the impact of the size of the population on the level of emission. To isolate the scale effect, we assume that consumers from different age groups have homogenous preferences with respect to clean and polluting goods. The aggregated consumption provided in the social accounting matrix is used to calibrate the share parameters for a representative consumer. Results from the calibration procedure show that a representative consumer uses 34% of his disposable income to consume polluting goods and 66% to buy clean commodities.[110]

An increase in the population growth rate leads to an increase in the total number of households in the economy. As both G1 and G2 represent the two working generations in the economy with positive savings, an increase in the population growth rate leads to a positive impact on the supply of both labour and capital as shown in Figure 5. The lag between the variations in the stock of capital versus the stock of labour in the economy reflects the fact that new cohorts (G1) enter the economy with no wealth.

[110] For more details about the share parameters associated with each commodity under Scenario 1 see Table 7.



The evolution of the rate of return on capital and wage is mainly derived from the evolution of aggregate capital and labour supply and the significance of the lag between these two variables. Two findings represented in Figure 6 are worthy of particular attention. First, during the demographic transition, the rate of return on capital seems to vary in the opposite direction to wage before converging to the benchmark level in the long run. Second, an increase in the population growth rate augments the rate of return on capital. However, it is less likely that variation in the rate of return on capital and wage will have a significant impact on domestic production (composition of the domestic production in terms of clean versus polluting goods) compared to the scale of the economic activity mainly affected by the magnitude of capital and labour supply and aggregate demand.

Results from simulations show that the average variation in the production of clean versus polluting goods is mainly affected by the scale of the economic activity and consumers' preferences for clean versus polluting goods.

Figure 6: Evolution of Wage and Rate of Return on Capital Over Time

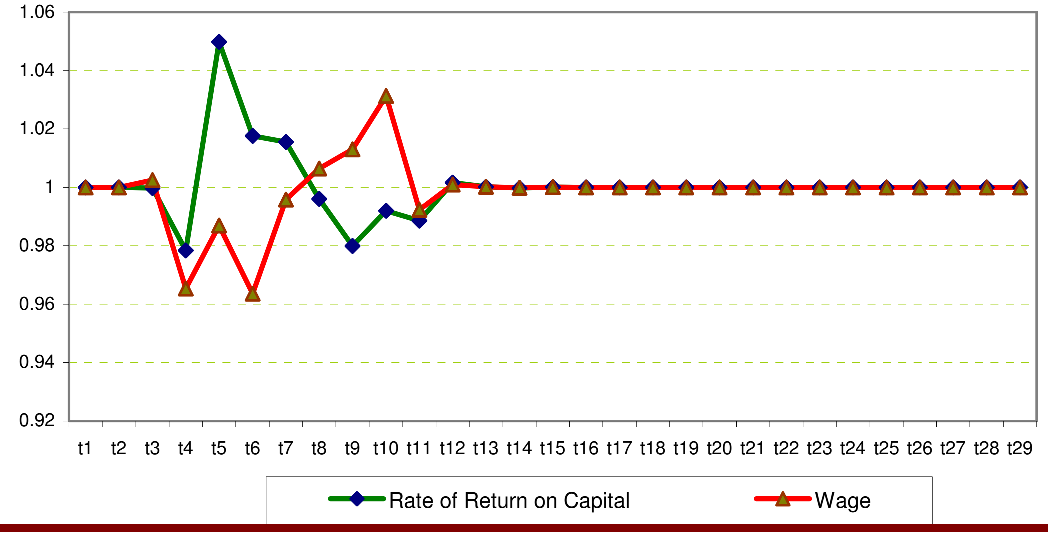
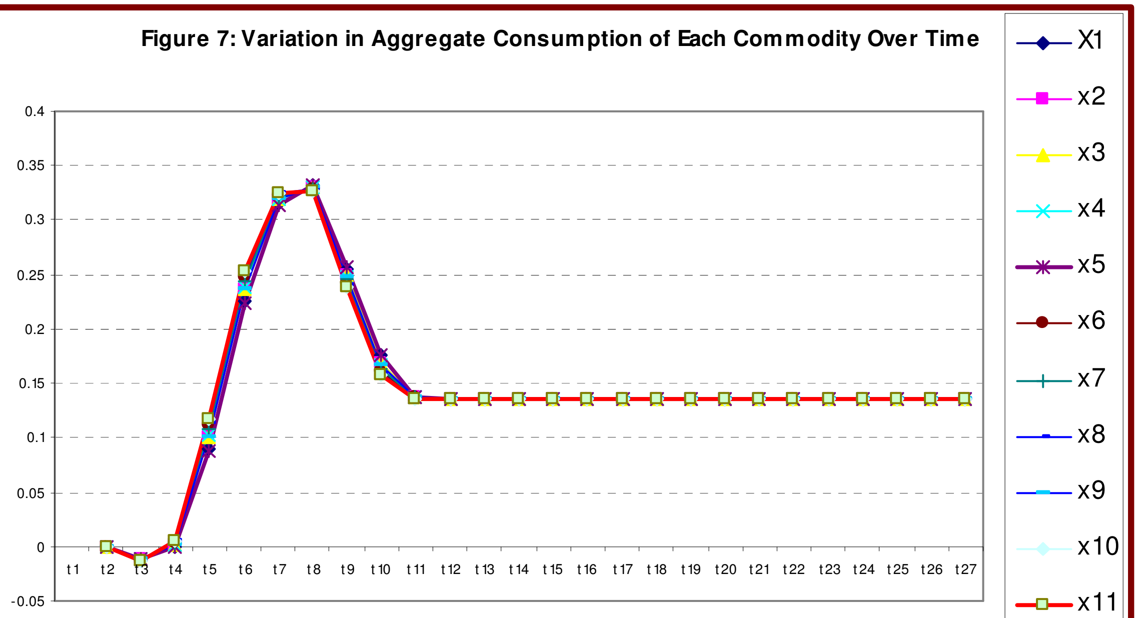
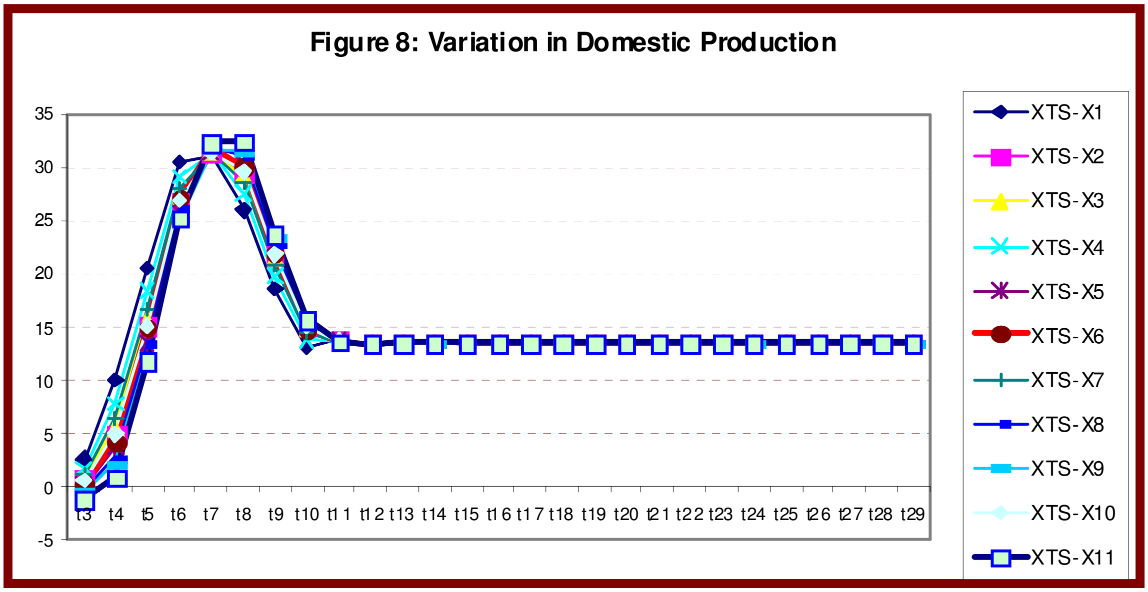


Figure 7 illustrates the impact of demographic shock on the aggregate consumption for each commodity.

Figure 7: Variation in Aggregate Consumption of Each Commodity Over Time



Results from demographic shock suggest that production of all goods varies in the same direction as for aggregate consumption. Figure 8 illustrates the variation in domestic production.



Differences in the graphs between Figures 7 and 8 reflect the demand for intermediate goods. In the long run, since the total population exceeds its level at the benchmark situation, domestic production of each commodity increases in the long run, which has a direct impact on the level of emission.

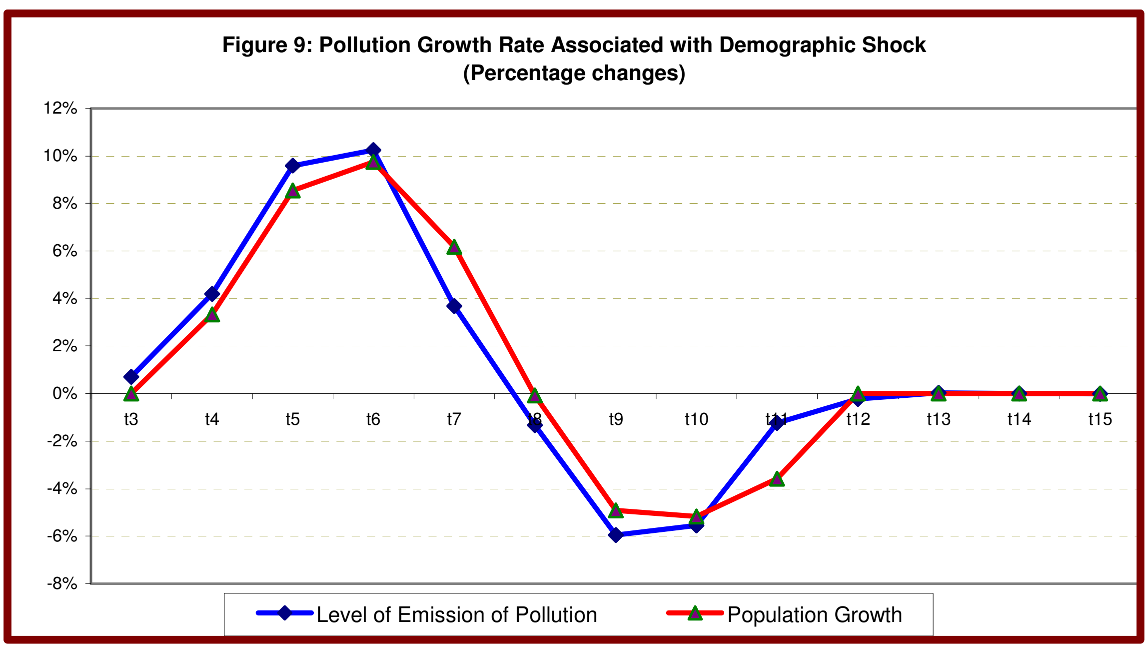


Figure 9 shows a strong correlation between population growth rate and the rate of growth of pollution during the demographic transition. Such correlation becomes even more apparent in the long run, and reflects fully the scale effect.

2.5.2 Scenario 2: Heterogeneous Preferences

This scenario is based on the assumption that consumers from different age groups exhibit different preferences with respect to the consumption of clean versus polluting goods. Young households are assumed to be more sensitive to the question of the environment, and they are more willing to preserve it. In comparison with seniors, they allocate a higher portion of their disposable income to consume clean goods. Preferences towards clean goods fall with age reflecting a steady decline in consumer willingness to preserve the environment over age.

More specifically, following Hersch and Viscusi findings, we first allocate the aggregate consumption (included in the SAM) across consumers from different age groups by allowing older generations to have the highest share in terms of consumption of polluting goods. In addition, we permit younger generations to have a relatively higher share in terms of aggregate consumption of clean goods relative to polluting ones. Such allocation procedure is conducted by taking into consideration the budget constraint of each representative consumer. Second, by backward induction, we use individual consumptions associated with each commodity to calibrate the composite consumptions and the share parameters for each group of consumers.

It is important to highlight that, despite the assumption making a positive relationship between age and the share of disposable income allocated to consume polluting goods, this does not prevent seniors from consuming a large share of clean goods relative to younger generations. In fact, since we assume that agents are rational, utility maximizers and more importantly cannot leave debt at the end of their life, in terms of dollar-value, our calibration shows that seniors are responsible for 40% of aggregate consumption of clean goods, while adults are responsible for 35% and younger consumers account only for 25%.

Table 7: Share Parameters for a Representative Consumer from Different Generations

Products		Scenario 1	Scenario 2: Composition Effect		
		G1/G2/G3	**G1**	**G2**	**G3**
Polluting Goods	Primary	1%	1%	1%	2%
	Other Manufacturing	8%	4%	6%	11%
	Material Manufacturing	3%	2%	3%	5%
	Machinery Manufacturing	6%	3%	4%	8%
	Utility	2%	1%	1%	2%
	Construction	10%	5%	14%	10%
	Transport and Communications	4%	2%	3%	5%
	Sub-total	**34%**	**17%**	**31%**	**42%**
Clean Goods	Trade, Hotels and Restaurants	21%	26%	21%	18%
	Finance, Insurance and Real Estates	16%	20%	16%	14%
	Business Services	1%	1%	1%	1%
	Personal Services	28%	37%	30%	26%
	Sub-total	**66%**	**83%**	**69%**	**58%**
Relative Weight		**51.5%**	**20%**	**46%**	**74%**
Total		**100%**	**100%**	**100%**	**100%**

Table 7 summarizes the consumers' disposable income allocation between polluting and clean goods over age. Moreover, it provides a comparative analysis between Scenario 1 (homogeneous preferences) and Scenario 2 (heterogeneous preferences). Under Scenario 1, a representative consumer whether he belongs to G1, G2, or G3 allocates 34% of his disposable income to consume polluting goods and 66% to consume clean commodities. However, under the heterogeneous preferences scenario, the share allocated to polluting goods increases with age. At the aggregate level, it goes from 17% for young consumers, to 31% for adults, and 42% for seniors. Such a trend is valid for all polluting goods except for "construction" where consumers from G2 spend more than seniors. This difference can be explained by seniors' willingness to live in smaller houses and to pay less for construction.

Figure 10: Average Variation in the Production of Clean versus Polluting Good

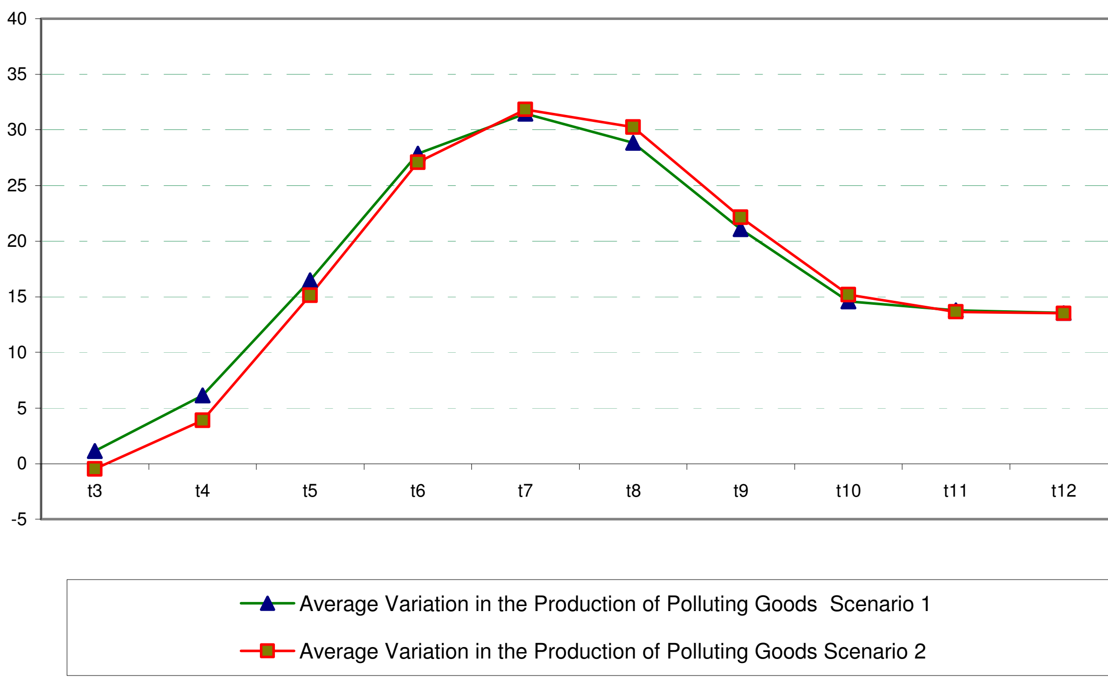
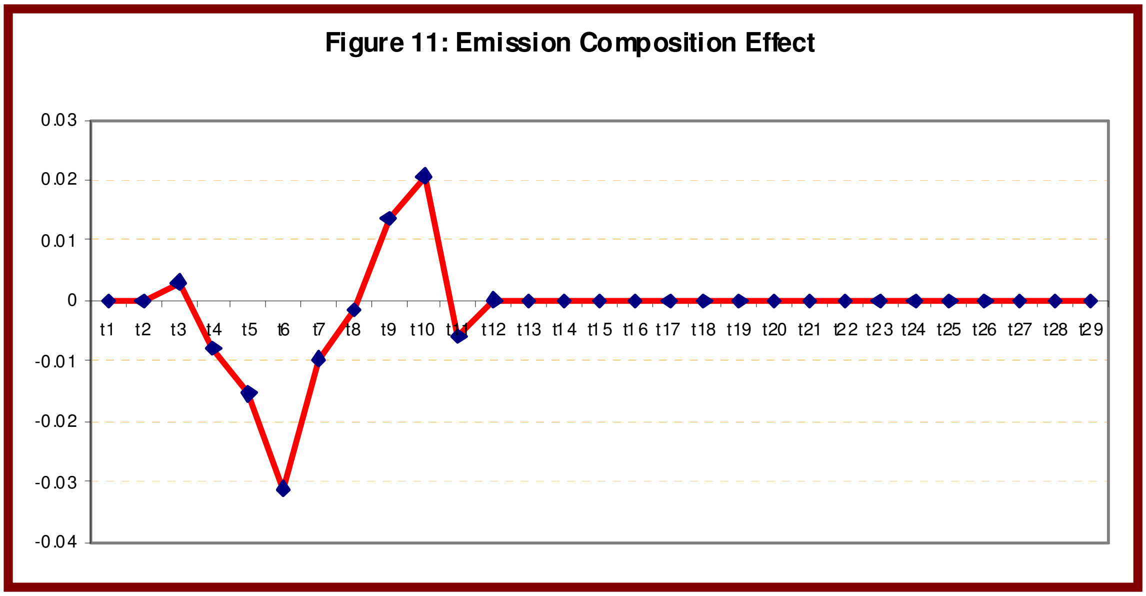
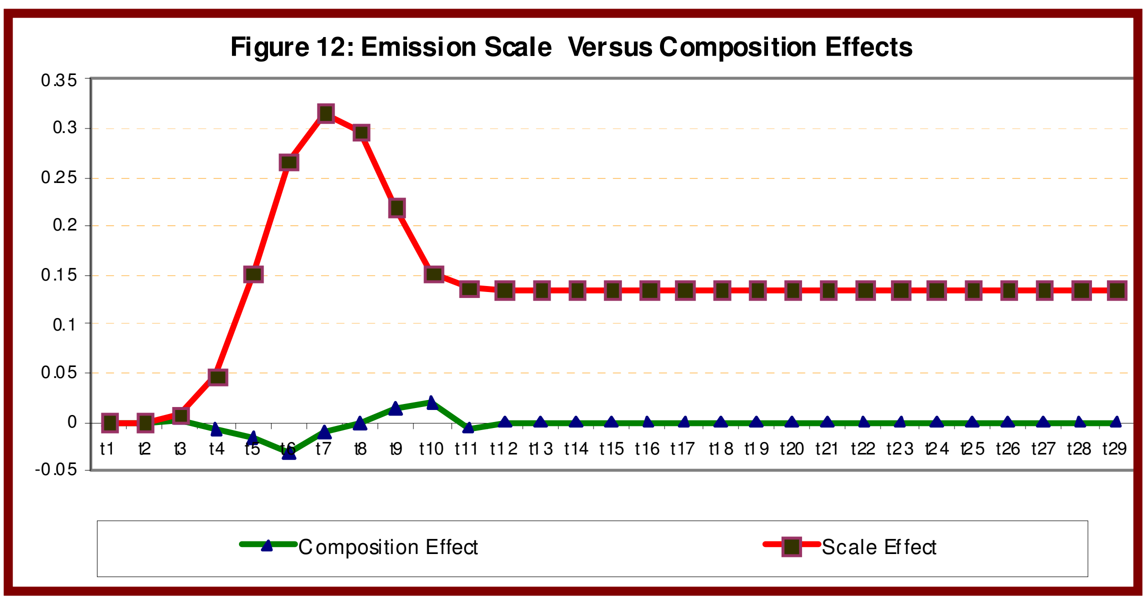


Figure 10 illustrates the change in average variation in the production of polluting goods by comparing scenarios 1 and 2. Under the homogeneous preferences scenario, production of the polluting goods exceeds the level found under the heterogeneous preferences scenario when the population is relatively young (t3 to t6). In the second part of the demographic transition (t6 to t10), production of the polluting goods is higher under Scenario 2. In the long run, the composition effect converges to zero.

Figure 11 illustrates the composition effect: a baby boom period (t3 to t6) reduces pollution emission; in contrast, ageing population that follows a baby bust period (t6 to t10) increases emission.



Notice that scale dominates the composition effect as illustrated in Figure 12. This suggests that pollution emission is much more sensitive to the size than to the age composition of the population.



2.5.3 Scenario 3: The Cohort Preferences

This scenario explores the possibility that new cohorts of consumers have a more pro-environment attitude. They are born and remain the rest of their life more concerned about the environment. A change in perception can be attributed to the increase in the level of awareness of the consequences of pollution and its impact on human lives. It is by altering their consumption towards more clean goods and less polluting ones that consumers in the model show their concern about the environment. Therefore, to simulate the impact of the cohort effect on the level of emission, we assume that starting from a specific period (t4) new cohorts have different income allocation across goods. Table 8 illustrates an example in which consumers choose to reduce their share parameters to consume polluting goods by 5%.

Table 8: New Share Parameters to Illustrate the Cohort Effect

Products	**Share Parameters and Consumption Distribution**					
	G1		**G2**		**G3**	
	Benchmark	$\alpha_{z,g}^{new}$	Benchmark	$\alpha_{z,g}^{new}$	Benchmark	$\alpha_{z,g}^{new}$
Polluting Goods	New Share Parameter is given by: $\alpha_{z,g}^{new}$ such that $\alpha_{z,g}^{new} = (1-\Delta)\alpha_{z,g}$					
X1	0.6%	0.6%	0.9%	0.9%	1.8%	1.7%
X2	3.9%	3.8%	5.8%	5.5%	11.1%	10.5%
X3	1.7%	1.6%	2.6%	2.4%	4.9%	4.6%
X4	2.8%	2.7%	4.1%	3.9%	7.9%	7.5%
X5	0.8%	0.8%	1.2%	1.1%	2.2%	2.1%
X6	5.1%	4.9%	14.1%	13.4%	9.6%	9.1%
X7	1.8%	1.7%	2.6%	2.5%	5.0%	4.8%
Sub-total	16.8%	16.0%	31.4%	29.8%	42.5%	40.4%
Clean Goods	New Share parameters are given by: $\alpha_{z,g}^{new}$ such that $\alpha_{z,g}^{new} = \alpha_{z,g}\left(1-\Delta\left\{\sum_{z}^{N^i}\alpha_{z,g} / \sum_{z}^{N^j}\alpha_{z,g}\right\}\right)$					
X8	25.8%	26.0%	21.3%	21.8%	17.8%	18.5%
X9	19.6%	19.8%	16.2%	16.5%	13.6%	14.1%
X10	0.9%	0.9%	0.7%	0.8%	0.6%	0.6%
X11	36.9%	37.3%	30.5%	31.1%	25.5%	26.5%
Sub-total	83.2%	84.0%	68.6%	70.2%	57.5%	59.6%
Total	100%	100%	100%	100%	100%	100%

* $\alpha_{z,g}^{new}$ represents the new share parameters as a result of the cohort effect

** The example is based on $\Delta = 5\%$

In this scenario, we assume all consumers born during (t4) and after decide to increase their allocation of income by 1% towards the consumption of clean goods. By comparing the aggregate level of emission from the previous simulations (Scenario 2) to the level of emission under the new level of awareness about the environment, the following graph describes the evolution of emission over time due to composition and cohort effects.

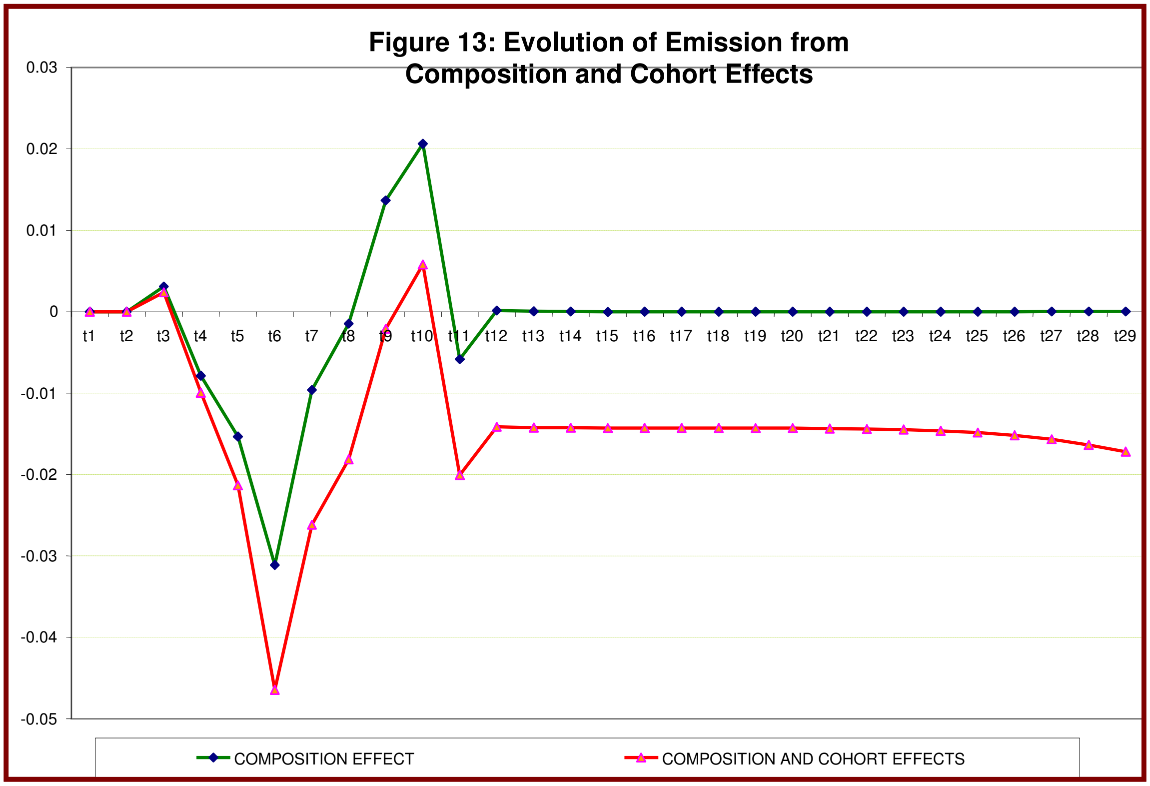


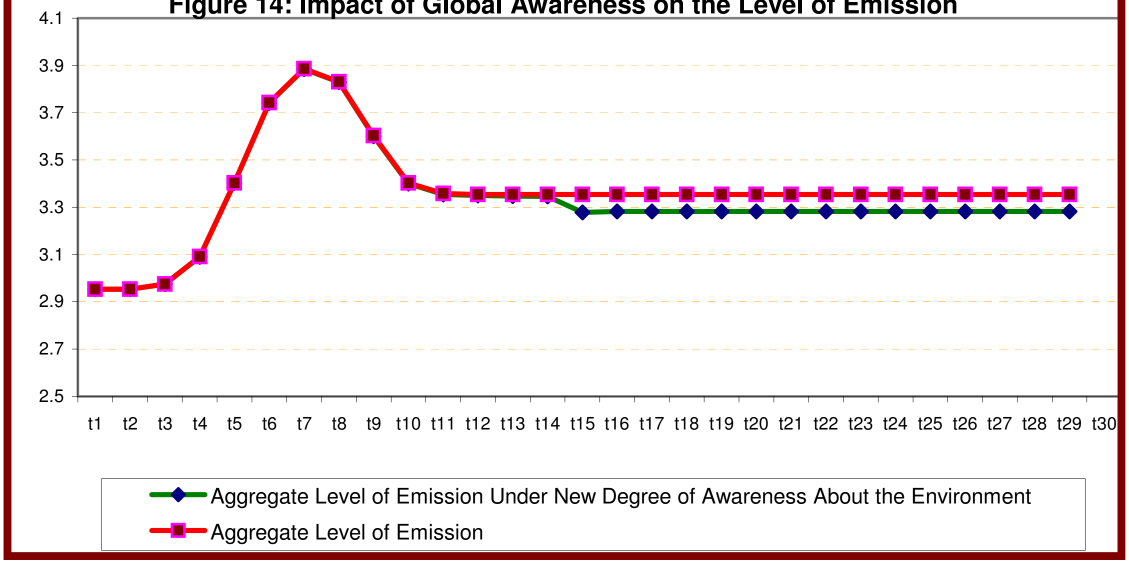
Figure 13 clearly shows that change of consumers' perception towards the consumption of more clean goods leads to a reduction in the level of emission generated in the economy. By reducing the share of polluting goods in a representative consumer's consumption by 1%, the level of emission declines by 0.5% at the full impact, that is after three periods.

It is important to highlight that, once associated with a higher level of awareness towards the preservation of the environment, the cohort effect can offset the negative impact of the composition effect on the environment. This finding reveals that, investing in elevating the level of awareness about the need to protect the environment can provide countries facing an ageing population with a new mechanism to prevent the level of emission from rising. By doing so, the impact of the demographic composition of the population can be entirely eliminated, and full impact of the scale effect on the environment can be preserved.

In our model, an increase in the level of awareness capable of reducing a representative consumers' consumption of the polluting goods by 2% is high enough to offset the demographic composition effect from ageing. However, it is noteworthy to mention that balance between level of awareness and composition effect depends on many factors such as consumers' preferences in terms of clean versus polluting goods and the way how consumers' level of awareness regarding the environment can be translated into resource allocation. Further, by comparing scale to cohort effect, we find that the former dominates the latter both in the short and the long run.

To be able to highlight the positive relationship between the increase in the global awareness about the need to preserve the environment and the level of emission, Figure 14 below describes the impact of a change in consumers' perception of the environment on the level of pollution. The result is based on a 5% increase in income allocation towards the consumption of clean goods that took place at period (t15).

Figure 14: Impact of Global Awareness on the Level of Emission



Starting from period (t15), all consumers decide to increase their allocation for the consumption of clean goods by 5%. Such change reduces pollution by almost 2.5% showing a positive relationship between global awareness and the environment.

2.5.4 Sensitivity Analysis

The results from simulations suggest that the scale effect dominates both the composition and cohort effect. In addition, we find that the cohort effect can be sufficiently strong to mitigate the composition effect, especially during the baby bust by providing ageing economies with a new mechanism to preserve the environment. It is however important to assess the robustness of our results to reasonable changes in the specification of the model. Therefore, we have performed sensitivity analysis of our core results related to the magnitude of the scale, composition and cohort effect. We have identified three areas for possible sensitivity analysis. These areas are associated with the demographic shock, the change in consumers' preferences with age, and the change in the perception of the environment as a result of an increase in the level of awareness.

More specifically, we attempt to vary the following parameters: the magnitude of population growth rate and the share parameters associated with the consumption of the polluting goods as a reflection of the cohort effect. However, with respect to the change in consumers' preferences with age, a comparative analysis between Scenarios 1 and 2 (Table 7) shows that younger consumers allocate 50% less and seniors assign 80% more of their disposable income to consume polluting good under scenario 2 in comparison to scenario 1. Therefore it is less likely that a reasonable change in the share parameters allocated by seniors to consume polluting good will have significant impact on the level of emission to allow the composition effect to dominate the scale effect. Intuitively, a change in the demographic shock will probably have a larger impact on the level of emission as a result of the change in the size of the population.

Table 9: Sensitivity Analysis Associated With the Magnitude of the Demographic Shock

Period	Sensitivity Analysis to the Demographic Shock by Varying the Magnitude of the Demographic Shock at the Central Case by About $\pm\Delta$ ($\Delta = 25\%$) % of Variation in the Emission Levels								
	Scale Effect			**Composition Effect**			**Cohort Effect**		
	$-\Delta$	Central Case	$+\Delta$	$-\Delta$	Central Case	$+\Delta$	$-\Delta$	Central Case	$+\Delta$
t3	0.59%	0.73%	0.86%	0.06%	0.10%	0.14%	-0.017%	-0.024%	-0.022%
t4	3.51%	4.64%	5.75%	-0.22%	-0.25%	-0.27%	-0.070%	-0.067%	-0.067%
t5	11.32%	15.23%	19.20%	-0.35%	-0.45%	-0.54%	-0.177%	-0.176%	-0.175%
t6	19.69%	26.70%	33.92%	-0.64%	-0.83%	-1.01%	-0.416%	-0.413%	-0.411%
t7	23.19%	31.57%	40.28%	-0.18%	-0.25%	-0.32%	-0.427%	-0.427%	-0.427%
t8	21.88%	29.69%	37.76%	-0.03%	-0.04%	-0.05%	-0.433%	-0.435%	-0.437%
t9	16.43%	21.97%	27.52%	0.27%	0.38%	0.49%	-0.433%	-0.436%	-0.439%
t10	11.64%	15.21%	18.60%	0.45%	0.61%	0.77%	-0.431%	-0.433%	-0.435%
t11	10.55%	13.68%	16.59%	-0.13%	-0.17%	-0.22%	-0.425%	-0.425%	-0.425%
t12	10.48%	13.58%	16.46%	0.00%	0.00%	0.00%	-0.425%	-0.425%	-0.426%
t13	10.46%	13.55%	16.42%	0.00%	0.00%	0.00%	-0.425%	-0.425%	-0.425%
t14	10.46%	13.56%	16.43%	0.00%	0.00%	0.00%	-0.425%	-0.425%	-0.425%
t15	10.46%	13.56%	16.43%	0.00%	0.00%	0.00%	-0.425%	-0.425%	-0.425%

Table 9 provides a comparative analysis between scale, composition and cohort effect as a result of a change in the population growth rate by about $\pm 25\%$. Results from the sensitivity analysis show a clear and persistent dominance of the scale effect. In addition, results from the sensitivity analysis associated with the magnitude of the change in consumers' attitudes towards the consumption of polluting goods as a manifestation of their new level of awareness regarding the need to preserve the environment show that cohort effect, particularly during the baby bust, can be strong enough to offset the composition effect. (see Table 10) For example if consumers decide to reduce the share of their disposable income allocated to consume polluting goods by 10%, the level of emission falls by 4.12%. However, although such reduction in the level of emission is almost seven times higher in absolute value than the highest level of emission generated by the demographic composition of the economy, the cohort effect is still small in magnitude to offset the scale effect.

Table 10: Sensitivity Analysis Associated With the Magnitude of the Change in Consumers Attitude towards the Consumption of Polluting Goods

Period	**Sensitivity Analysis Related to the Magnitude of the Change in the Share Allocated to Consume Polluting Goods as a Manifestation of the New Level of Awareness % of Variation in the Emission Levels**					
	Scale Effect	Composition Effect	Cohort Effect based on a reduction in the share parameters associated with the consumption of polluting goods			
			1%	2%	5%	10%
t3	0.73%	0.10%	-0.024%	-0.039%	-0.045%	-0.021%
t4	4.64%	-0.25%	-0.067%	-0.134%	-0.327%	-0.595%
t5	15.23%	-0.45%	-0.176%	-0.350%	-0.850%	-1.633%
t6	26.70%	-0.83%	-0.413%	-0.823%	-2.037%	-4.000%
t7	31.57%	-0.25%	-0.427%	-0.851%	-2.104%	-4.135%
t8	29.69%	-0.04%	-0.435%	-0.867%	-2.145%	-4.216%
t9	21.97%	0.38%	-0.436%	-0.869%	-2.150%	-4.227%
t10	15.21%	0.61%	-0.433%	-0.863%	-2.134%	-4.196%
t11	13.68%	-0.17%	-0.425%	-0.846%	-2.094%	-4.114%
t12	13.58%	0.00%	-0.425%	-0.848%	-2.097%	-4.122%
t13	13.55%	0.00%	-0.425%	-0.847%	-2.096%	-4.120%
t14	13.56%	0.00%	-0.425%	-0.848%	-2.097%	-4.121%
t15	13.56%	0.00%	-0.425%	-0.848%	-2.097%	-4.121%

2.6 Conclusion

In this paper, we explored the economic literature related to ageing and its impact on household perception of the quality of the environment. We notice that the potential impact of population ageing on the social preferences for environmental quality seems to be ignored in the economic literature. In an attempt to introduce population ageing into question of the environment, we focused on three avenues: the scale, composition, and cohort effects. Furthermore, based on our exploration of the empirical literature assessing the relationship between age and environmental concerns, age is found to be inversely related to the preservation of the environment. Building on these findings, we construct a general equilibrium model with overlapping generations to simulate the impact demographic shock on the level of emission.

A numerical version of the EOLG model is calibrated using data from the Canadian economy and then used to run a set of simulations based on three different scenarios. To address the impact of population growth on the volume of emission we used a decomposition approach into scale and composition effects. In addition, we run a third simulation to highlight the impact of cohort effect on the level of emission. The three effects generate different results.

i) By the composition effect, an increase in the population improves the quality of the environment by increasing the share of young individuals with respect to total population and hence the domestic demand for the clean good relative to the polluting one. Such derived demand contributed to attenuate the impact of the scale effect on the level of emission during the demographic transition. On the other hand, still through the composition effect, population ageing generates the opposite results.

ii) By the scale effect, an increase in the population growth rate that increases total population in the economy raises the aggregated demand for consumed goods. Domestic production follows the same trend and more pollution is emitted. However, under a scenario of population ageing, empirical results show that scale effect is positively related to the environment. By comparing scale to composition and cohort effect, we find that scale effect dominates the latter two.

iii) The cohort effect associated with a change in consumers' perception towards a cleaner environment is found to be negatively related to the level of emission. Consequently, overall population ageing reduces emissions as scale and cohort effects dominate the composition effect.

Our results join to a certain extent a somewhat controversial finding reported in the United Nations Population Fund report, in which it was argued that birth control can be considered as the most effective way of reducing greenhouse gas emission. According to The United Nations Population Fund report, global population could reach 10.5 billion by 2050, up from 6.8 billion today, unless urgent action is taken to reduce fertility rates. The report says that "The climate-change debate needs to be reframed, putting people at the centre. Unless climate policies take people into account, they will fail to mitigate climate change or to shield vulnerable populations from the potentially disastrous impacts."

As an attempt to investigate the impact of ageing on the environment using overlapping generations model, this paper constitutes a first step to explore the subject of population ageing and the environment. As reliable empirical estimations of households' disutility coefficients with respect to pollution across different age groups seem to be lacking, a potential avenue of research consists of estimating such coefficients. This may play a significant role to understand the link between age and the environment. Furthermore, a possible extension to this paper can be done by modeling an endogenous environmental policy. Such policy will take into consideration the role played by income in tightening the environmental policy, and reduce the level emission. Such effect can be significant enough to offset the impact of scale effect on the environment.

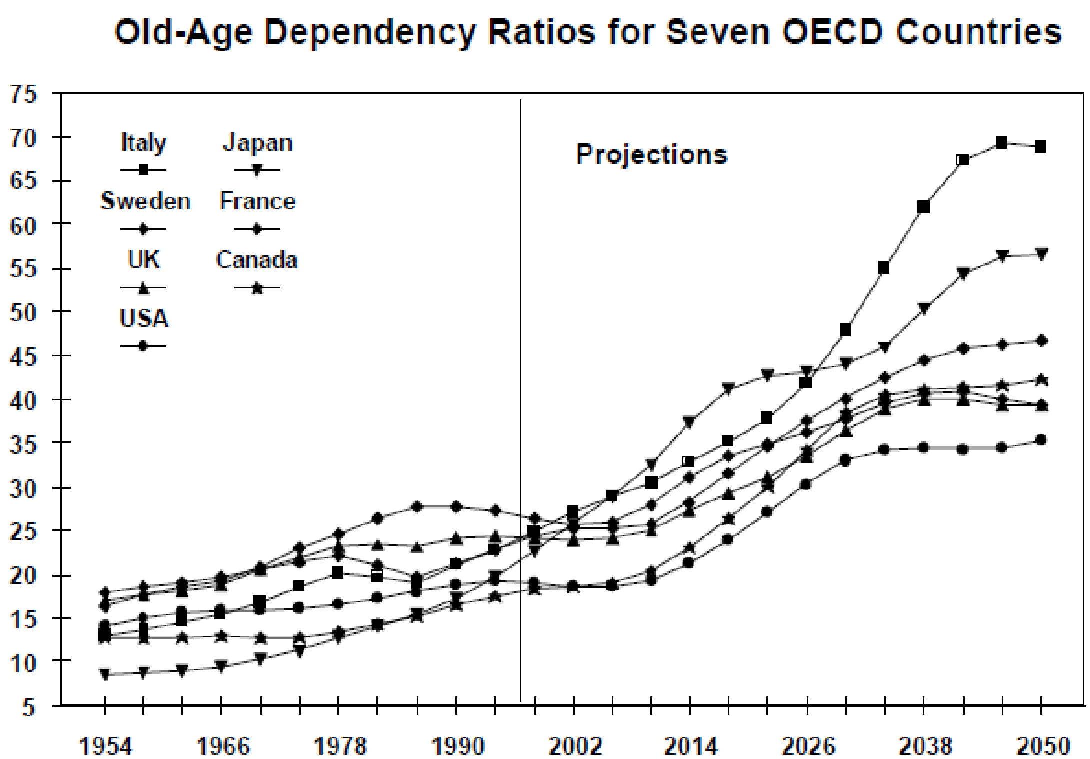
Appendix

Appendix 1: Proportion of Old-Age Population and Dependency Ratio

Proportion of Old-Age Population
(as a Percent of Total Population)

	1996	2050
Canada	12	24
France	15	24
Italy	17	34
Japan	15	30
Sweden	17	22
United Kingdom	15	23
United States	13	21

Source: United Nations



Source: United Nations

Appendix 2: Summary of Studies of the Relationship of Age and Educational Concern [Ref: Buttel (1979, PP. 244)]

Study	Population sample	Dependent Variable	Strength of Association	
			Age	Education
Costantini and Hanf, 1972	Lake Tahoe area community elites	Environmental Concern	0*	.197* (Gamma)
Tognacci, et al., 1972	Boulder, CO	Attainment of pure environment	-.27**	.17** (r)***
		Attitude toward pollution	-.41**	.35** (r)
Buttel and Flinn, 1976 b	Wisconsin	Awareness of environmental problems	-.334**	.204** (r)
		Support for environmental reform	-.295**	.231** (r)
Dillman and Christenson, 1972	Washington	Public value for pollution control	-.21**	.20** (r)
Martinson and Wilkening, 1975	Northwest WT counties	Awareness of environmental problems	-.405**	.334** (r)
Potter et al. 1977	US, 1976	Environmental concern	-.234**	.135** (r)
* Actual coefficient was not reported, but authors indicate the relationship was not statistically significant				
** Indicates that the coefficient was found to be statistically significant at the .05 level or beyond.				
*** indicates that the measure of strength of association was the product-moment correlation coefficient.				

Appendix 3: Explanatory Variables {Perception of the risk of climate change, how well informed individuals consider themselves about major environmental risks, income, sex, material status, education and age}

Perception of climate change risk: derived from a question asking respondents whether they were "very worried, somewhat worried, not very worried or not at all worried" about nine possible problems: A value equal to one is assigned for respondents who reported that they are very worried about "global warming. The authors use also the "urban problems" variable to capture perceptions of short-term environmental risks that may be reduced by higher gas prices, as opposed to longer-term risks associated with global climate change.

Degree of information that people have about environmental risks: "how well respondents were informed about major environmental problems, like holes in the ozone layer, global warming, the disappearance of forests, etc." An indicator variable equal to one is assigned for those respondents who considered themselves very well informed or fairly well informed. Table A provides information about global warming and knowledge about environmental problems.

Table A: Concern About Global Warming and Knowledge About Environmental Problems			
	Very Worried About Global Warming	Very Worried About Urban Problems (traffic, congestion, pollution)	Informed About Major Global Environmental Problems
Belgium	30.1	28	44.8
Denmark	26.9	19.6	65.2
West Germany	38	22.3	57.5
Greece	57.4	48.2	35.5
Italy	42.2	35.8	58
Spain	36.4	30.3	31.6
France	31	28	39.9
Ireland	34.9	30.6	42.1
Northern Ireland	35.1	29.5	42.4
Luxembourg	36.1	19.6	62.8
Netherlands	24.2	17.5	73.2
Portugal	54.6	40.1	28.8
Great Britain	39.2	33.2	54.7
East Germany	31.8	23.6	57.2
Finland	22	14.6	79.1
Sweden	43	14.9	60.9
Austria	38.2	27.8	56.3
Average	36.5	27.3	52.6

Source: Hersch and Viscusi (2005, P25)

In addition Table B summarizes the overall sample means.

Table B: Descriptive Statistics	
Variable	Percent or Mean (standard deviation)
Very worried about global warming	36.52
Very worried about urban problems	27.32
Informed about major environmental problems	52.64
Annual income if not missing ($1000 US 1999)	23.73 (16.86)
Male	47.69
Married	60.08
Years of education	13.07 (4.36)
Percent still studying	11.27
Age	
15 - 24	16.43
25 - 34	20.37
35 - 44	18.94
45 - 54	15.78
55 - 64	13.57
65 or older	14.91

Check emissions if not missing	46.69
Petrol price per liter ($US 1998-2000 average)	0.97 (0.13)
Number of observations	15,061
Source: Hersch and Viscusi (2005, P26)	

Appendix 4: Main Results from Tobit and Probit Estimation of Willingness to Pay for Gas Less Harmful to the Environment.[111]

	(1)	(2)	(3)	(4)
	Percent more willing to pay	Percent more willing to pay	Willing to pay more (0 – 1)	Cents more willing to pay
Very worried about global warming	0.563** (0.083)	0.464** (0.080)	0.040** (0.007)	0.458** (0.080)
Very worried about urban problems	0.232** (0.090)	0.200* (0.087)	0.013 (0.008)	0.216* (0.087)
Informed about environmental problems	0.511** (0.081)	0.474** (0.079)	0.040** (0.007)	0.467** (0.079)
Income x 10,000	0.192** (0.029)	0.068* (0.031)	0.004 (0.003)	0.068* (0.031)
Income missing	-0.122 (0.110)	-0.184 (0.112)	-0.016 (0.009)	-0.186 (0.112)
Male	-0.021 (0.078)	-0.062 (0.074)	-0.009 (0.006)	-0.064 (0.075)
Married	0.052 (0.090)	0.029 (0.086)	0.006 (0.007)	0.034 (0.087)
Education	0.090** (0.010)	0.073** (0.010)	0.006** (0.001)	0.072** (0.010)
Education – still studying	0.520** (0.152)	0.390** (0.145)	0.027* (0.013)	0.400** (0.146)
Age 15 - 24	1.277** (0.173)	1.309** (0.166)	0.098** (0.017)	1.326** (0.167)
Age 25 - 34	1.206** (0.145)	1.254** (0.140)	0.086** (0.014)	1.273** (0.140)
Age 35 - 44	0.912** (0.148)	0.960** (0.142)	0.068** (0.014)	0.982** (0.143)
Age 45 - 54	0.758** (0.154)	0.737** (0.147)	0.055** (0.014)	0.752** (0.148)
Age 55 - 64	0.628** (0.159)	0.603** (0.152)	0.050** (0.014)	0.620** (0.152)
Check emissions	0.152 (0.085)	0.309** (0.085)	0.029** (0.007)	0.310** (0.085)
Check emissions missing	0.315** (0.117)	0.183 (0.113)	0.008 (0.010)	0.209 (0.113)
Petrol price per liter	-2.054** (0.312)			
Belgium		-0.135 (0.231)	-0.006 (0.019)	-0.074 (0.232)
Denmark		2.230** (0.229)	0.149** (0.027)	2.440** (0.230)

[111] Source: Hersch and Viscusi (2005, P27)

East Germany		-0.620** (0.246)	-0.051** (0.017)	-0.613* (0.248)
Finland		0.563** (0.220)	0.044* (0.021)	0.744** (0.221)
France		-0.295 (0.234)	-0.021 (0.018)	-0.240 (0.235)
Great Britain		0.769** (0.219)	0.066** (0.022)	0.950** (0.219)
Greece		3.440** (0.210)	0.240** (0.026)	2.914** (0.212)
Ireland		0.713** (0.227)	0.080** (0.023)	0.685** (0.229)
Italy		1.469** (0.214)	0.121** (0.024)	1.654** (0.215)
Luxembourg		1.271** (0.244)	0.108** (0.027)	1.113** (0.250)
Netherlands		1.372** (0.215)	0.095** (0.023)	1.589** (0.216)
Northern Ireland		0.293 (0.328)	0.039 (0.031)	0.266 (0.331)
Portugal		0.537* (0.233)	0.061** (0.023)	0.519* (0.235)
Spain		0.849** (0.224)	0.064** (0.022)	0.721** (0.227)
Sweden		2.297** (0.215)	0.176** (0.026)	2.469** (0.216)
West Germany		0.064 (0.230)	0.007 (0.020)	0.072 (0.231)
Constant	-3.989** (0.345)	-6.020** (0.258)		-6.070** (0.259)
Observations	15,061	15,061	15,061	15,061

Appendix 5: Representative Consumer Utility Maximization

The problem can be solved using the Lagrange in the following manner:

$$L\left(cons_g(t);\lambda\right)=\frac{1}{1-\gamma}\left\{\frac{\left(cons_{G1}(t)\right)^{1-\gamma}}{(1+\rho)}+\frac{\left(cons_{G2}(t+1)\right)^{1-\gamma}}{(1+\rho)^2}+\frac{\left(cons_{G3}(t+2)\right)^{1-\gamma}}{(1+\rho)^3}\right\}+$$
$$\lambda\left[\begin{array}{l}\dfrac{TAX_{G3}(t+2)}{[1+r(t+2)][1+r(t+1)]}+\dfrac{\{w(t+1)L_{G2}(t+1)+TAX_{G2}(t+1)\}}{[1+r(t+1)]}+\\ \{w(t)L_{G1}(t)+TAX_{G1}(t)\}-\dfrac{PXY_{G3}(t+2)cons_{G3}(t+2)}{[1+r(t+2)][1+r(t+1)]}-\dfrac{PXY_{G2}(t+1)cons_{G2}(t+1)}{[1+r(t+1)]}-\\ PXY_{G1}(t)cons_{G1}(t)\end{array}\right] \quad (1)$$

The first order conditions ("FOCs") are given by:

$$\frac{dL(cons_g,\lambda)}{dcons_g}=0\ \forall g\in\{G1;G2;G3\} \quad (2)$$

By solving equation (2), we can write the following FOCs:

$$\frac{\left(cons_{G1}(t)\right)^{-\gamma}}{(1+\rho)}=\lambda PXY_{G1}(t) \quad (3)$$

$$\frac{\left(cons_{G2}(t+1)\right)^{-\gamma}}{(1+\rho)^2}=\frac{\lambda PXY_{G2}(t+1)}{\left(1+r(t+1)\right)} \quad (4)$$

$$\frac{\left(cons_{G3}(t+2)\right)^{-\gamma}}{(1+\rho)^3}=\frac{\lambda PXY_{G3}(t+2)}{\left(1+r(t+1)\right)\left(1+r(t+2)\right)} \quad (5)$$

By dividing equation (4) using equation (3) and by dividing equation (5) using equation (4), we can formulate the following relationship between consumptions at different stages of age:

(equation 4 / equation 3)

$$\frac{\left(cons_{G2}(t+1)\right)^{-\gamma}}{\left(cons_{G1}(t)\right)^{-\gamma}\left(1+\rho\right)}=\frac{PXY_{G2}(t+1)}{PXY_{G1}(t)\left(1+r(t+1)\right)} \Rightarrow \left(\frac{cons_{G2}(t+1)}{cons_{G1}(t)}\right)^{-\gamma}=\frac{\left(1+\rho\right)PXY_{G2}(t+1)}{\left(1+r(t+1)\right)PXY_{G1}(t)}$$

(equation 5 / equation 4)

$$\frac{\left(cons_{G3}(t+2)\right)^{-\gamma}}{\left(cons_{G2}(t+1)\right)^{-\gamma}\left(1+\rho\right)}=\frac{PXY_{G3}(t+2)}{PXY_{G2}(t+1)\left(1+r(t+2)\right)} \Rightarrow \left(\frac{cons_{G3}(t+2)}{cons_{G2}(t+1)}\right)^{-\gamma}=\frac{PXY_{G3}(t+2)\left(1+\rho\right)}{PXY_{G2}(t+1)\left(1+r(t+2)\right)}$$

As a result we get:

$$\frac{cons_{G2}(t+1)}{cons_{G1}(t)}=\left(\frac{\left(1+r(t+1)\right)PXY_{G1}(t)}{\left(1+\rho\right)PXY_{G2}(t+1)}\right)^{1/\gamma} \tag{6}$$

$$\frac{cons_{G3}(t+2)}{cons_{G2}(t+1)}=\left(\frac{PXY_{G2}(t+1)\left(1+r(t+2)\right)}{PXY_{G3}(t+2)\left(1+\rho\right)}\right)^{1/\gamma} \tag{7}$$

By substituting the inter-temporal constant elasticity of substitution between consumption at two periods of time into equation 6 and 7 we get:

$$cons_{G2}(t+1)=cons_{G1}(t)\left(\frac{\left(1+r(t+1)\right)PXY_{G1}(t)}{\left(1+\rho\right)PXY_{G2}(t+1)}\right)^{\sigma} \tag{8}$$

$$cons_{G3}(t+2)=cons_{G2}(t+1)\left(\frac{PXY_{G2}(t+1)\left(1+r(t+2)\right)}{PXY_{G3}(t+2)\left(1+\rho\right)}\right)^{\sigma} \tag{9}$$

Using equations (8) and (9), we can express the relationship between current and future consumptions at period T as:

$$Cons_{g+1}(T+1)=\left\{\frac{1+r(T+1)}{1+\rho}\frac{PXY_{g}(T)}{PXY_{g+1}(T+1)}\right\}^{\sigma}Cons_{g}(T)\,; \tag{10}$$

By substituting equation (8) into equation (9), we get:

$$cons_{G3}(t+2)=cons_{G1}(t)\left(\frac{\left(1+r(t+1)\right)PXY_{G1}(t)}{\left(1+\rho\right)PXY_{G2}(t+1)}\right)^{\sigma}\left(\frac{PXY_{G2}(t+1)\left(1+r(t+2)\right)}{PXY_{G3}(t+2)\left(1+\rho\right)}\right)^{\sigma}$$

Substituting $cons_{G2}(t+1)$ and $cons_{G3}(t+2)$ into the inter-temporal budget constraint, we get the following expression:

$$\left\{\begin{array}{l} \dfrac{TAX_{G3}(t+2)-PXY_{G3}(t+2)cons_{G3}(t+2)}{[1+r(t+2)][1+r(t+1)]}+ \\ \dfrac{\{w(t+1)L_{G2}(t+1)+TAX_{G2}(t+1)-PXY_{G2}(t+1)cons_{G2}(t+1)\}}{[1+r(t+1)]}+ \\ \{w(t)L_{G1}(t)+TAX_{G1}(t)-PXY_{G1}(t)cons_{G1}(t)\}=0 \end{array}\right\};$$

Via few manipulation we can solve for an analytical solution for $cons_g(t)$, which can be expressed as follow:

$$cons_{G1}(t)=\frac{\left[\begin{array}{l}[1+r(t+2)][1+r(t+1)]\{w(t)L_{G1}(t)+TAX_{G1}(t)\}+\\ [1+r(t+2)]\{w(t+1)L_{G2}(t+1)+TAX_{G2}(t+1)\}+\\ TAX_{G3}(t+2)\end{array}\right]}{[1+r(t+2)][1+r(t+1)]\left\{\begin{array}{l}PXY_{G1}(t)+\left(\dfrac{PXY_{G1}(t)}{(1+\rho)}\right)^{\sigma}\left((1+r(t+1))PXY_{G2}(t+1)\right)^{1-\sigma}+\\ PXY_{G3}(t+2)\left(\dfrac{1}{(1+\rho)}\right)^{2\sigma}\left(\dfrac{PXY_{G1}(t)}{PXY_{G3}(t+2)}\right)^{\sigma}\left((1+r(t+1))(1+r(t+2))\right)^{\sigma-1}\end{array}\right\}}$$

$$cons_{G2}(t+1)=\frac{\left(\dfrac{(1+r(t+1))PXY_{G1}(t)}{(1+\rho)PXY_{G2}(t+1)}\right)^{\sigma}\left[\begin{array}{l}[1+r(t+2)][1+r(t+1)]\{w(t)L_{G1}(t)+TAX_{G1}(t)\}+\\ [1+r(t+2)]\{w(t+1)L_{G2}(t+1)+TAX_{G2}(t+1)\}+\\ TAX_{G3}(t+2)\end{array}\right]}{[1+r(t+2)][1+r(t+1)]\left\{\begin{array}{l}PXY_{G1}(t)+\left(\dfrac{PXY_{G1}(t)}{(1+\rho)}\right)^{\sigma}\left((1+r(t+1))PXY_{G2}(t+1)\right)^{1-\sigma}+\\ PXY_{G3}(t+2)\left(\dfrac{1}{(1+\rho)}\right)^{2\sigma}\left(\dfrac{PXY_{G1}(t)}{PXY_{G3}(t+2)}\right)^{\sigma}\left((1+r(t+1))(1+r(t+2))\right)^{\sigma-1}\end{array}\right\}}$$

$$cons_{G3}(t+2) = \frac{\left(\frac{(1+r(t+1))(1+r(t+2))PXY_{G1}(t)}{PXY_{G3}(t+2)}\right)^{\sigma}\left(\frac{1}{(1+\rho)}\right)^{2\sigma}\begin{bmatrix}[1+r(t+2)][1+r(t+1)]\{w(t)L_{G1}(t)+TAX_{G1}(t)\}+\\ [1+r(t+2)]\{w(t+1)L_{G2}(t+1)+TAX_{G2}(t+1)\}+\\ TAX_{G3}(t+2)\end{bmatrix}}{[1+r(t+2)][1+r(t+1)]\left\{\begin{array}{l}PXY_{G1}(t)+\left(\frac{PXY_{G1}(t)}{(1+\rho)}\right)^{\sigma}\left((1+r(t+1))PXY_{G2}(t+1)\right)^{1-\sigma}+\\ PXY_{G3}(t+2)\left(\frac{1}{(1+\rho)}\right)^{2\sigma}\left(\frac{PXY_{G1}(t)}{PXY_{G3}(t+2)}\right)^{\sigma}\left((1+r(t+1))(1+r(t+2))\right)^{\sigma-1}\end{array}\right\}}$$

Appendix 6: Description of the List of Industries

Appendix 6: List of Industries [112]		
Sectors		**Description**
Primary	X1	Agriculture, hunting, forestry and fishing, Mining and quarrying (energy), Mining and quarrying (non-energy)
Other Manufacturing	X2	Food products, beverages and tobacco, Textiles, textile products, leather and footwear, Wood and products of wood and cork, Manufacturing nec; recycling (include Furniture)
Material Manufacturing	X3	Pulp, paper, paper products, printing and publishing, Coke, refined petroleum products and nuclear fuel, Chemicals excluding pharmaceuticals, Pharmaceuticals, Rubber and plastics products, Other non-metallic mineral products, Iron & steel, Non-ferrous metals, Fabricated metal products, except machinery and equipment
Machinery Manufacturing	X4	Machinery and equipment, Office, accounting and computing machinery, Electrical machinery and apparatus, Radio, television and communication equipment, Medical, precision and optical instruments, Motor vehicles, trailers and semi-trailers, Building & repairing of ships and boats, Aircraft and spacecraft, Railroad equipment and transport equipment
Utility	X5	Production, collection and distribution of electricity, Manufacture of gas; distribution of gaseous fuels through mains, Steam and hot water supply, Collection, purification and distribution of water
Construction	X6	Construction
Transport and Communications	X7	Land transport; transport via pipelines, Water transport, Air transport, Supporting & auxiliary transport activities; activities of travel agencies, Post and telecommunications
Trade, Hotels and Restaurants	X8	Wholesale and retail trade; repairs, Hotels and restaurants
Finance, Insurance and Real Estates	X9	Finance and insurance, Real estate activities
Business Services	X10	Renting of machinery and equipment, Computer and related activities, Research and development, Other Business Activities
Personal Services	X11	Education, Health and social work, Other community, social and personal services, Private households with employed persons & extra-territorial organizations & bodies

[112] Based on Norihiko Yamano and Nadim Ahmad (2006), "THE OECD INPUT-OUTPUT DATABASE: 2006 EDITION" STI WORKING PAPER 2006/8, Statistical Analysis of Science, Technology and Industry

Appendix 7: Total Number of Agent for Each Generation at Each Period of Time

Period	Total Population in G1	Total Population in G2	Total Population in G3	Total Population in the Economy
t1	10	10	10	30
t2	10	10	10	30
t3	10	10	10	30
t4	11	10	10	31
t5	12.65	11	10	33.65
t6	13.2825	12.65	11	36.9325
t7	13.2825	13.2825	12.65	39.215
t8	12.61838	13.2825	13.2825	39.18338
t9	11.35654	12.61838	13.2825	37.25741
t10	11.35654	11.35654	12.61838	35.33145
t11	11.35654	11.35654	11.35654	34.06961
t12	11.35654	11.35654	11.35654	34.06961
t13	11.35654	11.35654	11.35654	34.06961
t14	11.35654	11.35654	11.35654	34.06961
t15	11.35654	11.35654	11.35654	34.06961
t16	11.35654	11.35654	11.35654	34.06961
t17	11.35654	11.35654	11.35654	34.06961
t18	11.35654	11.35654	11.35654	34.06961
t19	11.35654	11.35654	11.35654	34.06961
t20	11.35654	11.35654	11.35654	34.06961
t21	11.35654	11.35654	11.35654	34.06961
t22	11.35654	11.35654	11.35654	34.06961
t23	11.35654	11.35654	11.35654	34.06961
t24	11.35654	11.35654	11.35654	34.06961
t25	11.35654	11.35654	11.35654	34.06961
t26	11.35654	11.35654	11.35654	34.06961
t27	11.35654	11.35654	11.35654	34.06961
t28	11.35654	11.35654	11.35654	34.06961
t29	11.35654	11.35654	11.35654	34.06961
t30	11.35654	11.35654	11.35654	34.06961

Chapter Three

Does Population Ageing in the North Lead to More Pollution in the South?

3.1 Introduction

In a world economy characterized by fast growing (emerging) economies such as China, which managed to sustain a remarkable 9.5% in average GDP growth rate since 1980,[113] the world demand for energy and material has been increasing dramatically. The world total production of good and services increased from $7 trillion in 1950 to $56 trillion in 2004.[114] Such increase in the world economic activities, according to Daly (1977),[115] generates large quantities of waste leading to more pollution and degradation of the environment quality. Most economists argue that trade liberalization constitutes the factor that helps expending the scale of economic activity. However, a heated debate takes place when assessing the nature of the relationship between free trade and environmental quality.

Free trade increases pollution by promoting long distance transport, scaling the size of the economic activities, altering the composition of the world production towards the most traded goods, and encouraging polluting industries to gravitate towards the developing countries with less stringent environmental policy. However, on the other side, for the defendant of trade liberalization, free trade is a source for economic growth, the origin of efficient allocation of resources including the environmental ones, the best alternative to transfer environmental technologies to poor countries to help them improve their environment, and a way to facilitate the convergence to a high level of environmental standard for all countries.[116]

---

[113] For more detail about the world economic growth see: http://www.earth-policy.org/Indicators/Econ/2005.htm

[114] United Nations, World Population Prospects: The 2004 Revision (New York: 2005).

[115] Quoted by Theodore Panayotou, 2003.

[116] For an excellent summary of proponent and opponent views on the impacts of free trade on environment, consult Ekins (2003).

In the economic literature, economists have been exploring several issues related to trade liberalization, quality of the environment, and environmental policy and regulation. Many questions still require extensive research. Is free trade good for the environment? Have dirty industries shifted from the developed to developing countries? How do environmental regulations affect inward and outward foreign direct investment? Are foreign plants less energy intensive? How does globalization affect firms' environmental self-regulation?

For decades, two potential but opposite theories have been in the centre of debates. In one hand, the pollution haven hypothesis[117] predicts that rich countries will benefit environmentally from free trade by exporting their polluting industries to countries with relatively weak environmental regulation, while trade liberalization renders poor countries dirtier.[118] On the other hand, the factor endowment hypothesis predicts that each country will specialise in the production that uses its abundant factor.[119] With free trade, emission of pollution increases in rich countries as a result of more specialisation in the production of the capital intensive goods. However, poor countries will concentrate in the production of the clean goods which is more labour intensive.

In testing the PHH using cross-country data of rich and poor countries and taking care of the endogeneity of trade, Frankel and Rose (2005) find that trade appears to have a beneficial effect on three measures of air pollution.[120] However, the authors did not find support for the PHH. In the same trend, Copland and Taylor (2003) argue that the theoretical support for the pollution haven hypothesis is weak. Their argument is that trade theory suggests that many other factors, in addition to pollution policy, affect trade flows.[121] It is worth highlighting that

[117] Frankel et al. (2005) define the pollution haven hypothesis based on the idea that countries endowed with large supply of environment quality become pollution havens by exporting polluting good to populated countries with less environmental endowments.

[118] Burnnermeier and Levinson (2004) provide a detailed literature review on the pollution haven hypothesis.

[119] According to Copland and Taylor (2004), if environmental policy has little or no effect on the trade pattern, then differences in endowments or technology may have a significant effect in shaping this pattern. FEH predicts that capital abundant countries will specialize in the production of capital-intensive goods without any consideration given to the environmental policy. As a result, rich countries by exporting polluting goods get dirtier, and countries that are relatively abundant in resources that are used in the production of the clean goods will become cleaner with free trade.

[120] In answering the following question: "Is Trade Good or Bad for the Environment? Sorting the Causality", Frankel and Rose (2005) find that trade tends to reduce three measures of air pollution. These three measures are: sulphur dioxide (SO2), nitrogen dioxide (NO2), and total suspended particulate matter (PM).

[121] According to Copland and Taylor (2003, page 4), it is possible for a pollution haven effect to exist. This effect is related to "..*the stringency of pollution regulations*(which) *does affect plant location and trade flows..*"

outcomes from these empirical attempts remain ambiguous. In fact, while Frankel et al (2005), Grossman and Krueger (1993), and Tobey (1990) argue that the FEH dominates the PHH, Lucas et al (1992) and Low and Yeats (1992) believe that free trade leads to more specialization in polluting industries in poor countries.

Mostly ignored in the economic literature is the impact of population ageing. As the proportion of seniors increases over time in most of the OECD countries,[122] the question becomes more relevant. For instance, Hersch and Viscusi (2005) find a steady decline with age in the willingness to pay for environmental preservation. Furthermore, Mohai and Twight (1987) find that age is the strongest and most consistent negative predictor of the perception of the environment.

Our main focus in this paper is to assess the impact of both demographic shock and trade liberalization on the level of emissions in rich and poor countries. Firstly, we survey the economic literature on free trade, economic growth, and the environment from PHH and FEH perspectives. Secondly, we build on Copland and Taylor (1994) a two-country model using a dynamic overlapping generations framework. Third, we conduct two sets of simulations. We first simulate a demographic shock based on an increase in population growth rate in the South and population ageing in the North. In a second stage, we simulate an import tariff reduction in both countries and evaluate the impact of free trade on the level of emission.

We find that an increase in the population growth rate augments the volume of emission in the long term. However, population-ageing generates the opposite results. By decomposing the impact of demographic shock on emission into scale and composition effects, we find that the former dominates the latter, and the level of emission is found to be positively related to the size of the population. These results seem to find more support in the United Nations Population Fund report, which states that population growth is one of the main responsible cause of pollution.

In answering the question whether rich countries with population ageing challenge will be responsible for making young and poor countries dirty with trade liberalization, we find that

[122] See Jones (1998) and Kohl and O'Brien (1998) for OECD countries and Mérette (2002) for Canada.

the level of emission increases in the North and falls in the South. Trade liberalization seems to facilitate a country specialization in the production that uses its abundant factor and is consistent with the FEH. Our results differ from Copland and Taylor (2004) findings under exogenous environmental policy. The reason is that our model takes into consideration not only differences in endowments and environmental policy stringency, but also differences in the demographic structure of each country. Further, by using a dynamic version of Copland and Taylor model with overlapping generations, we find that the demographic shock is high enough to dominate the trade effect and the aggregate level of emission worldwide declines as a result of population ageing in the North. Moreover, our analysis suggests that population ageing in rich countries with stringent environmental policy will not increase pollution in poor young countries due to their lack of stringent environmental policy.

The remainder of the paper is structured as follow: Section 2 explores the link between population growth, trade liberalization, and the environment through the empirical literature related to the PHH versus the FEH. Section 3 describes a dynamic overlapping generations model, calibrated in section 4 and used to run simulations in section 5. Finally, section 6 concludes.

3.2 Literature Review

3.2.1 Population Growth and the Environment

Growing at a rate of 3,500 human lives every 20 minutes, while loosing 27,000 species per year both animal and plant life mainly due to pollution;[123] world population growth seems to be strongly linked to environmental degradation through world consumption of polluting goods. Such derived demand shapes and determines the level of production. As world population increases, more resources are allocated to increase production of consumed goods on the detriment of the environment. The United Nations Population Fund (UNPF) (2001) states that, since 1960, world population has doubled to exceed 6 billion, mostly in poor countries, while since 1970, consumption expenditures have more than doubled mainly in rich countries.

---

[123] Ken Strom, *Population and Habitat in the New Millennium*, National Audubon Society and The Global Stewardship Initiative (Boulder CO 1998).

In an attempt to address the impacts of population dynamics on green gas emission and climate change, the UNPF (2009) reaches the conclusion that population growth, both in terms of speed and magnitude, is responsible of boosting future emissions.[124] According to the World Resources Institute, until 2002, developed countries accounted for an estimated 76% of cumulative emission from fossil-fuel combustion, while developing countries are only responsible for 24% of global emissions. However, when taking into consideration land-use changes, deforestation, and growing population in developing countries, the picture is somewhat different. Based on 2005 estimations, the UNPF approximates developing countries' share in global emission to be at 54%. In fact, even though developed countries are the main responsible of the increment in pollution that has accumulated in the atmosphere since the Industrial revolution, according to the International Energy Agency (IEA), developing countries will account for the most part of the increase in global emission between 2008 and 2030.[125] Population growth in developing countries and population ageing in developed countries seem to play a significant role in shaping these trends associated with total level of the worldwide emissions.

Based on the United Nations Department of Economics projections of the world population size in 2050, under the low population growth scenario, the world total population will reach 8 billion. This may result in a reduction of 1 billion to 2 billion tons of carbon emissions in comparison with a medium growth scenario, which potentially leads to a world population in excess of 9 billion by 2050.[126] Such emission saving is equivalent to what can be achieved by the application of known energy efficiency techniques in all new buildings worldwide, or by erecting 2 million 1-megawatt wind turbines to replace coal-fired power plants.[127] Supported by the United States National Academy of Sciences 1992 report,[128] the UNPF (2009) argues

---

[124] United Nations Population Fund, State of world population (2009), "Facing a changing world: women, population and climate".
[125] Asian Development Bank. 2009. The Economics of Climate Change in Southeast Asia: A Regional Review. Manila: Asian Development Bank.
[126] O'Neill, B.C. (2009), "Climate Change and Population Growth," in Mazur, L. 2009. *A PivotalMoment: Population, Justice and the Environmental Challenge.* Island Press, Washington, D.C.
[127] Pacala, S. and R. Socolow, (2007), "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies", *Science,* Volume 305, pages 968-972.
[128] The United States National Academy of Sciences states (1992, page 811) that: "The reduced population growth associated with higher income growth…offsets in large part the higher greenhouse-gas emissions associated with faster economic growth. The family planning effects indicate that, as of 2020, carbon emissions will be about 15 per cent lower for the lower-, middle- and upper-middle income countries than they would be

that slower population growth in both developing and developed countries can be the solution to reduce worldwide emissions. It is by preventing unintended pregnancies, increasing access to reproductive-health services that help lowering fertility rates, promoting voluntary family planning, and increasing opportunities, education and freedom for women,[129] that the world can reduce the worldwide emissions. According to Wheeler and Hammer (2009), results from birth control to reduce population growth can reduce emissions in the long-run by at least as much as the same investment in nuclear and wind energy.

It is worth mentioning that, despite the controversial debate between rich and poor countries on whether patterns and level of consumption have more impacts on the environment than population growth, it is clear that most of the threat to the environment comes from both the wealthiest and the poorest countries. The former is responsible for more than 50% of the world emission from the consumption of almost 80% of all goods and services. However, the latter is damaging the environment by its straggling to avoid starvation, mainly caused by higher population growth. Furthermore, the remained four billions of people are in a continuous effort to improve their standards of living by increasing their consumption and production. What is more alarming is that, where the industrialized world is responsible of producing 60% of worldwide emission in 2009, the developing world will be producing 60% of it by 2015. According to the UNPF, even if technological advances can alleviate some of the effects of population growth on the environment, it is very likely that unchecked consumption and rapid population growth can overwhelm the technological progress towards the preservation of the environment. We believe that addressing these two arguments (population growth and disparity in consumption between rich versus poor countries) is crucial to the analysis of the impact of demographic changes on the level of emissions.

In rich countries, population ageing can be explained by an increase in life expectancy and declining fertility rate. However, in poor countries the picture is somewhat different. Based on recent projection by the United Nations Population Division in its "World Population

---

without family planning. Strong family planning programmes are in the interests of all countries for greenhouse-gas concerns as well as for broader welfare concerns."

[129] According to UNPF (2009, page 26), "Investing in women and girls in ways that improve their health, well-being and status in their societies leads to reductions in fertility rates and will thus contribute to a reduction in greenhouse-gas emissions in the long run."

Prospects: The 2008 Revision", both life expectancy and fertility rate are expected to increase over the next 40 years. Moreover, it is important to mention that, over time, the gap between the two groups of countries in terms of fertility rate is increasing in favour of poor countries, whereas the gap in life expectancy is shrinking. Figure 1 illustrates the evolution in these gaps over time.[130]

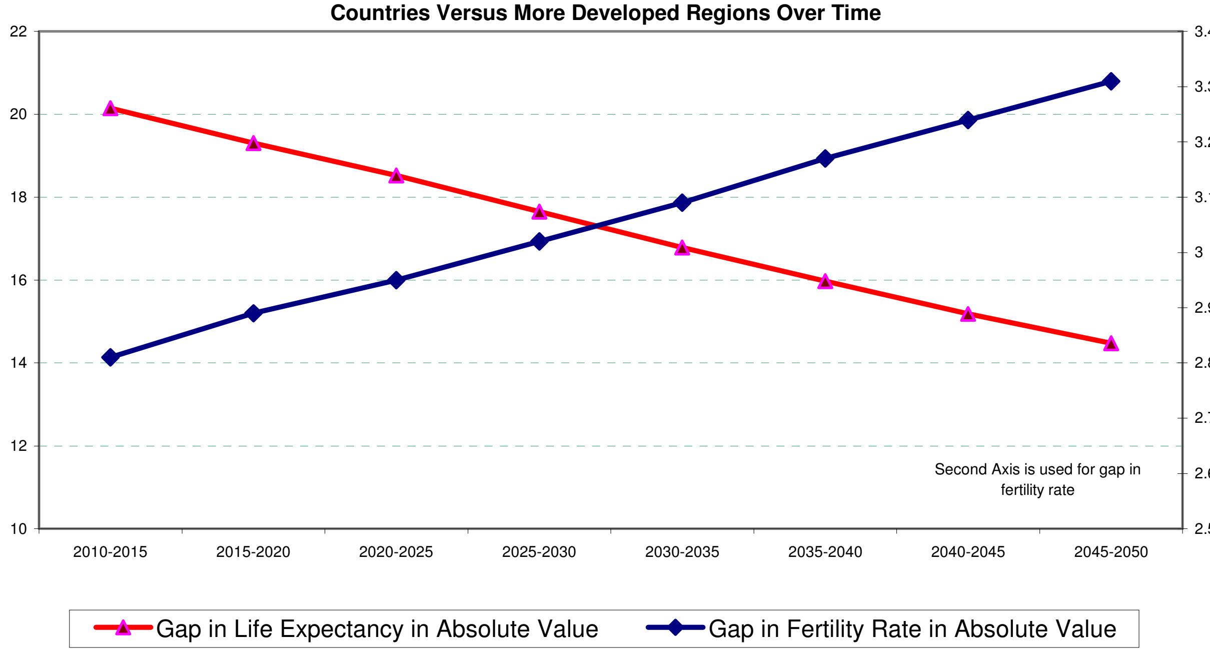


Figure 1: Evolution of Life Expectancy and Fertility Rate Gap Between Least Developed Countries Versus More Developed Regions Over Time

Guest (2010) argues that only little consideration has been given to address the effect of population age structure on the optimal carbon price, optimal abatement and optimal level of emission. In fact, despite the work pioneered by Lenzen et al. (2006), O'Neill and Chen (2002), Wier et al. (2001), Yamasaki et al. (1997), and Schipper (1996) to establish the link between household age composition and energy use and its impact on the level of emission, most of these studies seem to ignore the role played by the demographic change in assessing the optimal carbon price and the optimal level of abatement. Guest (2010) uses a simple Ramsey model to simulate the effect of changes in global population age structure on the optimal level and price of carbon emission. Guest simulates three scenarios based on low, medium, and high demographic projections. Results from simulations suggest that emissions are positively related to the fertility rate. A lower fertility rate implies a lower level of

[130] More details about the evolution of life expectancy and fertility rate over time are provided in Appendix 1. Also for more details on child and elderly dependency ratio see Appendix 2.

emission as a result of lower output. Guest demonstrates the existence of a possible trade-off between climate change and birth control. He states that "population ageing is itself a carbon abatement mechanism".[131]

However, it is worth noting that Guest model presents the following caveats. First, the model is based on a high level of aggregation by considering the world economy as a single economy producing one good that generates carbon emissions. Such aggregation neglects the potential substitution effect at the firms' level when choosing among technologies with different level of intensity of emission. Moreover, at the consumers' level Guest's model ignores the possibility of substitution among goods with different emission levels. Second, the model is based on perfect foresight. Third, Guest omits the demographic and economic disparities between rich versus poor countries, which may lead to a different path of production, consumption and emissions. Finally, even though Guest's model raises a key question which is related to the need to take into consideration the change in age structure when assessing the optimal carbon price and abatement, the model seems to omit the potential change in consumers' preferences through age. By growing older, consumers may change their preferences towards the consumption of more polluting goods. Therefore, to remedy to these caveats, but at the same time building on Guest analogy, we construct a general equilibrium model of ageing, environment and trade.

3.2.2 Relationship Between Trade Liberalization and the Environment: Ambiguity/lack of Empirical Evidence on the PHH/FEH

By exploring the interaction between free trade, capital mobility and environmental quality in developing countries, Copland and Gulati (2003) state that empirical evidences supporting the PHH seem to be lagging. In fact, differences in environmental policy do not seem to be the main determinants of the direction of trade and other factors such as capital abundance, technology differences, infrastructures, and distance to major markets may have a bigger role in shaping trade patterns. According to Copland and Gulati, income growth in developing counties can offset the impact of trade liberalization on the environment by increasing

[131] Guest, R. (2010, page 12), "Global Demographic Change, Carbon Emissions, the Optimal Carbon Price and Carbon Abatement", Global Economy Journal, Volume 10, Issue 2.

demand for cleaner consumption goods.[132] However in developing countries with weak property rights regimes, the opposite scenario is most likely to happen and trade may increase the degradation of the quality of the environment. The authors highlight a potential problem associated with the composition effect, which is the implicit assumption of input mobility. For instance, the mobility of labour from declining industries to expanding ones may not occur in developing countries, due to the inaccessibility of education and training.

In the same trend, according to Copland and Gulati (2003), Antweiler et al. (ACT) (2001), and Grossman and Krueger (1993), pollution intensive industries seem to be heavily concentrated in high-income countries. Such finding is in contradiction with the PHH. In addition, Copland and Gulati raise a question that focuses on the relationship between competitiveness and environmental quality by investigating the linkage between trade and environmental policies in global trade negotiation. They argue that by banning explicitly export subsidies from rich countries and tolerating implicit export subsidies from poor countries with weak environmental policies, the World Trade Organization seems to play an inconsistent and contradictory role vis-à-vis the preservation of the environment.[133] Furthermore, Frankel and Rose (2005) find that there is no evidence that poor or rich countries use trade to exploit a comparative advantage in pollution. Moreover, they did not find any evidence to support the PHH.

Frankel and Rose (2005) find that trade may have beneficial effects on some measures of environmental quality. Jaffe et al. (1995) state that by treating pollution regulation as exogenous and being unable to control for unobserved heterogeneity across countries, the empirical literature seems to reach a consensus that differences between environmental policies have little or no impact on trade and investment flows. By using endogenous pollution policy, Copland and Taylor (2003) managed to show empirical evidences supporting the pollution haven effect. According to Copland and Gulati (2003), the existence of very few evidences supportive of the idea that, environmental policies affect trade and

[132] This affirmation is coherent with the EKC theory. In order to prevent the degradation of the quality of the environment in these countries, "*…improvements in resources management and environmental policy may be an important precondition for broad-based trade policy reform.*" Copland and Gulati, "Trade and Environment in Developing Economies", 2003, page 39.
[133] Such practices may lead to protectionism, which benefit countries with weak environmental policy by allowing them to scarify the environment by exporting polluting products.

investment flows between rich and poor countries can be explained by the fact that the studies that lead to these evidences do not account for the endogeneity of pollution policy and unobserved heterogeneity. When taking these omissions into consideration, recent studies show that plant location within the United States, and trade and investment flows between the US and the rest of the world are affected by environmental policy.[134] As an example, Levinson and Taylor (2006), cited few studies that demonstrate small but significant pollution haven effects, such as Becker and Henderson (2000),[135] List et al (2004),[136]Greenstone (2002),[137] Ederington, Levinson and Minier (2003).[138]

Other researchers have focused on empirically testing the relationship between free trade, growth, and environmental quality, by simply examining the evolution in trends for produced, consumed and traded dirty goods. By examining the variation in the structure of the manufacturing industry in relation to toxic emissions of component industries, Lucas et al (1992), find an inverted U-shape relationship between industrial pollution intensity and income. They conclude that the intensity of pollution is growing faster in poor and closed country. Mani and Wheeler (1997) use international data on industrial production, trade, and environmental regulation for the period 1960-1995 to perform a cross-country analysis testing the PHH. They find that the weight of the pollution intensive good in total manufacturing outputs has fallen in developed countries and risen in the developing ones. Following the same trend, Low and Yeats (1992) explore the composition of exports in term of clean and dirty goods in comparing rich and poor countries using data from 1965 to 1988. They find that the share of dirty goods in provenance from poor countries had increased over

---

[134] Copland and Gulati state that "*This suggests that is premature to conclude that there is no evidence for a pollution haven effect. In fact, there is pollution haven effect within the United States, it is reasonable to conjecture that such an effect will also be operative in the context of trade and investment between rich and poor countries because of greater variation in the stringency of environmental policy. However, a definitive answer to this question will require more research.* " (Ref: Copland and Gulati (2003), pages 23-24)

[135] By using a panel of county-level US data to investigate the effects of federal air pollution regulation on location decisions for new manufacturing plants, Becker and Henderson were able to control for unobserved heterogeneity across location. They find a large, negative and significant relationship between environmental regulation stringency and birth and location of new plants.

[136] List et al (2002) confirmed Becker and Henderson (2000) results.

[137] ibid

[138] By looking at US trade flow, and by dividing their sample into OECD and non-OECD countries, Ederington, Levinson and Minier (2003) find evidences showing that abatement costs do not have a significant effect on US net imports from OECD countries. However, abatement costs have positive and statistically significant effect on net imports from non-OECD countries.

time; whereas, the share of dirty goods in exports from developed countries fell from 20% to 16% during the same period.[139]

Copland and Taylor (2004), identify three conclusions to the recent wave of debates on free trade, growth and the environment. First, income is positively related to the quality of the environment. Second, both trade and investment are influenced by pollution regulation. Third there is little evidence to support the pollution haven hypothesis, whereas there is evidence of a pollution haven *effect*, which is one of the many factors that determine trade patterns.[140] To answer the fundamental question whether free trade is good or bad for the environment, Copland and Taylor suggest that further research on that area needs to be done.

In this paper, we intend to contribute to this literature by developing a two-country overlapping generations model.

3.2.3 The North-South Model and the Need to Include the Demographic Composition Dimension

Copland and Taylor (1994) develop a theoretical static general equilibrium model (the North-South model) of trade and environment to explore the relationship between national income, pollution and international trade. An updated version of the model is used by Copland and Taylor (2004) to emphasize the link between trade, economic growth and the environment. The North-South model is based on the assumption that the world is made of two countries the "North" (rich country) and the "South" (poor country). The two countries are identical except for the factor endowments and the pollution policies. Using the decomposition approach, Copland and Taylor link the scale, composition, and technique magnitudes to tastes, technologies and endowments.[141] The model is used to examine the impact of trade

[139] In West America the percentage of dirty goods exported rises from 9% to 13%; In Eastern Europe the percentage increase from 21% to 28%; In South-East Asia the percentage remains flat at 11%.

[140] Copland and Taylor define the pollution haven *effect* as: "a tightening-up of pollution regulation will, at the margin, have an effect on plant location decisions and trade flows." (Ref: Copland and Taylor, 2004, page 9)

[141] Grossman and Krueger (1991), Copeland and Taylor (1994), Lopez (1994), Liddle (2001), Antweiler et al. (2001), and Copland and Taylor (2004), follow a decomposition approach to explain the impact of free trade on the quality of the environment by measuring three effects: scale, technique, and composition effects. In one hand, trade liberalisation can make the environment cleaner through the technique effect. By increasing the income, free trade tightens the environmental policy, increases the demand for cleaner goods relative to polluting ones, and facilitates the adoption of modern and clean technologies. On the other hand, the scale effect can lead to more pollution due to the expansion of the economic activity if the nature of that activity remains the same in terms of volume of emission. Concerning the third effect, which is the composition effect, according to

liberalization, exogenous increase in production capacity, and international transfers on the volume of pollution. Copland and Taylor find that, if the income elasticity of marginal damage is one,[142] economic growth in autarky has no effect on pollution level.[143] However, it may raise pollution in a free trade environment, as the distribution of growth across countries seems to matter.

Copland and Taylor (2004) use the differences in autarky prices to infer the trade pattern, by considering the PHH and the FEH separately. With respect to the former, they explore two versions; a simple PHH and an endogenous PHH. The simple version is based on the assumption that all countries are identical except for exogenous differences in pollution policy. If North and South were totally identical, the two countries would have the same relative supply curve and there would be no trade. However, if the environmental policy in the South becomes less stringent relative to the North, production of the polluting good increases, while the production of the clean good contracts in the South. As a result, prices of the polluting good become higher in the North and cheaper in the South, which generates trade. Since by assumption each country keeps pollution taxes fixed, pollution rises in the South because of the weak pollution policy and falls in the North. As a conclusion, trade induced by differences in pollution regulations creates a pollution haven in the country with a weaker policy.

The endogenous pollution haven is a version of the North-South model (1994) in which endogenous income-induced policy differences create and respond to trade. For that, Copland and Taylor assume that the two countries are different only in terms of the scale of their endowment vector. They have the same number of consumers, in such a way that any difference in labour is simply due to the difference in efficiency. North is assumed to have highly skilled worker in comparison to South. However, the ratio of capital to effective

---

Antweiler et al. (2001) and Liddle (2001), this effect consists in the alteration due to free trade of the composition of the economic activity. More specifically, the composition effect measures the change in the level of emissions as a result of each country specialization in the sector in which it hold a comparative advantage.

[142] According to Copland and Taylor (2004, page 11), marginal damage is given by the marginal rate of substitution between pollution and income.

[143] Copland and Taylor (2004, page 24) state that, “If the income elasticity of marginal damage is one, the scale and technique effects of growth exactly offset each other in autarky, so growth has no effect on pollution. In contrast, in free trade, with the same preferences and technology, growth in the North raises both Northern and Southern pollution; and growth in the South lowers both Northern and Southern pollution.”

labour is assumed to be the same in both countries. As a result, even if the North is richer than the South, because the two countries have the same capital to effective labour ratio, there is no incentive to trade in the absence of pollution policy.

Copland and Taylor (2004) assume that regulators behave as a price taker in the world good markets when choosing their pollution policy. Since environmental policy is considered a normal good, rich countries are expected to choose higher pollution tax for any given goods price. The differences generated between environmental policies between rich and poor countries will create an incentive to trade. The North will export the clean goods and import the dirty goods from the South. As a consequence of that, pollution falls in the North as a result of both substitution and income effects of trade liberalization, which induce the policy maker to opt for less pollution. However in the South, pollution continues to rise as long as the income effect is not strong enough to offset the scale and composition effects. At the world level, if the income effect is not strong enough, pollution will rise as a consequence of shifting in the polluting industry to countries with weaker pollution regulation.

To explore the FEH, Copland and Taylor (2004) assume that pollution taxes are identical and exogenous across countries, but relative factors endowments differ. Also, they assume that the North is relatively capital abundant compared to the South, in such a way that the capital to effective labour ratio is higher in the North. Since the polluting good is intensive in capital, and since emission intensity is held constant, the North will be in a position to produce more of this commodity. In autarky, the price of the polluting good is lower in the North compared to the South. With trade, the North exports the capital intensive good in which it detains a comparative advantage and pollution rises in the North. On the other hand, pollution falls in the South as the polluting industry contracts in this country.

It is worth mentioning that Copland and Taylor ignore the demographic structure of both countries in addition to the possibility that preferences may be age sensitive. In fact, the demographic composition can play a significant role in assessing the nature of interaction between rich and poor countries and its impact on the level of emission. Both theoretical and empirical findings in the literature support the idea that young households are more sensitive and seemed to be more concerned about the quality of the environment than relatively older people. As micro based surveys reveal that demographic structure variation could have a significant impact on social preferences about the environment. Magnani and Tubb (2007) claim that population ageing increases emission of pollution, as a tighter government budget constraint would divert expenditure away from the environment protection. Moreover, Magnani and Tubb argue that empirical studies in the finance literature demonstrate that age is an important determinant of the individual rate of time preference. By growing older, seniors prefer a shorter time span of investment returns. Seniors are more willing to invest in less risky assets with short term returns, rather than investing in "risky" environmentally friendly technologies. Finally, higher proportion of seniors my create a political power that supports short term growth rather than having a long run policy oriented to preserve the environment.

Hersch and Viscusi (2005) use a 1999 Eurobarometer survey of European citizens by interviewing 16000 respondents from 15 countries to find a steady decline with age in the willingness to pay to preserve the environment. Empirical results show that, seniors are less likely to support a high price of gas if such measure is designed to protect the environment.

Building on Copland and Taylor North-South Model, we develop a dynamic, overlapping generations framework reflecting the demographic composition of each economy. As rich countries face a population ageing, while the proportion of young is increasing in poor countries, this paper provides an assessment of the impact of trade liberalisation and demographic structure on the environment.

3.3 Dynamic Model of Trade North-South (OLG-NS)

For the purpose of analysis, we construct a dynamic two-country overlapping generations model that is capable of evaluating the comparative effect of change in demographic structure and trade policy on aggregate demand, production, and level of emission. First, we discuss the assumptions. Second, we formulate the main equations characterizing the OLG-NS model.

3.3.1 Assumptions

In addition to the CT (1994) assumptions with respect to the technology of production and the emission of pollution, the OLG-NS model is based on two major assumptions. The first assumption describes the demographic structure and characteristics of the two countries and their endowments in term of labour, capital and environment. The second assumption is related to international trade, which is assumed to be based on the Armington hypothesis. A brief description of the OLG-NS model assumptions is provided below.

First, the OLG-NS Model is composed by two open economies; the North (rich) and the South (poor), made respectively of N^N and N^S consumers. Each country has two industries "X1" and "X2", producing respectively two goods x_1^i and x_2^i $\forall i \in \{North, South\}$ using two factors of production labour (L) and capital (K). The industry X1 is capital intensive. On the other hand, the industry X2 is labour intensive. Both industries are characterized with constant returns to scale technology. The labour and capital markets are competitive, so that the wage and the rate of return on capital are determined by the interaction of supply and demand. In terms of environmental policy, the North is assumed to have a more stringent policy than the South.

Second, by adopting an Armington Hypothesis, the traded goods between the North and the South are assumed to be not perfectly substitutable, in such a way that each country can export and import the same type of product, since consumers have different preferences between domestic and imported products. In total, the OLG-NS Model is characterized with four traded goods. Both countries export their excess of production and import their shortage of consumption in such a way that trade balance will be counterbalanced by capital transfer from the net exporter to the net importer due to the perfect mobility of capital.

Lets, $P_s^i*; P_s^i$ denote respectively the world and the domestic prices for the good x_s^i $\forall s \in \{1,2\}$, $\forall i \in \{North, South\}$. Imports are taxed at a rate "$\tau^m(i,ii); \forall i, ii \in \{North, South\}$". The tariff return on imports is simply redistributed equally to the consumers. For the domestically produced good, the consumers are assumed to be paying the producers' price adjusted with respect to abatement and tax on pollution.[144] However, for the imported good, the local price is inflated by the imports tariff.

Third, we assume that the emission of pollution is generated by the industry X1. To compensate for the negative externality caused to the economy, the emission is taxed at a price $\tau^i \forall i \in \{North, South\}$. This tax is calibrated and used exogenously in the model. In both countries, we assume that industry X1 uses a part of its production to reduce its emission through a technology of abatement given by coefficient of emission $e^i(\theta)$ It is a function of the intensity of abatement $\theta^i = x_a^i / x_1^i$, where x_a^i is the proportion of x_1^i used for the abatement, as defined by ACT (2001).[145]

Fourth, we define the emission of pollution using the following expression: $z^i = e^i(\theta)x_1^i$, where z^i represents the volume of emission generated by production of x_1^i. It is positively related to both the coefficient of emission $e^i(\theta)$ and the volume of production of x_1^i.

Fifth, we assume that each consumer lives three periods of times. Therefore, in each period, households can be classified into three generations $\{G1; G2; G3\}$. The generation "G1" is the generation of young consumers. They enter the economy without any wealth. They participate in the labour market and allocate their wage between consumption and saving. The second generation "G2" represents the adult consumers. They start their second period of life with positive amount of wealth, which is equal to their savings in the pervious period. They participate in the labour market and save a part of their income. Finally the generation "G3" represents seniors or retired consumers. Household agents are assumed to be rational, utility maximizers, who spend their entire wealth by the end of their third period of life before exiting the economy.

Moreover, the relationship between age and environmental perception is assumed to be negative. By growing older, consumers demand less "high environmental quality" and become less interested in protecting the environment. Their preferences towards the

[144] With respect to clean goods, consumers pay the world price for the domestically produced good.
[145] ACT (2001) assume a constant abatement technology.

environment are reflected in their disposable income allocation between clean versus polluting good. The share allocated to consume polluting good is assumed to be increasing with age.[146]

Finally, we assume a CES utility function to describe representative consumer preferences. Each consumer allocates his disposable income between two composite goods based on the origin and the destinations of each commodity.

3.3.2 The OLG-NS Model

This section provides a detailed description of the main equations characterising the OLG-NS Model. We first solve the consumer problem. Second, we list the main equations describing the producer problem. Third we express the current account, saving, investment, and trade equations. Finally, we provide equations clearing all markets.

3.3.2.1 The Consumer Problem

By using the Armington assumption, we allow for the possibility of intra-sectoral trading across both countries. Consumers are consuming two sets of products clean and polluting goods, which are made of domestically produced and imported goods. In comparison with the EOLG model, one additional step is added to solve the consumer problem. This stage consists in identifying the origin of each good consumed by a representative consumer from a specific generation over time. Therefore, consumer problem is solved through five stages. A detailed description of the first three stages is provided in Appendix3. In this section we focus on the decomposition of the composite consumption into clean versus polluting goods and by origin of production and destination of consumption.

Decomposition of the Composite Consumption into x_1 ***and*** x_2 [147]

[146] This assumption is mainly based on the detailed discussion provided in the second chapter investigating the link between age and consumers willingness to preserve the environment. Furthermore, since the main purpose of this paper is to assess the impact of population ageing in the North on the level of emission in the South and the role played by international trade in such context, we simply used our findings of the second chapter as a starting point to construct a two-country model of population ageing, trade, and environment.

To determine the optimal level of individual consumption of x_1 and x_2 by a representative consumer from each generation at any period of time,[148] such consumer needs to minimize his consumption spending using the following objective function:

$$\begin{aligned}
&Min\left\{PXY_g^i cons_g^i = PXYS^i(x_1)consj_g^i(x_1) + PXYS^i(x_2)consj_g^i(x_2)\right\}\\
&Subject - to\\
&cons_g^i = CES\left(consj_g^i(x_1), consj_g^i(x_2), \sigma c, \alpha c_g^i\right)
\end{aligned} \qquad (1)$$

$cons_g^i(t)$ and $PXY_g^i(t)$ represent respectively the volume and the price of a composite good consumed by a representative consumer from generation g in country i over time. $PXYS^i(x_s), \forall s \in \{1,2\}$ is the price of a composite good $consj_g^i(x_s)$, which is made of domestically produced and imported goods x_s. σc denotes the elasticity of substitution between goods. αc_g^i is the share parameter of the CES utility function of a representative consumer from generation g in country *i*.

Using Lagrangian, we can express the first-order condition describing the consumption of goods x_1 and x_2 as:

$$consj_g^i(x_1) = Cons_g^i \left\{\alpha c_g^i \frac{PXY_g^i}{PXYS^i(x_1)}\right\}^{\sigma c} \qquad (2)$$

$$consj_g^i(x_2) = Cons_g^i \left\{\left(1 - \alpha c_g^i\right)\frac{PXY_g^i}{PXYS^i(x_2)}\right\}^{\sigma c} \qquad (3)$$

In addition to the first order conditions, equations (1), (2) and (3) can be used to formulate the price PXY_g^i as a function of the composite prices $PXYS_g^i(x_s), \forall s \in \{1,2\}$. It can be expressed as:

---

[147] At this stage, for simplicity we will drop the time dimension, which is added to the final solution of the consumer problem.
[148] It is important to notice that at this stage of the consumer maximization problem, the optimal level of consumed good $x_j; \forall j \in \{1,2\}$ is a composite made of domestically produced and imported goods.

$$PXY_g^i = \left[\left(\alpha c_g^i\right)^{\sigma c} \left(PXYS^i(x_1)\right)^{(1-\sigma c)} + \left(1-\alpha c_g^i\right)^{\sigma c} \left(PXYS^i(x_2)\right)^{1-\sigma c} \right]^{1/(1-\sigma c)} \tag{4}$$

Decomposition of the Consumption by Origin of Production and Destination of Consumption

Since by assumption, each country can import and export the same good under the Armington hypothesis, once we solved for the optimal level of consumption $consj_g^i(x_s)$, which is considered as a composite of domestically produced and imported good x_s, we can solve for the optimal level of goods consumed by a representative consumer from each generation in each country. Lets $c(i,ii,x_s,g)$ denotes the volume of good x_s produced in country "*i*", consumed by a representative consumer from generation g located in the country "*ii*". At this stage, the consumer problem consists in decomposing $consj_g^i(x_s)$ into its imported and domestically produced components. The problem can be stated in a similar way as in stage 4.

$$\begin{bmatrix} \forall g \in \{G1,G2,G3\}; \forall i,ii \in \{North,South\}; \forall s \in \{1,2\}; \\ Min\left\{PXYS^i(x_s)consj_g^i(x_s) = Pc(i,i,x_s)c(i,i,x_s,g) + Pc(ii,i,x_s)c(ii,i,x_s,g)\right\}; \\ S.T. \\ consj_g^i(x_s) = CES\left(c(i,i,x_s,g), c(ii,i,x_s,g), \sigma c, \alpha m^i(x_s)\right) \end{bmatrix} \tag{5}$$

Where $Pc(ii,i,x_s)$ represents the consumption price for the good x_s produced in country "*ii*" and consumed in country "*i*". $c_j(i,ii,x_s,g); \forall s \in \{1;2\}; \forall i,ii \in \{North;South\};$ $\forall g \in \{G1;G2;G3\}$ represents the amount of good x_s originated in "*i*" and consumed by a representative consumer from generation g in "*ii*". $\alpha m^i(x_s)$ is the share parameter of the good x_s domestically produced and consumed in country *i* in the CES utility function for a representative consumer from generation g, which can expressed as follow:

$$consj_g^i(x_s) = \left\{ \alpha m^i(x_s)\left(c(i,i,x_s,g)\right)^{\frac{(\sigma c-1)}{\sigma c}} + \left(1-\alpha m^i(x_s)\right)\left(c(ii,i,x_s,g)\right)^{\frac{(\sigma c-1)}{\sigma c}} \right\}^{\frac{\sigma c}{(\sigma c-1)}} \tag{6}$$

Following the same procedures to derive equations (2) and (3), we can express the optimal levels of final consumed goods as:

<u>For the domestically produced component of the consumed good</u>

$$c(i,i,x_s,g) = Consj_g^i(x_s)\left(\alpha m^i(x_s)\frac{PXYS^i(x_s)}{pc(i,i,x_s)}\right)^{\sigma c} \tag{7}$$

<u>For the imported component of the consumed good</u>

$$c(ii,i,x_s,g) = Consj_g^i(x_s)\left(\left(1-\alpha m^i(x_s)\right)\frac{PXYS^i(x_s)}{pc(ii,i,x_s)}\right)^{\sigma c} \tag{8}$$

<u>The Consumers' Prices</u>

Concerning the prices at the consumers' level, for the domestically produced goods, the consumption price of the clean good is assumed to be equal to the world price. It can be expresses as:[149]

$$Pc(i,ii,x_2) = P_2^* \tag{9}$$

However for the imported good, the consumption price is given by:

$$Pc(ii,i,x_2) = P_2^*\left(1+\tau^m(ii,i)\right) \tag{10}$$

3.3.2.2 The Producer Problem

From the producers' perspective, the OLG-NS model uses the same equations as the ACT (2001) model to solve for the producers problem. In fact, in each country, two industries produce a clean and a polluting good using a Cobb-Douglas technology. The clean good is labour intensive, while the polluting good is capital intensive. The markets for capital and labour are kept competitive, so that wage and rate of return on capital are freely determined by the interaction of demand and supply. In comparison with ACT (2001) framework, only

[149] Concerning the polluting good, consumers pay the producer price adjusted with respect to abatement and tax on pollution.

the country dimension is added to all equations and parameters describing the Producers' problem in each country.[150] (see Table 1)

Table 1: Main Equations Describing the Producer Problem

Expressions $\forall i \in \{North, South\}$	Producer Problem at Any Period of Time *t*	
	Good x_1^i	**Good** x_2^i
Production Function	$x_s^i(t) = A_s^i\left(K_s^i(t)\right)^{\alpha_s^i}\left(L_s^i(t)\right)^{(1-\alpha_s^i)}; \forall s \in \{1;2\}$	
Optimal Level of Labour Demand	$L_s^i(t) = \dfrac{(1-\alpha_s^i)P_s^i(t)x_s^i(t)}{w^i(t)}; \forall s \in \{1;2\}$	
Optimal Level of Capital Demand	$K_s^i(t) = \dfrac{\alpha_s^i P_s^i(t)x_s^i(t)}{r^i(t)}; \forall s \in \{1,2\}$	
Condition of Null Profit	$P_s^i(t)A_s^i\left(K_s^i(t)\right)^{\alpha_s^i}\left(L_s^i(t)\right)^{1-\alpha_s^i} = w^i(t)K_s^i(t) + r^i(t)L_s^i(t); \forall s \in \{1,2\}$	
Producers Domestic Prices for x_1	$P_1^i(t) = \left(1-\theta^i(t)\right)P_1^*(t) - \tau^i(t)e^i\left(t, \theta^i(t)\right)$	
Producers Domestic Prices for x_2	$P_2^i(t) = P_2^*(t)$	

3.3.2.3 Saving Decisions and Current Account

In a context of open economy world saving equals to world investment, and it can be expressed as:

(11)

$$\sum_i \left\{ \sum_g \left[N_{g+1}^i(t+1)wealth_{g+1}^i(t+1) \right] - \sum_g \left[N_{g+1}^i(t)wealth_{g+1}^i(t) \right] \right\} = \sum_i \left\{ Pinv^i(t)Ks^i(t+1) - Pinv^i(t-1)Ks^i(t) \right\}$$

N_g^i denotes the number of agent in generation g in country *i*. $wealth_g^i$ represents the amount of wealth accumulated by a representative consumer from generation *g* in country *i*. Ks^i denotes the stock of capital in the economy. $Pinv^i$ is the price of the investment *("inv")* in country *i*, which is a composite that uses both goods x_1 and x_2.

[150] For more details about the producers' problem see Appendix 4.

The first part of equation (11) constitutes the world assets accumulation in period *t* (world saving). The second part of the equation represents the world physical capital (world investment).

In term of current account ("CA") for each country, which is given by the accumulation of net foreign assets, using equation (11), we can formulate CA^i as:

$$CA^i = \left\{ \sum_g^{G3} N^i_{g+1}(t+1) wealth^i_{g+1}(t+1) - Pinv^i(t) Ks^i(t+1) \right\} - \left\{ \sum_g^{G3} N^i_{g+1}(t) wealth^i_{g+1}(t) - Pinv^i(t-1) Ks^i(t) \right\}$$

Via few manipulations we can express CA^i as the difference between domestic saving and domestic investment.

$$CA^i = \left\{ \sum_g^{G3} N^i_{g+1}(t+1) wealth^i_{g+1}(t+1) - \sum N^i_{g+1}(t) wealth^i_{g+1}(t) \right\} - \left\{ Pinv^i(t) Ks^i(t+1) - Pinv^i(t-1) Ks^i(t) \right\} \tag{12}$$

Moreover, it is important to notice that domestic investment represents the increment in the value of the capital stock. It can be expressed as:

$$Ks^i(t+1) = inv^i(t) + (1-\psi^i) Ks^i(t) \tag{13}$$

Inv(t) denotes the gross investment at time t. ψ^i is rate of depreciation of capital.

3.3.2.4 Investment

Gross investment is a composite of x_1 and x_2. Let $invs^i(x_s)$ denotes investment demand for x_s. The demand for x_s can be derived by minimizing the investment spending subject to the investment technology.

$$\begin{aligned} & Min_{invs^i(x_s)} Pinv^i(t) inv^i(t) = \sum_s PXYS^i(x_s,t) invs^i(x_s,t) \\ & S.T \\ & inv^i(t) = CES\left(invs^i(x_1,t), invs^i(x_2,t), \sigma^i_{inv}, \alpha^i_{inv} \right) \end{aligned} \tag{14}$$

The first-order conditions can be expressed as follow:

$$invs^i(x_1,t) = inv^i(t)\left\{\alpha^i_{inv}\frac{Pinv^i(t)}{PXYS^i(x_1,t)}\right\}^{\sigma^i_{inv}} \tag{15}$$

$$invs^i(x_2,t) = inv^i(t)\left\{(1-\alpha^i_{inv})\frac{Pinv^i(t)}{PXYS^i(x_2,t)}\right\}^{\sigma^i_{inv}} \tag{16}$$

By substituting equations (15) and (16) into equation (14), we can formulate the optimal price for the composite as:

$$Pinv(t) = \left[\left(\alpha^i_{inv}\right)^{\sigma^i_{inv}}\left(PXYS^i(x_1,t)\right)^{(1-\sigma^i_{inv})} + (1-\alpha^i_{inv})^{\sigma^i_{inv}}\left(PXYS^i(x_2,t)\right)^{1-\sigma^i_{inv}}\right]^{1/(1-\sigma^i_{inv})} \tag{17}$$

3.3.2.5 Trade Balance

Total domestic demand for good x_s in country i is given by:

$$DD^i(x_s,t) = \left[\sum_g N^i_g(t)consj^i_g(x_s,t)\right] + Invs^i(x_s,t) \tag{18}$$

Since equation (18) is a function of a composite good that is made of domestically produced and imported goods, therefore we need to decompose this aggregate demand in term of origin of the production and destination of the final consumption. We assume that the choice of origin for investment is the same as for consumption. Hence, we have:

$$E(i,i,x_s,t) = \left\{\left(\sum_g N^i_g(t)consj^i(x_s,t)\right) + invs^i(x_s,t)\right\}\left(\alpha m^i(x_s)\frac{PXYS^i(x_s)}{Pc(i,i,x_s,t)}\right)^{\sigma c} \tag{19}$$

$$E(ii,i,x_s,t) = \left\{\left(\sum_g N^i_g(t)consj^i(x_s,t)\right) + invs^i(x_s,t)\right\}\left(\left(1-\alpha m^i(x_s)\right)\frac{PXYS^i(x_s)}{Pc(ii,i,x_s,t)}\right)^{\sigma c} ;\forall i \neq ii \tag{20}$$

$E(ii,i,x_s,t)$ is the domestic aggregate consumption of good x_s. Furthermore, we can formulate the price of the composite $consj^i(x_s,t)$ as follows:

$$PXYS^{i}(x_s,t)=\left[\left(\alpha m^{i}(x_s)\right)^{\sigma c}\left(Pc(i,i,x_s,t)\right)^{(1-\sigma c)}+\left(1-\alpha m^{i}(x_s)\right)^{\sigma c}\left(Pc(ii,i,x_s,t)\right)^{1-\sigma c}\right]^{1/(1-\sigma c)} \tag{21}$$

3.3.2.6 Market Clearing

The OLG-NS model involves the following markets that need to be cleared:

- Market for Consumed Goods: The equilibrium condition establishes the relationship between the domestic production of good x_s in a specific country and the world demand for such commodity. It can be expressed as:

$$x_2^{i}(t)=\sum_{ii}E(ii,i,x_2,t) \tag{22}$$

$$x_1^{i}(t)(1-\theta^{i})=\sum_{ii}E(ii,i,x_1,t)$$

- Labour Market: In equilibrium, total supply of labour in each country is set to be equal to total demand for labour by domestic producers. The equilibrium condition can be expressed as:

$$\sum_{g}N_g^{i}(t)Ls_g^{i}(t)=L_1^{i}(t)+L_2^{i}(t) \tag{23}$$

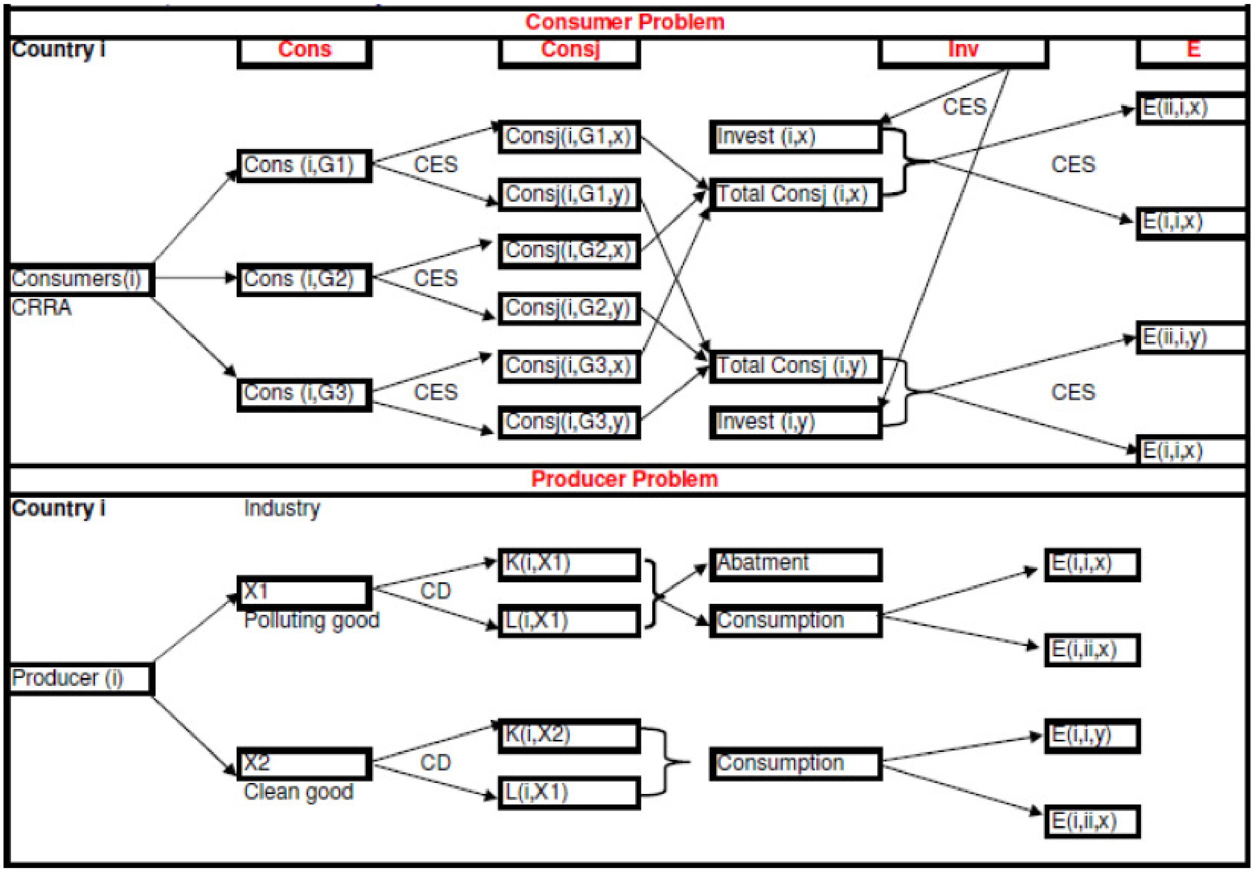
Ls_g^{i} denotes the effective labour supply by a representative consumer from generation g in country *i*.

- Capital Market: Physical capital equilibrium is given by the following equation:

$$\sum_{i}Ks^{i}(t)=\sum_{i}\left[K_1^{i}(t)+K_2^{i}(t)\right] \tag{24}$$

Finally the table below provides a detailed description of the economy under the OLG-NS Model.

Table 2: Description of the Economy in the OLG-NS Model



3.4 Data and Model Parameterization

This section is dedicated to empirically describe the data and the calibrated parameters of the OLG-NS model. First, we provide a description of the data used for simulation. Second, we report the calibrated parameters.

3.4.1 Social Accounting Matrix ("SAM")

Simulation of the OLG-NS model is based on data collected from two countries: a rich country with a population ageing problem and a poor country with young population. In addition, environmental policy is assumed to be relatively tighter in rich country. Selection of the two countries is based on the following criteria: capital endowment given by the capital to labour ratio, the stringency of the environmental policy given by the intensity of abatement and the tax on pollution, the trade policy given by the import tariffs, and the volume of emission generated in the economy in 2000.

The selected criteria are used to create two countries profiles. In one hand, the "North" is considered as a rich country, highly endowed in capital. The North is characterised with highly productive labour, stringent environmental policy, and less protectionist trade policy. Moreover, the North is facing population ageing. On the other hand, The "South" is a poor and young country with low capital to labour ratio, less productive labour force, less tighter environmental policy, and high level of protectionism. For illustration purposes, we identify two countries that satisfy our criteria of selection: the USA to represent the North and Brazil to represent the South. Table 3 reports the base year 2000 data describing the two countries.

Table 3: Country Characteristics Based on Year 2000 Data

	Brazil	USA
Real Gross Domestic Income	8396	39377
K/L($1000/worker)	3.17	24.35
Tax on Pollution	1.12%	11.18%
Intensity of Abatement	1%	10%
Coefficient of emission	0.0059	0.0058
Level of emission SO2 (thousand metric tons)	2852.7	17866
Import Tariff	31.40%	3.50%

For each country, we construct a social accounting matrix ("SAM") based on year 2000 data collected from several sources. With respect to the data on the volume of sulfur dioxide ("SO2") emission, we use The Emission Database for Global Atmospheric Research (EDGAR) 3.2,[151] which provides measurement of SO2 between 1990 and 2000. In addition, we use the World Trade Organization Report 2005 to calculate the amount of trade between the North and the South, and we used the average import tariffs to represent the level of protectionism in each country.[152] Furthermore, we assume that both primary and secondary sectors constitute the polluting industry and the tertiary sector represents the clean

[151] Data on sulfur dioxide emissions were calculated based on data from the World Resources Institute, at the following address: http://earthtrends.wri.org/text/climate-atmosphere/variable-812.htm
[152] For the tariff on imports, we use average tariff provided by the World Trade Organization Report on Tariff Profiles available at:
http://www.wto.org/english/tratop_e/tariffs_e/tariff_profiles_2006_e/tariff_profiles_2006_e.pdf

industry.[153] Finally, we use data available at the United Nation Statistics Division and the Bureau of Economic Analysis to collect data about the US economy and data available through the "Instituto Brasileiro de Geografia e Estatistica" for the Brazilian economy. [154] [155]

3.4.2 Calibration

We calibrate the OLG-NS model to a 2000 base case projected forward over 30 periods. After balancing the SAM in both countries, we numerically calculate all parameters characterizing the consumers and the producers' behaviour and describing both trade and environmental policy. Based on these estimated parameters, we are able to reproduce the initial equilibrium reported in the SAM.

More specifically, the calibration of the OLG-NS Model parameters consists of findings values for the share and shift parameters characterizing the two production functions, the share parameter of the CES utility function, the tax on pollution at the benchmark situation, the coefficient of emission, and the intensity of abatement. Table 4 gives a detailed description and estimation of the calibrated parameters associated with the production side and the environmental policy, while Table 5 reports the estimated parameters characterizing the consumers' problem.

---

[153] Primary sector includes agriculture, forestry and fishing; Secondary sector represents manufacture industry; and tertiary sector is made of the service industry. To simplify the SAM, and follow ACT assumptions, we ignore the consumption of intermediary goods as factors, which are needed to produce the final goods. We only used capital and labour as the two production factors to produce x_1 and x_2.

[154] The USA data is available at the United Nations Statistics Division at the following address: http://unstats.un.org/unsd/snaama/Introduction.asp, and the Bureau of Economic Analysis "National Economic Accounts", "Table 301. Value Added and Its Components" and "Table 501. Final Consumption Expenditure of Households by Purpose, Expanded Detail", available at the following address: http://www.bea.gov/national/sna.htm

[155] Data is available through the "Instituto Brasileiro de Geografia e Estatística" via the following address: http://www.ibge.gov.br/home/estatistica/economia/contasnacionais/referencia2000/2004_2005/defaulttab.shtm

Table 4: Calibrated Parameters Characterizing the Producer Problem and the Pollution Emission

Calibrated Parameters		Expression	Calibrated Value (North)	Calibrated Value (South)
Industry X1	Shift Parameter	$A_1 = x_1 / (K_1^{\alpha} L_1^{1-\alpha})$	2.173	2.020
	Share Parameter	$\alpha = RK_1 / (P_1 x_1)$	0.393	0.512
Industry X2	Shift Parameter	$A_2 = x_2 / (K_2^{\beta} L_2^{1-\beta})$	1.922	1.083
	Share Parameter	$\beta = RK_2^{\beta} / (P_2 x_2)$	0.360	0.016
Tax on pollution at the Benchmark Situation		$\tau^e = \dfrac{P_1 \theta^{1-\delta}}{\Lambda \delta}$	0.112	0.011
Intensity of Abatement		$\theta^*(t) = \left(\dfrac{\tau^e(t) \Lambda \delta}{P_1(t)} \right)^{1/1-\delta}$	0.1	0.01

Table 5: Consumers' Calibrated Parameters Characterizing the OLG-NS Model

Calibrated Parameters			Calibrated Value (North)	Calibrated Value (South)
G1	Share Parameter	Polluting Good	0.259	0.259
		Clean Good	0.741	0.741
	Productivity		1.221	1.212
G2	Share Parameter	Polluting Good	0.327	0.327
		Clean Good	0.673	0.673
	Productivity		1.386	1.348
G3	Share Parameter	Polluting Good	0.448	0.448
		Clean Good	0.552	0.552
Share Parameter by Origin Polluting Good		North	0.9	0.287
		South	0.1	0.713
Share Parameter by Origin Clean Good		North	0.986	0.238
		South	0.014	0.762
Inter-Temporal Elasticity of Substitution			3	3
Elasticity of Substitution Between Consumed Goods			1.5	1.5

With respect to the consumer preferences, relative consumption of polluting good is higher at old age.

3.5 Simulations and Main Findings

This section provides computational economic assessment of two sets of simulations. First, we assess the impact of demographic shock on the volume of emission by computing an increase in the population growth rate in the South, while in the North we simulate an ageing population. The demographic shock is used to establish a new benchmark situation for the second set of simulations. Second, we simulate the impact of trade liberalization on emission. Based on these two sets of simulations, we explore the impact of population ageing and trade liberalization on the level of emission in rich and poor countries.

3.5.1 Population Ageing and the Environment

Starting from a benchmark situation where population in each country is made of three equal size generations, we simulate two opposite shocks which are equal in magnitude to keep the global population constant over time.[156] For the North, we generate a decline in the population growth rate for six periods of time before reaching the long-term steady state given by a rate of replacement of the young generation equal to 100%. However, for the South, we simulate an increase in the population growth rate for six periods of time causing the total size of the population in the South to increase. These two shocks are constructed by manipulating the rate of replacement of the young generation (RYG).

Table 6: Evolution of Total Population over Time (sample [t1, t10])

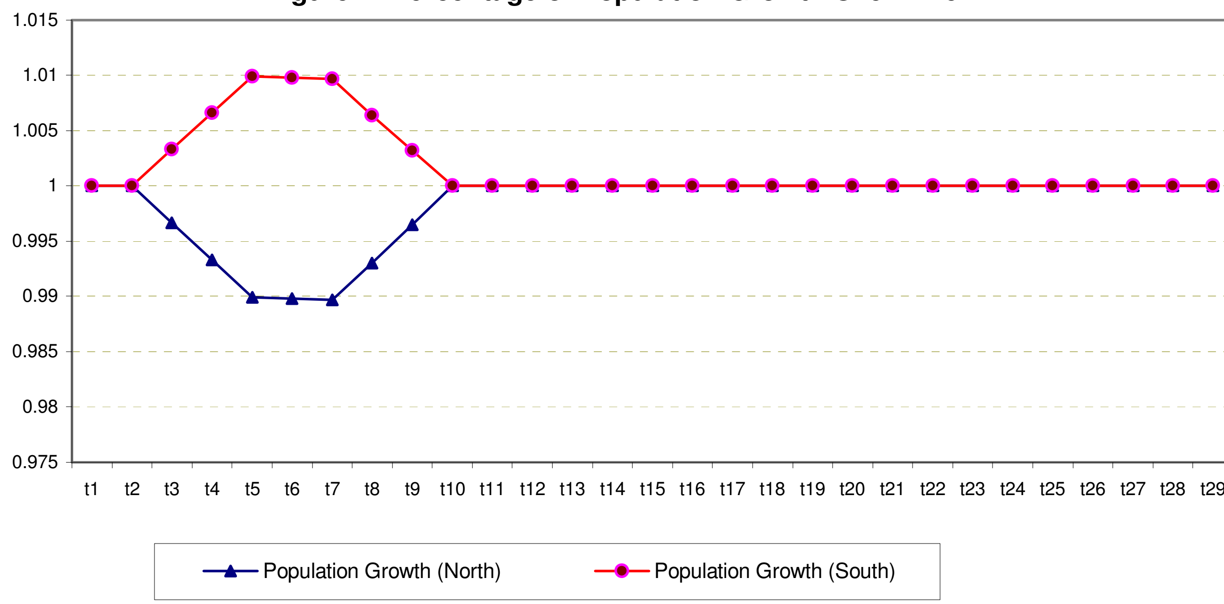
Period	Population In the North				Population In the South				Global Population
	G1	G2	G3	Total	G1	G2	G3	Total	
t1	100	100	100	300	100	100	100	300	600
t2	100	100	100	300	100	100	100	300	600
t3	100	100	100	300	100	100	100	300	600
t4	99	100	100	299	101	100	100	301	600
t5	98	99	100	297	102	101	100	303	600
t6	97	98	99	294	103	102	101	306	600
t7	96	97	98	291	104	103	102	309	600
t8	95	96	97	288	105	104	103	312	600
t9	95	95	96	286	105	105	104	314	600
t10	95	95	95	285	105	105	105	315	600

[156] It is important to highlight that global population is kept constant over time to eliminate the impact of its size on the level of emission caused by the demographic shocks. A numerical program using GAMS is constructed to simulate the demographic shocks. A copy of the program is available upon request.

Table 6 reports the results describing the impact of the demographic shocks on total population over time. Total population rises in the South and falls in the North during the demographic transition. Starting from period (t10), total population in both countries converges to its long term level.

In terms of percentage of population growth over time, Figure 2 provides a detailed description of the evolution of percentage of total population growth over time.

Figure 2: Percentage of Population Growth OverTime



A first implication of the demographic shocks is a change in the labour and capital supply in both countries. A population ageing in the North is a synonym of a reduction of the labour force. However, in the South, the size of the population increases. During the demographic transition, labour and capital supply fall in the North and rise in the South. In addition, as a manifestation of the demographic composition effect that results from the demographic shock, reduction in labour supply is higher in the North relative to Capital supply, while in the South, variation in labour supply exceeds the increase in capital supply. For example, as a result of 2% reduction in the size of the population, labour supply falls by 2.47% in comparison to a reduction by about 2.03% in capital supply in the North. However, in the

South, a 2% increase in total population boosts labour supply by 2.47% relative to 2.4% increase for capital supply.

Figure 3 below reports the evolution of labour supply as a result of demographic shock.

Figure 3: Evolution of Labour Supply Over Time

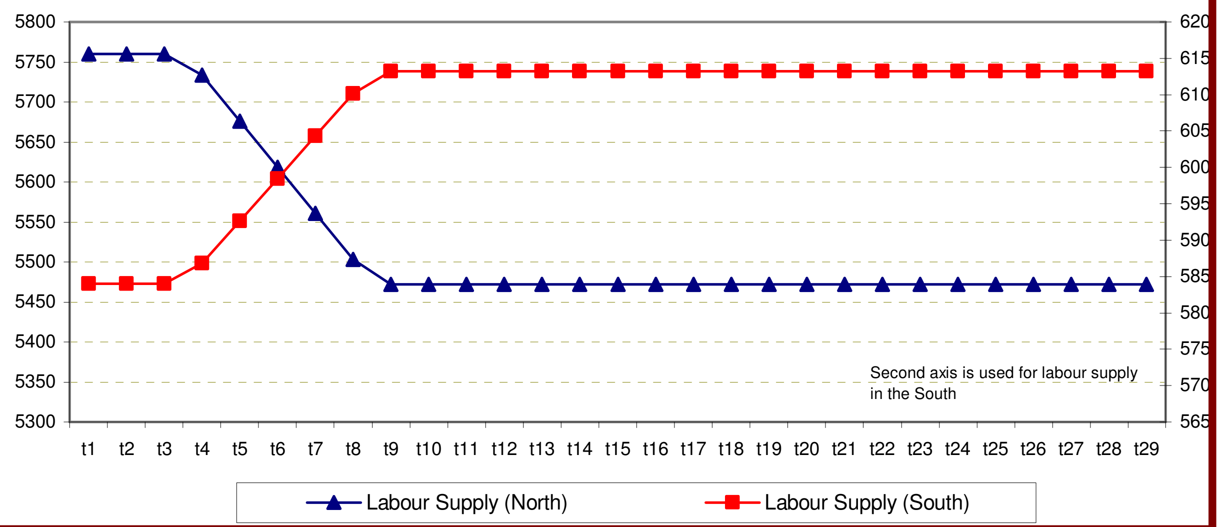
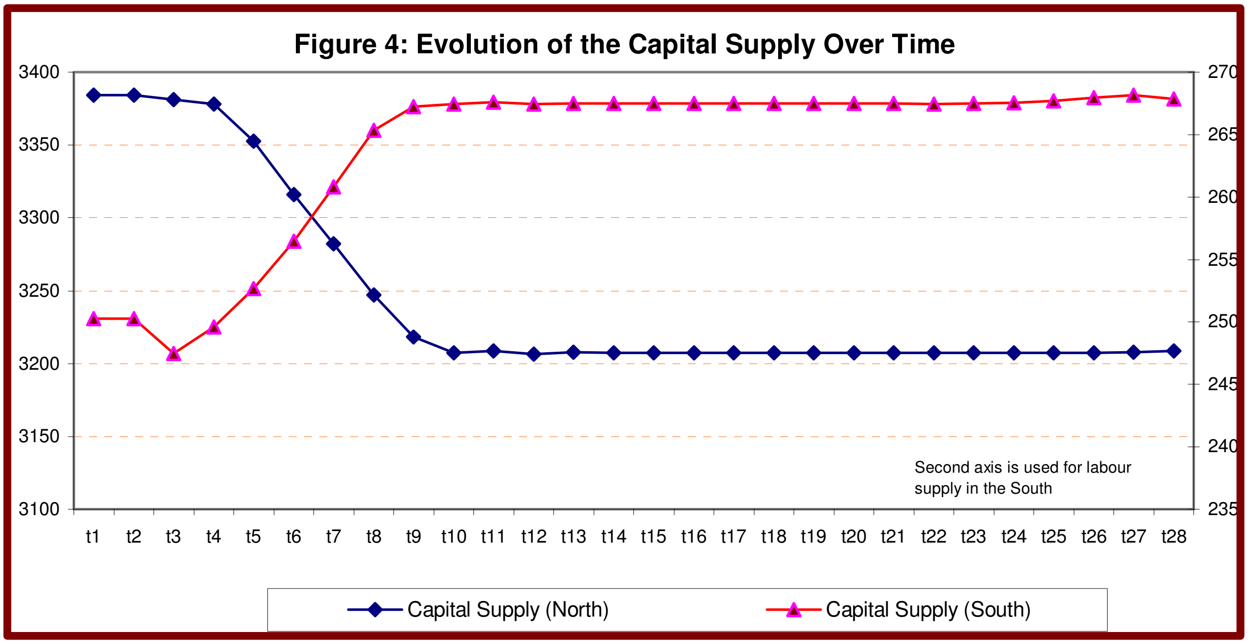
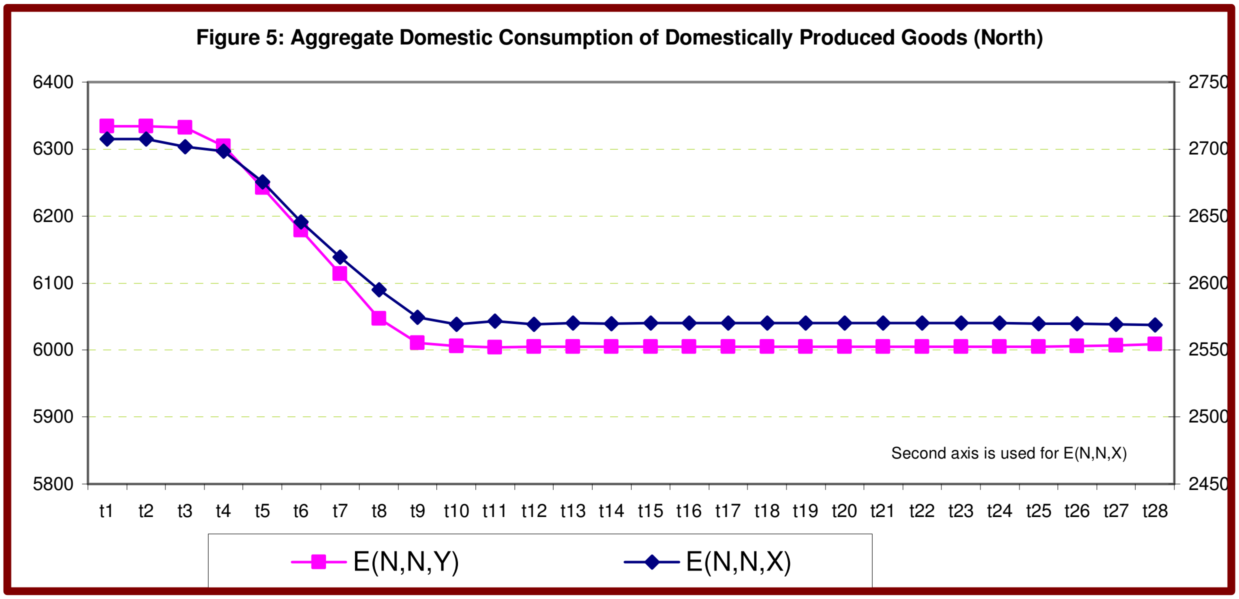
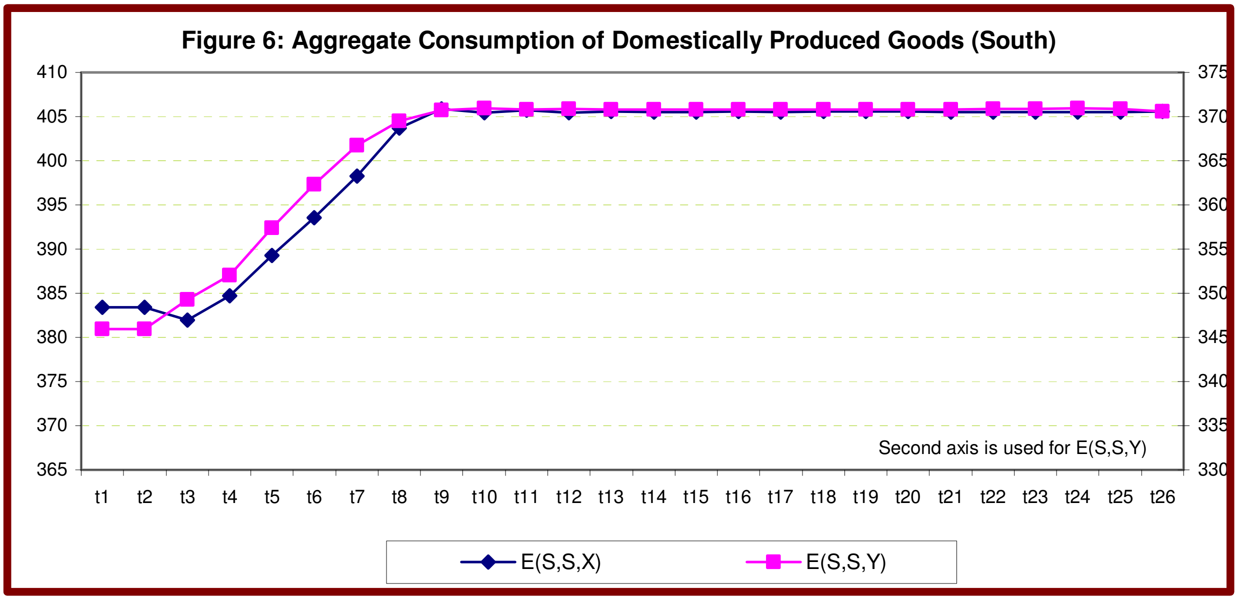


Figure 4 illustrates the impact of demographic shocks on aggregate supply of physical capital in both countries. After a short period of fluctuation, which can be attributed to change in the amount of saving by G1 and G2, starting from period (t10) capital supply reaches its long-term stable level.



Turning our focus to aggregate consumption by origin and destination, we find that an increase in total population in the South increases both imports and domestically produced and consumed goods in the South. However, population ageing creates the opposite effect. Figure 5 and Figure 6 below provide a detailed description about the evolution of aggregate domestic consumption of domestically produced goods as a result of demographic shock. Moreover, it is important to notice that imports in both countries follow the same path as the aggregate consumption of domestically produced goods.





To highlight the role played by the demographic composition of the population on the aggregate demand for clean versus polluting goods, we used the proportion of aggregate consumption that is satisfied from domestic production as a means to illustrate the impact of the composition effect. Empirical results show that, even though an increase in the population growth rate seems to increase aggregate demand for both consumed goods in the South as shown in Figure 6, variation in the aggregate demand for clean goods exceeds the variation in the aggregate demand for polluting goods. The opposite is also true in the North, where an increase in the weight of seniors in the economy during the demographic transition causes the level of aggregate consumption of the polluting commodity to fall by a lower magnitude in comparison to the aggregate consumption of clean goods.(Table 7)

Table 7: Variation in Aggregate Consumption over Time as a Manifestation of the Composition Effect (Percentage of Change)

	North				South			
Period	E(N,N,X)	E(N,N,Y)	E(S,N,X)	E(S,N,Y)	E(S,S,X)	E(S,S,Y)	E(N,S,X)	E(N,S,Y)
t3	-0.20	-0.03	-1.49	-0.03	-0.39	0.98	0.92	0.98
t4	-0.33	-0.47	-1.89	-0.47	0.35	1.76	1.95	1.76
t5	-1.17	-1.45	-3.07	-1.45	1.53	3.31	3.52	3.31
t6	-2.28	-2.46	-4.38	-2.46	2.64	4.73	4.89	4.73
t7	-3.25	-3.47	-5.38	-3.47	3.87	6.01	6.21	6.01
t8	-4.14	-4.53	-5.79	-4.53	5.29	6.81	7.14	6.81
t9	-4.91	-5.11	-6.22	-5.11	5.87	7.17	7.34	7.17
t10	-5.11	-5.19	-6.59	-5.19	5.75	7.24	7.42	7.24

It is worth mentioning that, with respect to the aggregate consumption of imported goods, as a result of the demographic shock, the North seems to reduce its imports of the polluting good in a higher proportion relative to the clean one. However, in the South, imports of the polluting goods seem to exceed the imports of the clean commodity. This constitutes a manifestation of the comparative advantage in each country as it reacts to a change in its demographic composition.[157]

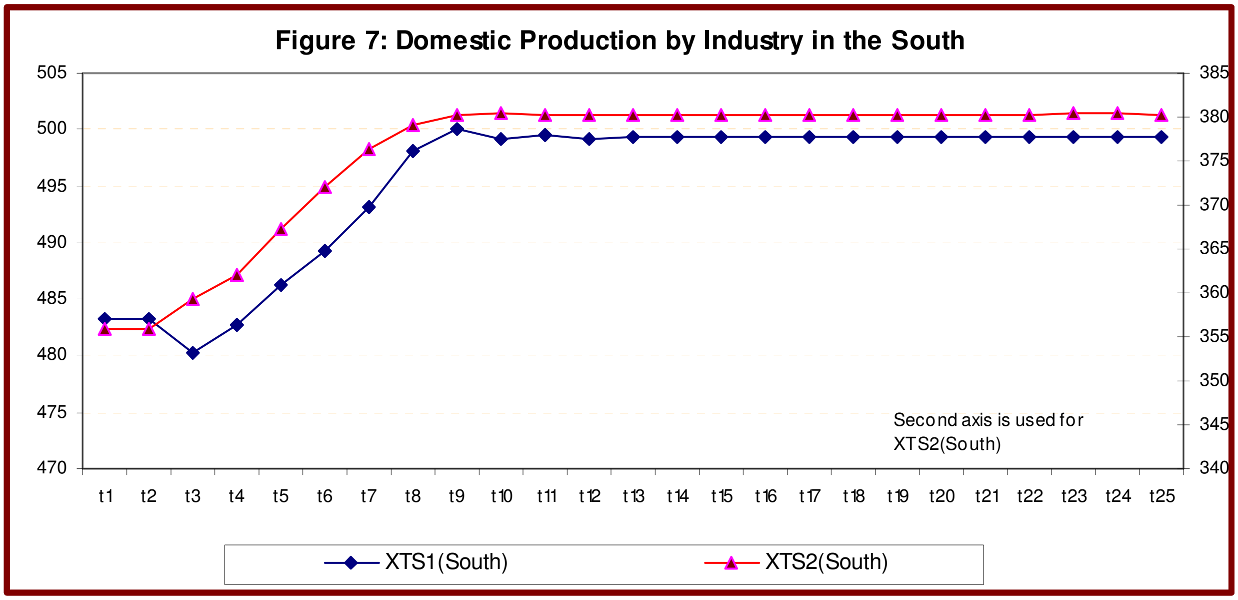
Facing an increase in the aggregate consumption of domestically produced goods, domestic production of clean and polluting goods increases in the South as shown in Figure 7.[158] [159]

---

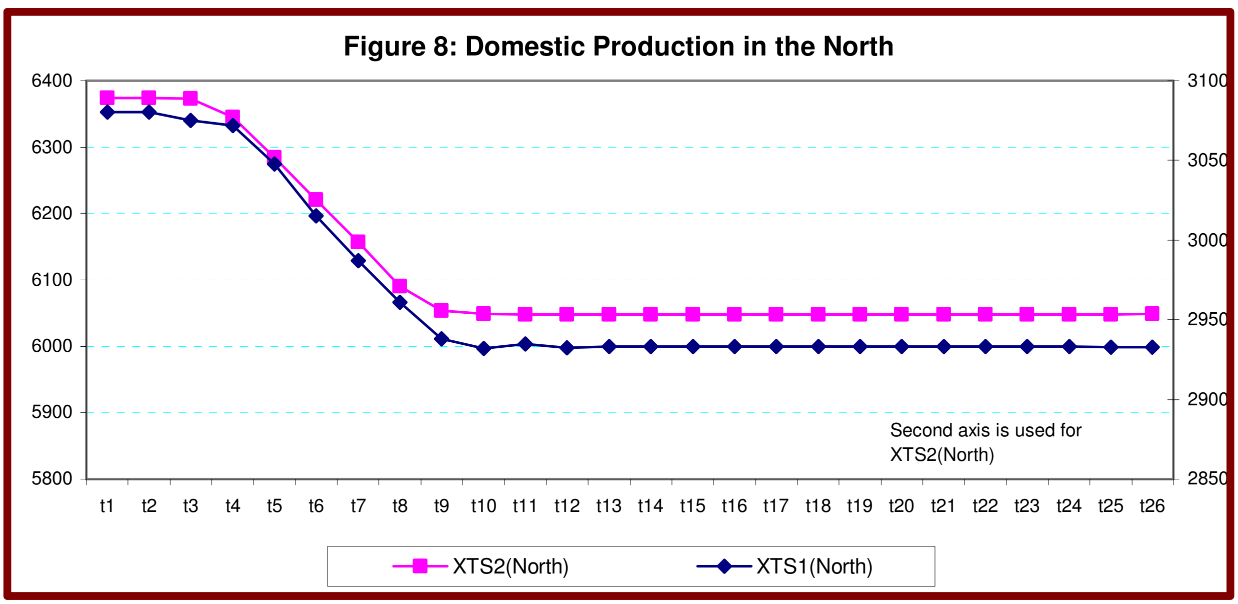
[157] Since the main purpose of this section is to assess the impact of the demographic shock on the emission levels, it is less likely that terms of trade effects may play a significant role. However the latter may have a central role in a possible welfare analysis.

[158] It is worth mentioning that labour demand by domestic industries in the South follow the same path as the variation of the production of polluting and clean good. However the demand for capital seems to be highly affected by transfer from the North due to perfect mobility of capital between the two countries.

[159] XTS1 is the production of the polluting good and XTS2 is the production of the clean good.

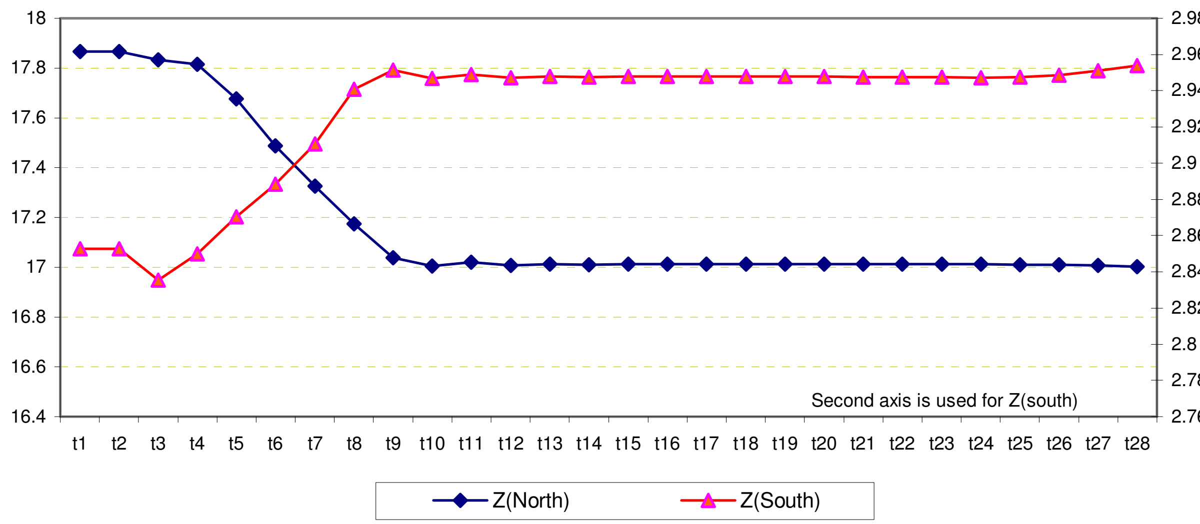


In the North, production of the clean and polluting goods decreases in comparison with the benchmark situation. Such a decline can be explained by a reduction in both capital and labour supply and a decline in aggregate demand for consumed goods. Figure 8 illustrates the evolution of the domestic production in the North from demographic shock.



Results from simulation suggest that, in the North, population ageing diminishes the production of the polluting good, thus causing the volume of emission to fall. However, in the South, the level of emission increases to meet a higher aggregate demand for polluting goods as the total population increases. Figure 9 illustrates the evolution of the level of emission in both countries as a result of demographic shocks.

Figure 9: Evolution of the Volume of Emission Over Time



From Figure 9, the scale effect dominates the composition effect. More specifically, the level of emission is found to be positively related to the population size. In fact, despite the increase in the weight of seniors in the North leading to a positive composition effect towards the consumption and the production of more polluting goods, a negative scale effect is found to be high enough to bring the level of emission down. However, in the South, both polluting and clean industries augment their production in the medium run; causing the level of emission to increase.

Despite the fact that the simulated demographic shocks are equal in magnitude in both countries, the global level of emission falls both during the demographic transition and in the long run. The reason is that population ageing effect in the North dominates the impact of the increase in the population size in the South. Such a result is supported by the findings of the United Nation Population Fund reports highlighting the disparity in consumption between rich and poor countries. In fact, in the NS-OLG model, the North is responsible for more than 80% to total consumption.[160] Therefore, a relative reduction in the size of the population seems to offset the increase in the level of emission generated in the South.

In the long run, results from simulation suggest that a 5% reduction in the population leads to a fall of 4.8% of the volume of emission in the North. In the South, an increase in the size of

---

[160] According the UNPF 2009 report, rich countries are responsible for more than 50% of the world emission from the consumption of almost 80% of all goods and services.

the population by 5% leads to an increase of pollution by 3.3%. In terms of welfare effect, which is calculated based on the maximization of current and future consumption by a representative consumer who takes into consideration his inter-temporal budget constraint (equation 5), we find that an increase in the population growth rate improves consumers' welfare of the current cohorts, while population ageing improves welfare of future cohorts.[161]

3.5.2 Free Trade in a Context of Demographic Transition

This section explores the effect of import tariff reduction on the level of emission. The trade liberalisation is applied to a new benchmark situation generated by the demographic changes in the previous sub-section. We simulate a 20% reduction on the imports tariff in both countries. A separate analysis is provided for each one. More specifically, we focus on the impact of trade liberalization on variation in domestic consumption of both domestically produced and imported goods, variation in total domestic production of clean and polluting good, and variation in the volume of emission, both during the demographic transition and in the long run.

3.5.2.1 Impact of imports Tariff Reduction in the South

Empirical results from imports tariff reduction suggest that, trade liberalisation reduces the volume of emission in the South. During the demographic transition, the level of emission fluctuates between (t3) and (t7) and then starts stabilizing at the beginning of period (t8). To explain such variation in the volume of emission, we provide a comprehensive assessment of consumers and producers' reactions to trade liberalization.

Facing lower prices for the goods originated in the North, consumers increase their demand for imported goods. Our estimates indicate that a 20% reduction in the imports tariff raises imports by about 8.74% for the polluting good and 8.55% for the clean one in the long term. However, in terms of domestically produced and consumed goods, consumers reduce their consumption of the polluting commodities by 0.39% and increase their consumption of the clean good by 0.87%. Table 8 reports the variations in the consumption of domestically produced and imported goods in the South.

---

[161] For more details about the welfare effect see Appendix 5.

Table 8: Percentage of Variation in the Main Variables Describing The Consumers Behaviour in the South (Sample [T3;T10])						
Period	Wage	Rate of return on Capital	E(S,S,X)	E(S,S,Y)	E(N,S,X)	E(N,S,Y)
t3	1.901	0.00	-0.42	0.95	8.80	8.64
t4	1.698	0.00	-0.39	0.83	8.65	8.52
t5	1.799	-0.059	-0.37	0.87	8.77	8.56
t6	1.755	-0.026	-0.39	0.85	8.71	8.54
t7	1.788	-0.038	-0.39	0.86	8.74	8.55
t8	1.777	-0.035	-0.39	0.86	8.74	8.55
t9	1.780	-0.035	-0.39	0.87	8.74	8.56
t10	1.779	-0.036	-0.39	0.87	8.74	8.55

During the demographic transition, variation in imports and aggregate consumption of the clean good that is domestically produced seem to fluctuate. However, aggregate consumption of the polluting domestically produced good seems to vary in the opposite direction. Trade liberalization boosts aggregate demand in the South.

Turning to the production side, the South is a poor country with a comparative advantage in labour intensive production. Results from simulation show that trade liberalization increases both capital and labour demand to produce the clean good. To be more specific, a 20% reduction in the imports tariff increases production of the clean good by 0.86%, while production of the polluting good falls by 0.4%. Simulations show that as imports tariff falls, the South specializes in the production of the clean good. Table 9 illustrates the variation in the demand for capital and labour, variation in the domestic production of both clean and polluting goods, and variation in the level of emission as a result of import tariff reduction in the south.

Table 9: Percentage of Variation in Main Variables Characterizing the Producer Problem in the South (Sample [T3; T10])							
Period	K_1	K_2	L_1	L_2	XTS1	XTS2	Z
t3	0.47	2.83	-1.40	0.91	-0.45	0.94	-0.446
t4	0.43	2.52	-1.25	0.81	-0.39	0.83	-0.392
t5	0.52	2.72	-1.32	0.84	-0.39	0.87	-0.385
t6	0.46	2.62	-1.30	0.82	-0.40	0.85	-0.399
t7	0.48	2.68	-1.32	0.83	-0.40	0.86	-0.403
t8	0.48	2.66	-1.31	0.83	-0.40	0.86	-0.399
t9	0.48	2.67	-1.31	0.84	-0.40	0.87	-0.398
t10	0.48	2.67	-1.31	0.84	-0.40	0.86	-0.399

Table 9 suggests that by reducing production of the polluting good in the long run, trade liberalization causes the volume of emission to fall. Results from simulations show that as a result of 20% reduction in the imports tariff pollution falls by around 0.4% in the South.

3.5.2.2 Impact of Imports Tariff reduction in the North

By reducing imports tariff by 20%, we find that trade liberalization in a rich and opened economy increases pollution in the long run. However, in terms of magnitude, free trade seems to have a very small effect on pollution. In fact, as a result of 20% of import tariff reduction in the North, the level of emission increases by 0.175%. To fully understand such variation in the volume of emission in the North, a complete assessment of the impact of imports tariff shock on consumers' behaviour and domestic production is provided below.

One direct result of imports tariff reduction of 20% is a drop in the price of imports from the South. In particular, price of the clean good imported from the South declines by 0.68%. Such reduction in the consumers' prices triggers an increase in domestic demand for such commodity. Results from simulation show that consumption of the clean good imported from the South increases by 0.83% in the long term. As the North specializes in the production of the polluting good, imports of such commodity decline by 0.46%. Moreover, domestic consumption of clean domestically produced good has declined by almost 0.20% due to the South specialization in the labour intensive production. In addition, consumption of the polluting good domestically produced seems to fall slightly by 0.06%. Overall, trade liberalization negatively impacts North's aggregate consumption of the polluting good. Table 10 below describes the variation in the main variables describing the consumers' problem.

Table 10: Percentage of Variation in Main Variables Describing Consumer Problem in the North (Sample[t3 to t15])

Period	Tax per Agent	Wealth (G2)	Wealth(G3)	E(N,N,X)	E(N,N,Y)	E(S,N,X)	E(S,N,Y)
t3	-13.07	-0.29	-0.16	-0.06	-0.19	-0.56	0.83
t4	-12.99	-0.17	-0.19	-0.09	-0.17	-0.41	0.85
t5	-12.97	-0.16	-0.14	-0.03	-0.18	-0.44	0.84
t6	-12.96	-0.19	-0.17	-0.06	-0.19	-0.44	0.84
t7	-12.96	-0.18	-0.17	-0.05	-0.19	-0.46	0.83
t8	-12.98	-0.19	-0.18	-0.06	-0.19	-0.45	0.83
t9	-13.00	-0.19	-0.18	-0.06	-0.19	-0.46	0.83
t10	-12.99	-0.19	-0.18	-0.06	-0.19	-0.46	0.83

Turning to the production side, trade liberalization accelerates North specialization in the production of the polluting good, while domestic production of the clean good falls. Table 11 describes the variation in the main variables describing the producer problem in the North.

Table 11: Percentage of Variation in Main Variables Characterizing the Producer Problem in the North (Sample [T3; T15])

Period	K_1	K_2	L_1	L_2	XTS1	XTS2	Z
t3	0.059	-0.226	0.202	-0.083	0.146	-0.134	0.146
t4	0.053	-0.187	0.170	-0.070	0.124	-0.112	0.124
t5	0.135	-0.183	0.225	-0.093	0.189	-0.125	0.189
t6	0.092	-0.199	0.206	-0.085	0.161	-0.126	0.161
t7	0.109	-0.200	0.218	-0.090	0.175	-0.130	0.175
t8	0.106	-0.202	0.218	-0.091	0.174	-0.131	0.174
t9	0.107	-0.202	0.219	-0.091	0.175	-0.131	0.175
t10	0.108	-0.202	0.219	-0.091	0.175	-0.131	0.175

It is clear from Table 11 that trade liberalization increases domestic production of the polluting good and generates the opposite effect concerning the production of the clean good. For instance, as a result of 20% reduction in the imports tariff, North's production of the polluting good increases by 0.175%, and production of the clean good falls by 0.131%. In addition, it is important to highlight that, during the demographic transition, production of the polluting good seems to vary in the opposite direction as the production of the clean one.

In terms of evolution in the level of emission in both countries (global emission), we find that the demographic shock dominates the impact from trade liberalisation. The aggregate level of emission declines worldwide due to population ageing in the North. Furthermore, trade liberalization increases the aggregate level of emission only by 0.09% in the long term. Table 12 below summarizes the evolution in the level of emission due to trade liberalization and population ageing.

Table 12: Evolution in the Level of Emission from Both Demographic and Trade Shocks (Sample [t1; t10])

Period		t1	t2	t3	t4	t5	t6	t7	t8	t9	t10
Initial Benchmark	Z(North)*	17.87	17.87	17.87	17.87	17.87	17.87	17.87	17.87	17.87	17.87
	Z(South)*	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85
	Global Emission*	20.72	20.72	20.72	20.72	20.72	20.72	20.72	20.72	20.72	20.72
Demographic Shock Based on Initial Benchmark	Z(North)*	17.87	17.87	17.83	17.82	17.68	17.49	17.33	17.17	17.04	17.01
	Z(South)*	2.85	2.85	2.84	2.85	2.87	2.89	2.91	2.94	2.95	2.95
	Global Emission*	20.72	20.72	20.67	20.67	20.55	20.38	20.24	20.11	19.99	19.95
	Percentage Variation in Global level of Emission	0	0	-0.2%	-0.3%	-0.8%	-1.7%	-2.3%	-2.9%	-3.5%	-3.7%
Trade Shock Using Second Benchmark	Z(North)*	17.87	17.87	17.86	17.84	17.71	17.52	17.36	17.20	17.07	17.04
	Z(South)*	2.85	2.85	2.82	2.84	2.86	2.88	2.90	2.93	2.94	2.94
	Global Emission*	20.72	20.72	20.68	20.68	20.57	20.39	20.26	20.13	20.01	19.97

	Percentage Variation in the Level of Global Emission Relative to Second Benchmark	0	0	0.06%	0.05%	0.11%	0.08%	0.09%	0.09%	0.09%	0.09%
Percentage of Variation in the Level of Global Emission as a Result of Both Shocks		0	0	-0.2%	-0.2%	-0.7%	-1.6%	-2.2%	-2.8%	-3.4%	-3.6%
*Level of emission is expressed in million metric tons											

Concerning the welfare impact of trade liberalization, which is highly correlated with the level of consumption, consumers' welfare seems to fluctuate for young cohorts, while it increases in both countries for future cohorts. Furthermore, variation in consumer welfare is very small in magnitude.[162]

To conclude, free trade leads to more pollution in the North and less in the South. Theses empirical evidences provide more support for the FEH. Trade liberalization does not push rich countries to take advantage of the lack of stringent environmental policy in poor countries and make them dirtier. In fact, the North specializes in the production that uses its abandon factor which is capital. Therefore, production of the polluting good increases. On the other hand, in the South, trade liberalization creates more incentive to produce the labour intensive good.

3.5.3 Sensitivity Analysis

Empirical results from the simulation of equal sized demographic shocks, leading to an increase in the population size in the South and a fall in the total population in the North keeping global population constant over time, show the dominance of population ageing effect and a reduction in global emissions. Furthermore, a comparative analysis assessing the impact of demographic and trade shocks on the level of global emission reveals the high magnitude of the demographic shock to offset the increase in the level of emission caused by more specialisation in the production of the polluting good in the North as imports tariff falls. These two important results are worthy of particular attention. Therefore, we have conducted a sensitivity analysis to assess their robustness.

We have identified the magnitude of the demographic shock in both countries and the imports tariff reduction as the key parameters to test the solidity of our results. In fact, since

[162] For more details about the welfare impact from trade liberalisation see Appendix 6.

consumers from different age group are assumed to be behaving in a similar manner in both countries, also, since the size of the global population is kept constant to eliminate its impact on the scale of production, we choose to vary the demographic shock by 100% to generate a variation of 10% in the total population in each country. Moreover, with respect to the magnitude of the imports tariff reduction, we allow a drop of 30%, 40% and 50% simultaneously in both countries. A detailed discussion about the variation in the level of global emission is provided in the following two tables:

Table 13: Sensitivity Analysis To Model Parameter on Magnitude of Demographic Shock

Period	Emission Under 5% Demographic Shock				Emission Under 10% Demographic Shock			
	Z(North)	Z(South)	Global Emission	Percentage of Change	Z(North)	Z(South)	Global Emission	Percentage of Change
t1	17.87	2.85	20.72		17.87	2.85	20.72	
t2	17.87	2.85	20.72	0.00%	17.87	2.85	20.72	0.00%
t3	17.83	2.84	20.67	-0.24%	17.84	2.84	20.68	-0.19%
t4	17.82	2.85	20.67	-0.25%	17.82	2.85	20.67	-0.25%
t5	17.68	2.87	20.55	-0.83%	17.67	2.87	20.55	-0.83%
t6	17.49	2.89	20.38	-1.65%	17.49	2.89	20.38	-1.64%
t7	17.33	2.91	20.24	-2.33%	17.33	2.91	20.24	-2.29%
t8	17.17	2.94	20.11	-2.92%	17.16	2.93	20.09	-3.06%
t9	17.04	2.95	19.99	-3.51%	16.99	2.95	19.94	-3.78%
t10	17.01	2.95	19.95	-3.70%	16.82	2.97	19.78	-4.52%
t11	17.02	2.95	19.97	-3.61%	16.64	2.99	19.63	-5.26%
t12	17.01	2.95	19.95	-3.69%	16.47	3.01	19.47	-6.01%
t13	17.01	2.95	19.96	-3.66%	16.32	3.04	19.36	-6.57%
t14	17.01	2.95	19.96	-3.67%	16.18	3.05	19.23	-7.17%
t15	17.01	2.95	19.96	-3.67%	16.15	3.04	19.19	-7.36%

Table 13 shows a negative relationship between the magnitude of the demographic shocks and the level of global emission. Such a result is consistent with our findings with respect to the impact of demographic shocks on the level of world emissions. More specifically, empirical results provided in Table 13 support the conclusion that the population ageing effect in the North dominates the impact of increasing the population size in the South, causing the level of the global emission to fall.

It is important to highlight that our findings in this paper support the idea that, since most countries seem to reach a highly advanced level in liberalizing their economies, only little can be done to help protect and preserve the environment from trade liberalization perspective. However, on the other hand, population ageing in rich countries and population growth in poor countries is likely to affect greatly the environment. Results from the simulation of the NS-OLG model reveal the need and the necessity to explore more in detail the impact of the size of the global population and its demographic composition (when investigating/exploring means) to help protect the environment. (See Table 14)

Table 14: Sensitivity Analysis To Model Parameter on Magnitude of Trade Shock

Period		t1	t2	t3	t4	t5	t6	t7	t8	t9	t10
Global Emission At the Benchmark Situation		20.72	20.72	20.72	20.72	20.72	20.72	20.72	20.72	20.72	20.72
Global Emission After Demographic Shock		20.72	20.72	20.67	20.67	20.55	20.38	20.24	20.11	19.99	19.95
Emission Under 30% Trade Shock	Z(North)	17.87	17.87	17.87	17.85	17.73	17.53	17.37	17.22	17.09	17.05
	Z(South)	2.85	2.85	2.82	2.83	2.85	2.87	2.89	2.92	2.93	2.93
	Global Emission	20.72	20.72	20.69	20.68	20.58	20.40	20.27	20.14	20.02	19.98
Percentage of Change From Demographic and Trade Shocks			0.00%	-0.14%	-0.17%	-0.66%	-1.53%	-2.19%	-2.78%	-3.38%	-3.56%
Emission Under 40% Trade Shock	Z(North)	17.87	17.87	17.89	17.86	17.75	17.55	17.39	17.24	17.10	17.07
	Z(South)	2.85	2.85	2.81	2.83	2.85	2.86	2.89	2.92	2.93	2.92
	Global Emission	20.72	20.72	20.70	20.69	20.59	20.41	20.28	20.15	20.03	19.99
Percentage of Change From Demographic and Tarde Shocks			0.00%	-0.10%	-0.14%	-0.60%	-1.48%	-2.13%	-2.73%	-3.32%	-3.51%
Emission Under 50% Trade Shock	Z(North)	17.87	17.87	17.91	17.88	17.77	17.57	17.41	17.26	17.12	17.09
	Z(South)	2.85	2.85	2.80	2.82	2.84	2.86	2.88	2.91	2.92	2.91
	Global Emission	20.72	20.72	20.71	20.70	20.61	20.42	20.29	20.16	20.04	20.00
Percentage of Change From Demographic and Trade Shocks			0.00%	-0.06%	-0.11%	-0.53%	-1.43%	-2.08%	-2.67%	-3.27%	-3.46%

3.6 Conclusion

As the question of population ageing is becoming a serious issue in the North, some believe that population ageing in association with trade liberalization may increase the level of emissions in the South. Such believe is mainly supported by the existence of a relatively stringent environmental policy and more open trade policy in the North. Our main goal is to assess the impact of trade liberalization in a context of demographic transition on the level of emissions in rich and poor countries. Survey of the economic literature on free trade, population growth, economic growth and their impact on the environment led us to explore two opposite theories: the pollution haven hypothesis and the factor endowment hypothesis. Empirical literature shows that the empirical evidences supporting the pollution haven hypothesis are ambiguous and largely lacking for the factor endowment hypothesis.

By constructing a dynamic overlapping generation model of free trade, population ageing, and environment based on Copland and Taylor (1994), we run two sets of simulations. First, we simulate a demographic shock by increasing the population growth rate in the South and decreasing it in the North to assess the relationship between population ageing/growth and the environment. Second, we simulate a reduction in the imports tariff to evaluate the impact of trade liberalization on the level of emission in each country.

We find that pollution is positively related to population growth rate. An increase in the population growth rate increases capital and labour supply, imports, and aggregate consumption leading to a higher level of emission in the long term. However, population-ageing generates the opposite effects. During the demographic transition, the level of emission in both countries fluctuates to take into consideration change in wage and rate of return on capital. The scale effect is found to be high enough to dominate the composition effect in both countries. As a result, the level of emission is found to be positively related to the size of the population. Pollution increases in the South and falls in the North.

To answer the question whether rich countries with a population ageing challenge will be responsible for making young and poor countries dirty with free trade, we find that trade liberalization in a context of demographic transition leads to more pollution in the North and less in the South. Free trade facilitates a country specialization in the production intensive in its abundant factor. The North specializes in the production of the capital-intensive good, while the South specializes in the production of the labour intensive good. Furthermore, the demographic shock dominates the trade effect and the aggregate level of emission worldwide declines as a result of population ageing in the North. Overall, trade liberalization is found to be bad for the environment; but its impact is very small.

Our analysis suggests that population ageing in rich countries with stringent environmental policy will not increase pollution in poor young countries due to their lack of stringent environmental policy. One extension to our work would be to use endogenous tax on pollution, which allows the environmental policy to adjust to change in real income. This may lead to a potential improvement in the production technology as a result of more stringent environmental policy.

Appendix

Appendix 1: Life Expectancy and Fertility Rate

Table 10: Evolution of Life Expectancy and Fertility Rate Over Time Based on Constant-fertility scenario

Period	Life Expectancy		Fertility Rate	
	More developed regions	Least developed countries	More developed Regions	Least developed Countries
2045-2050	82.79	68.32	1.73	5.04
2040-2045	82.20	67.02	1.72	4.96
2035-2040	81.64	65.66	1.71	4.88
2030-2035	81.04	64.25	1.70	4.79
2025-2030	80.42	62.77	1.68	4.70
2020-2025	79.72	61.20	1.66	4.61
2015-2020	78.93	59.63	1.64	4.53
2010-2015	78.03	57.88	1.64	4.45

United Nations, Department of Economic and Social Affairs, Population Division, World population Prospects: The 2008 Revision, New York, 2009 (advanced Excel tables).

Appendix 2: Child and Elderly Dependency Ratio Over Time

According to recent United Nations' demographic projections, by 2050, the proportion of seniors (aged 60 or above) is expected to exceed 33% in the more developed regions, leading to a higher elderly-dependency ratio in excess of 45%. However, in the least developed countries, it is the child-dependency ratio that is projected to reach 76%, three times higher in comparison with the rich countries. The following table provides a comparative analysis in terms of percentage of seniors, child-dependency ratio, and elderly-dependency ratio.

Table 11: Demographic Characteristics Based on Constant-fertility scenario

Period	More Developed Regions			Least Developed Countries		
	Percentage Aged 60 or Over	Child-Dependency Ratio	Elderly-dependency ratio	Percentage Aged 60 or Over	Child-Dependency Ratio	Elderly-dependency ratio
2010	21.76	24.44	23.61	5.18	70.18	5.83
2015	23.57	24.75	26.33	5.43	68.47	5.98
2020	25.52	24.88	29.47	5.69	68.71	6.34
2025	27.44	24.55	32.87	5.96	70.45	6.79
2030	28.95	24.26	36.27	6.26	71.17	7.22
2035	30.27	24.14	38.96	6.59	71.57	7.65
2040	31.28	24.37	41.37	6.93	72.43	8.15
2045	32.26	24.73	43.31	7.26	73.98	8.71
2050	33.12	25.1	45.33	7.48	75.91	9.27

United Nations, Department of Economic and Social Affairs, Population Division, World Population Prospects: The 2008 Revision, New York, 2009 (advanced Excel tables).

Appendix 3: Solving Consumer Problem

Stage 1: Dynamic Budget Constraint

This stage provides a description of a representative consumer's behaviour over his life time. As he ages, his participation in wealth creation and his consumption vary. To assess, and analytically formulate his inter temporal budget constraint, we can proceed as follow:

Let $cons_g^i(t)$ and $PXY_g^i(t)$ represent respectively the volume and the price of a composite good consumed by a representative consumer from generation *g* over time. We can express his dynamic budget constraints as follow:

- For G1 at period t the dynamic budget constraint is given by:

$$PXY_{G1}^i(t)cons_{G1}^i(t) + sav_{G1}^i(t+1) = w^i(T)L_{G1}^i(t) + TAX_{G1}^i(t); \qquad (1)$$

Where $sav_g^i(t)\forall i \in \{North, South\}; \forall g \in \{G1, G2, G3\}$ denotes the level of saving by a representative consumer from generation g at period *t* in country *i*. $L_g^i(t)$ is the supply of productive labour by a representative consumer from generation g. $TAX_g^i(t)$ is the representative consumer's share of total tax collected from taxing the polluting industry and the volume of imports in country "*i*".

- When G1 becomes G2 at period *t+1*, the budget constraint becomes:

$$\begin{aligned} &PXY_{G2}^i(t+1)cons_{G2}^i(t+1) + sav_{G2}^i(t+2) = w^i(t+1)L_{G2}^i(t+1) + \\ &sav_{G1}^i(t+1)\left(1 + r^i(t+1)\right) + TAX_{G2}^i(t+1); \end{aligned} \qquad (2)$$

- When G2 becomes G3, the budget constraint is given by:

$$PXY_{G3}^i(t+2)cons_{G3}^i(t+2,G3) = \left(1 + r^i(t+2)\right)sav_{G2}^i(t+2,G3) + TAX_{G3}^i(t+2); \qquad (3)$$

By rewriting the equations (1), (2) and (3), we can formulate the amount of wealth for each generation over time as:

$$\begin{cases} sav^i_{G1}(t+1) = w^i(t)L^i_{G1}(t) + TAX^i_{G1}(t) - PXY^i_{G1}(t)cons^i_{G1}(t); \\ \\ sav^i_{G2}(t+2) = w^i(t+1)L^i_{G2}(t+1) + sav^i_{G1}(t+1)\left(1+r^i(t+1)\right) + \\ TAX^i_{G2}(t+1) - PXY^i_{G2}(t+1)cons^i_{G2}(t+1); \\ \\ 0 = \left(1+r^i(t+2)\right)sav^i_{G2}(t+2) + TAX^i_{G3}(t+2) - PXY^i_{G3}(t+2)cons^i_{G3}(t+2); \end{cases}$$

Stage 2: Present Value of the Life-Time Budget Constraint

By manipulating equations (1), (2), and (3), we can express the present value of the time-life budget constraint as:

$$\begin{aligned} &0 = TAX^i_{G3}(t+2) - PXY^i_{G3}(t+2)cons^i_{G3}(t+2) + \\ &\left[1+r^i(t+2)\right]\left\{w^i(t+1)L^i_{G2}(t+1) + TAX^i_{G2}(t+1) - PXY^i_{G2}(t+1)cons^i_{G2}(t+1)\right\} + \\ &\left[1+r^i(t+2)\right]\left[1+r^i(t+1)\right]\left\{w^i(t)L^i_{G1}(t) + TAX^i_{G1}(t) - PXY^i_{G1}(t)cons^i_{G1}(t)\right\}; \end{aligned}$$

By dividing the expression above by: $\left[1+r^i(t+2)\right]\left[1+r^i(t+1)\right]$, we can reformulate the expression of the present value of the life-time budget constraint as:

(4)

$$\begin{aligned} &\frac{PXY^i_{G3}(t+2)cons^i_{G3}(t+2)}{\left[1+r^i(Tn+2)\right]\left[1+r^i(Tn+1)\right]} + \frac{PXY^i_{G2}(t+1)cons^i_{G2}(t+1)}{\left[1+r^i(Tn+1)\right]} + PXY^i_{G1}(t)cons^i_{G1}(t) = \\ &\frac{TAX^i_{G3}(Tn+2)}{\left[1+r^i(t+2)\right]\left[1+r^i(t+1)\right]} + \frac{\left\{w^i(t+1)L^i_{G2}(t+1) + TAX^i_{G2}(t+1)\right\}}{\left[1+r^i(t+1)\right]} + \left\{w^i(t)L^i_{G1}(t) + TAX^i_{G1}(t)\right\}; \end{aligned}$$

Based on this equation, the present value of the life-time consumption is equal to the present value of the life-time income and transfer from the government.

Stage 3: The Consumer Utility Maximization

We assume a constant relative risk aversion ("CRRA") utility function to describe the relationship between current and future consumption for a representative consumer. Such function is subject to an inter-temporal budget constraint given by equation (4). When first entering the economy, a representative consumer needs to allocate his permanent revenue over his three stages of life to smooth his consumption. Therefore he needs to maximize the following objective function:

$$MaxU = \frac{1}{1-\gamma^i}\left\{\frac{\left(cons_{G1}^i(t)\right)^{1-\gamma^i}}{\left(1+\rho^i\right)} + \frac{\left(cons_{G2}^i(t+1)\right)^{1-\gamma^i}}{\left(1+\rho^i\right)^2} + \frac{\left(cons_{G3}^i(t+2)\right)^{1-\gamma^i}}{\left(1+\rho^i\right)^3}\right\} \tag{5}$$

subject to

$$\frac{PXY_{G3}^i(t+2)cons_{G3}^i(t+2)}{\left[1+r^i(Tn+2)\right]\left[1+r^i(Tn+1)\right]} + \frac{PXY_{G2}^i(t+1)cons_{G2}^i(t+1)}{\left[1+r^i(Tn+1)\right]} + PXY_{G1}^i(t)cons_{G1}^i(t) =$$
$$\frac{TAX_{G3}^i(Tn+2)}{\left[1+r^i(t+2)\right]\left[1+r^i(t+1)\right]} + \frac{\left\{w^i(t+1)L_{G2}^i(t+1)+TAX_{G2}^i(t+1)\right\}}{\left[1+r^i(t+1)\right]} + \left\{w^i(t)L_{G1}^i(t)+TAX_{G1}^i(t)\right\}$$

$cons_g^i(t)$ constitutes a composite consumption of both goods x_1 and x_2 by a representative consumer from generation $g, \forall g \in \{G1, G2, G3\}$ in country $i, \forall i \in \{North, South\}$. $\gamma^i = 1/\sigma^i$ is the inverse of the inter-temporal constant elasticity of substitution between consumption at two periods of time. ρ^i represents the rate of time preference in country *i*.

Using Lagrange to solve equation (5), in each country at any period of time, the FOC can be expressed as:

$$Cons_{g+1}^i(t+1) = \left\{\frac{1+r^i(t+1)}{1+\rho^i}\frac{PXY_g^i(t)}{PXY_{g+1}^i(t+1)}\right\}^{\sigma^i} Cons_g^i(t) \tag{6}$$

Equation (6) describes the relationship between a representative consumer's consumptions at different periods of time. It can be used to formulate analytical expressions for the consumption of the composite good as function of interest rate, wage, and taxes over time.

Appendix 4: The Producer Problem

<u>**The production of the polluting good**</u>*:* Producers of the polluting industry maximize the following profit equation:

$$\Pi_1^i(t) = x_1^i(t)P_1^*(t) - c^i\left(t, x_1^i(t)\right) - \theta^i x_1^i(t)P_1^*(t) - \tau^i e^i x_1^i(t) \tag{1}$$

$c^i\left(t, x_1^i(t)\right) \forall i \in \{North; South\}$ represents the cost function to produce $x_1^i(t)$ of the polluting good X1 at period *t*. It is given by: $c^i(t, x_1^i(t)) = w^i(t)L_1^i(t) + r^i(t)K_1^i(t)$; where w^i and r^i denote respectively the wage and the rate of return on capital in country *i*. $\theta^i x_1^i(t)P_1^*(t)$ constitute the amount of resources invested for the abatement in country *i*. $\tau^i e^i$ represents the unit cost of polluting in country *i*, which include two exogenous parameters, the rate of tax on pollution and a constant coefficient of emission.

Under perfect competition, the null profit condition due to the assumption of constant return to scale is given by:

$$x_1^i(t)P_1^*(t) = c^i\left(t, x_1^i(t)\right) + P_1^*(t)\theta^i x_1^i(t) + \tau^i e^i x_1^i(t) \tag{2}$$

Via few manipulations of the above equations, the domestic price for the polluting good can be expressed as:

$$P_1^i(t) = \left(1 - \theta^i\right)P_1^*(t) - \tau^i e^i \tag{3}$$

By maximizing its profit, the industry X1 in each country maximizes the following objective function.

After choosing the optimal level of abatement:

$$\max_{x_1^i}\left(\Pi_1^i(t)\right)=x_1^i(t)P_1^*(t)-c^i\left(t,x_1^i(t)\right)-P_1^*(t)\theta^i x_1^i(t)-\tau^i e^i x_1^i(t) \tag{4}$$

The maximization of the equations (4) permits to determine the optimal level of labour and capital demanded by the industry X1 in each country which can be given by the following equations:

$$L_1^i(t)=\frac{(1-\alpha_1^i)P_1^i(t)x_1^i(t)}{w^i(t)}\forall i\in\{North;South\}; \tag{5}$$

$$K_1^i(t)=\frac{\alpha_1^i P_1^i(t)x_1^i(t)}{r^i(t)}\forall i\in\{North;South\}; \tag{6}$$

Using the equations (1) and (2), we can rewrite the null profit condition for the industry X1 as:

$$P_1^i(t)A_1^i\left(K_1^i(t)\right)^{\alpha_1^i}\left(L_1^i(t)\right)^{1-\alpha_1^i}=w^i(t)K_1^i(t)+r^i(t)L_1^i(t);\forall i\in\{North;South\} \tag{7}$$

<u>The production of the clean good</u>*:* For the clean industry in both countries, the profit function of the industry X2 can be formulated as follow:

$$\Pi_2^i(t)=x_2^i(t)P_2^*(t)-c^i\left(t,x_2^i(t)\right);\forall i\in\{North;South\} \tag{8}$$

$c^i(t,x_2^i(t))$ represents the cost function for the industry X2 in the country "i" at period *t*.

By maximizing the equation (8), the industry X2 in each country determines the optimal level of labour and capital needed to maximize its profit. These levels are given by:

$$L_2^i(t)=\frac{(1-\alpha_2^i)P_2^i(t)x_2^i(t)}{w^i(t)};\forall i\in\{North;South\} \tag{9}$$

$$K_2^i(t)=\frac{\alpha_2^i P_2^i(t)x_2^i(t)}{r^i(t)};i\in\{North;South\} \tag{10}$$

Concerning the price at the producer level, the domestic price is given by the following expression:

$$P_2^i(t) = P_2^*(t); \forall i \in \{North; South\} \tag{11}$$

We can formulate the null profit condition of the industry X2 in both countries as:

$$P_2^i(t) A_2^i K_2^{\alpha_2^i}(t) L_2^{1-\alpha_2^i}(t) = w^i(t) K_2^i(t) + r^i(t) L_2^i(t); \forall i \in \{North; South\} \tag{12}$$

Appendix 5: Impact of Demographic Shock on Consumers' Welfare

Period of Birth	**Welfare Analysis in the North**		**Welfare Analysis in the South**	
	Total Welfare	Percentage of Change in Comparison with Cohort Born in t1	**Total Welfare**	Percentage of Change in Comparison with Cohort Born in t1
t1	**12.143**		**1.808**	
t2	12.296	0.013	1.685	-0.068
t3	12.165	0.002	1.838	0.016
t4	12.161	0.001	1.814	0.003
t5	12.179	0.003	1.847	0.021
t6	12.205	0.005	1.828	0.011
t7	12.209	0.005	1.814	0.003
t8	12.187	0.004	1.805	-0.002
t9	12.174	0.003	1.804	-0.002
t10	12.176	0.003	1.803	-0.003
t11	12.175	0.003	1.803	-0.003
t12	12.175	0.003	1.803	-0.003
t13	12.175	0.003	1.803	-0.003
t14	12.175	0.003	1.803	-0.003
t15	12.175	0.003	1.803	-0.003

Appendix 6: Impact of Trade Liberalization on Consumers' Welfare

Period of Birth	Welfare Analysis in the North		Welfare Analysis in the South	
	Total Welfare	Percentage of Change in Comparison with Cohort Born in t1	**Total Welfare**	Percentage of Change in Comparison with Cohort Born in t1
t1	12.162		1.764	
t2	12.270	0.009	1.773	0.005
t3	12.175	0.001	1.811	0.027
t4	12.149	-0.001	1.839	0.042
t5	12.176	0.001	1.849	0.048
t6	12.196	0.003	1.840	0.043
t7	12.204	0.003	1.821	0.032
t8	12.180	0.001	1.815	0.029
t9	12.168	0.000	1.813	0.028
t10	12.169	0.001	1.812	0.027
t11	12.169	0.001	1.812	0.027
t12	12.169	0.001	1.812	0.027
t13	12.169	0.001	1.812	0.027
t14	12.169	0.001	1.812	0.027
t15	12.169	0.001	1.812	0.027

References

Anderson, K. (1998), “Agricultural Trade Reform, Research Incentives and the Environment”, Policy Discussion Paper No. 98/04, University of Adelaide, Australia.

Anderson, K. and Blackhurst, R. (1992), *The Greening of World Trade Issues*, Ann Arbor: University of Michigan Press and London: Harvester Wheatsheaf, 276 pages.

Andraca, R. and McCready, K. F. (1994), *Internalizing Environmental Costs to Promote Eco-Efficiency*, Geneva: Business Council for Sustainable Development, 107 pages.

Antweiler, W., Copland, B. R., and Taylor, M. S. (2001), “Is Free Trade Good for the Environment?”, *The American Economic Review*, Volume 91, Issue 4, pages 877 - 908.

Arden-Clarke, C. (1992), “South-North Terms of Trade: Environmental Protection and Sustainable Development”, *International Environmental Affairs*, Volume 4, Issue 2, pages 122- 139.

Arntzen, J., I. Hemmer and O. Kuik (1992), *International Trade and Sustainable Development*, Amsterdam: VU University Press, 172 pages.

Arrow, K. J. and Debreu, G. (1954), “Existence of Equilibrium for a Competitive Economy”, *Econometrica*, Volume 22, Issue 3, pages 265–90.

Arrow, K., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C.S., Jansson, B.O., Levin, S., Mäler, K.G., Perings, C., and Pimental, D. (1995), “Economic Growth, Carrying Capacity and the Environment”, *Science*, Issue 268, pages 520-521.

Atkinson, A. (1975), *The Economics of Inequality*, Oxford University Press, London, 295 pages.

Audley, J. J. (1994), “National Environmental Groups and the North American Free Trade Agreement: Political Resources and the Politics of Issue Neutralization”, Cambridge, MA: Harvard University for Science and International Affairs.

Becker, R. and Henderson, V. (2000), “Effects of Air Quality Regulations on Polluting Industries”, *Journal of Political Economy*, Volume 108, Issue 2, pages 379-421.

Beckerman, W. (1992), “Economic Growth and the Environment: Whose Growth? Whose Environment?”, *World Development*, Volume 20, Issue 4, Pages 481-496.

Bellante, D. and Green, C. A. (2004), “Relative Risk Aversion among Elderly”, *Review of Financial Economics*, Volume 13, pages 269-81.

Benarroch, M. and Gaisford, J. (2005), “Intra-Industry Trade Liberalization and the environment”, University of Calgary Department of Economics, Working Paper.

Bengtsson, A. (1994), *The Environment and Free Trade*, Uppsala, SW: Uppsala University. Research Programme on Environmental Policy and Society, 138 pages.

Bergman, L., Jorgenson, D. W., and Zalai, E. (1990), *General equilibrium modeling and economic policy analysis*, Oxford: Basil Blackwell.

Bhagwati, J. and Herman D. (1993), “Debate: Does Free Trade Harm the Environment?”, *Scientific American*, pages 41-57.

Bochniarz, Z. and Toft D. (1995), “Free Trade and the Environment in Central Europe”, *European Environment*, Volume 5, Issue 2, pages 52-57.

Bond, C. A. and Farzin, Y. H. (2004). “Freedom from Pollution? The State, the People, and the Environmental Kuznets Curve”, Working Paper No. 04-003, Department of Agricultural and Resource Economics University of California Davis.

Brunnermeier, S. B. and Levinson, A. (2004), “Examining the Evidence on Environmental Regulations and Industry Location”, *Journal of Environment and Development*, Volume 13, Issue 1 pages 6-41.

Buitenkamp, M., H. Venner, and T. Wams (1992), *Action Plan : Sustainable Netherlands*, Amsterdam : Friends of the Earth, Netherlands, 186 pages.

Buttel, F. H and Flinn, W. L. (1978), “Social Class and Mass Environmental Beliefs: A Reconsideration”, *Environment and Behavior*, Volume10, Issue 3, pages 433-50.

Buttel, F. H. (1979), “Age and environmental concern: a multivariate analysis”, *Youth and Society*, Volume 10, Issue 3, pages 237-56.

Cameron, J. (1994), *Trade and the Environment: the Search for Balance*, 2 Volumes, London.

Campbell, B. (1994), *Moving in the Wrong Direction: the North American Free Trade Agreement and Environmental Sustainability*, Ottawa: Canadian Centre for Policy Alternatives, 11pages.

Chaudhuri, S. and Pfaff, A. (1998), “Household Income, Fuel Choice, and Indoor Air Quality: Microfoundations of an Environmental Kuznets Curve”, mimeo, Columbia University, Economics Department.

Chou, C., Melmed-Sanjak, J., and Shy, O. (1991) "The Environment and International Trade", Unpublished Paper.

Christmann, P. and Taylor, G. (2001), "Globalization and the Environment: Determinants of Firm Self-Regulation in China", *Journal of International Business Studies*, Volume 32, Issue 3, pages 439- 458.

Copeland, B. R. (2005), "Differentiated Emission Taxes and the Market for Abatement Services", Preliminary draft, March 4, 2005.

Copeland, B. R. and Gulati, S. (2003), "Trade and the Environment in Developing Economies", Working paper, October 2003.

Copeland, B. R. and Taylor, M. S. (1994), "North-South Trade and the Environment", *Quarterly Journal of Economics*, Volume 109, Issue 3, pages 755-87.

Copeland, B. R. and Taylor, M. S. (2003), "Trade, Growth and the Environment", Working Paper 9823.

Copeland, B. R. and Taylor, M. S. (2004), "Trade, Growth, and the Environment", *Journal of Economic Literature*, Volume 42, Issue 1, pages 7-71.

Copeland, B. R. and Taylor, M. S., (2003), "Trade, Growth and the Environment", National Bureau of Economic Research. Working Paper 9823, Cambridge, MA 02138.

Criqui, P., Mima, S., and Viguier, L. (1999), "Marginal Abatement Costs of CO2 Emission Reductions, Geographical Flexibility and Concrete Ceilings: An Assessment Using the POLES Model", *Energy Policy*, Volume 27, Issue 10, pages 585-601.

Cutler, S. J. and Kaufman, R. L., (1974), "Cohort Changes in Political Attitudes: Tolerance of Ideological Nonconformity", *Public Opinion Quarterly*, Volume 39, Issue 1, pages 69-81.

Dalton, M., B. O'Neill, A. Prskawetz, L. Jiang, and J. Pitkin (2008), "Population Aging and Future Carbon Emissions in the United States", *Energy Economics*, Issue 30, pages 642-675.

Dalton, M., L. Jiang, S. Pachauri , and B. C. O'Neill (2008), "Demographic Change and Future Carbon Emissions in China and India", Paper presented at the Annual Meeting of the Population Association of America, 28-31 March 2007, New York.

Daly, H.E. (1991), *Steady-State Economics*, San Francisco, Freeman & Co., 2nd. eds, Washington, D.C., Island Press.

De Bruyn, S.M. (1997), "Explaining the Environmental Kuznets Curve: Structural Change and International Agreements in Reducing Sulfur Emissions", *Environment and Development Economics*, Volume 2, Part 4, pages 485-503.

Dean, J. M. (2002), "Testing the Impact of Trade Liberalization on the Environment: Theory and Evidence", *Canadian Journal of Economics*, Volume 35, Issue 4, pages 819 – 842.

Dessus, S. and Bussolo, M. (1998), "Is There a Trade-off Betwen Trade Liberalization and Pollution Abatement? A Computable General Equilibrium Assessment Applied to Costa Rica", *Journal of Policy Modeling*, Volume 20, pages 11- 31.

Dissou, Y. (2004), "Cost-Effectiveness of the Performance Standard System to Reduce CO2 Emissions in Canada: A General Equilibrium Analysis", *Resource and Energy Economics*, Volume 27, Issue 3, pages 187-207.

Dissou, Y. and Robichaud, V. (2003), "Curbing GHG Emissions Using an Output-Based Permit Trading System A Dynamic General Equilibrium Analysis", Economic Studies and Policy Analysis Division Economic and Fiscal Policy Branch Department of Finance, Ottawa, Canada.

Dunlap, R. E. (1975), "The Impact of Political Orientation on Environmental Attitudes and Actions", *Environment and Behavior*, Volume 7, Issue 4, pages 428-454.

Ederington, J., Levinson, A., and Minier, J. (2003), "Footloose and Pollution-Free", NBER Working Paper 9718.

Ederington, J., Levinson, A., and Minier, J. (2005), "Footloose and Pollution-Free", *The Review of Economics and Statistics*, Volume 87, Issue 1, pages 92-99.

Ekins, P. (2003), "The Kuznets Curve for the Environment and Economic Growth: Examining the Evidence", *Environment and Planning*, Volume 29, pages 805-830.

Ekins, P. (2003), "Trade and Environment", International Society for Ecological Economics Internet Encyclopaedia of Ecological Economics.

Eskeland, G. S. and Harrison, A. E. (2003), "Moving to Greener Pastures? Multinationals and the Pollution Haven Hypothesis", *Journal of Development Economics*, Volume 70, Issue 1, pages 1-23.

Esty, D. C. (2001), "Bridging the Trade-Environment Divide", *Journal of Economic Perspectives*, Volume 15, Issue 3, pages 113-130.

Fougère, M. and Mérette, M. (1999), "Population Ageing and Economic Growth in Seven OECD Countries", *Economic Modeling*, Volume 16, Issue 3, pages 411-427.

Frankel, J. A. and Rose, A. K. (2005), "Is Trade Good or Bad for the Environment? Sorting tout the Causality", *Review of Economics and Statistics*, Volume 87, Issue 1, pages 85-91.

Georgarakos, D. (2003), “Risky Assets Ownership Decision by the Elderly: Evidence from the UK Retirement Survey”, Paper No. 84, Royal Economic Society Annual Conference 2003.

Georges, P. and Mérette, M. (2007), “Overlapping-Generations General Equilibrium Modeling with GAMS A Practical Guide to a Simple Overlapping Generations Model”, Manuscript.

Georgescu-Roegen, N. (1971), *The Entropy Law and the Economic Process*, Cambridge, Harvard University Press.

Germain, M. and Lambrecht, S. (2005), “Modèles à générations imbriquées et environnement, une révue de littérature”, Document de travail CLIMNEG n°75.

Gianluigi V. (2003), “Environmental Externality and Capital Accumulation in an Overlapping Generations Model”, Working Paper, University of Warwick.

Ginsburgh, V. (1994), “In the Cournot-Walras general equilibrium model, there may be “more to gain” by changing the numéraire than by eliminating imperfections: A two-good economy example”, In *Applied General Equilibrium and Economic Development*, ed. J. Mercenier and T. N. Srinivasan, pages 217–24, Ann Arbor: University of Michigan Press.

Grossman, G. and Kreuger, A. (1995), “Economic Growth and the Environment”, *Quarterly Journal of Economics*, Volume 110, Issue 2, pages 353-377.

Grossman, G. M. and Krueger, A. B. (1991), “Environmental Impact of a North American Free Trade Agreement”, NBER Working Papers Series. Working Paper No. 3914.

Grossman, G. M. and Krueger, A. B. (1993), “Environment Impacts of North American Free Trade Agreement”, in Garber, Peter, M., ed., *The Mexico-U.S. free trade agreement*, Cambridge and London: MIT Press, pages 13 - 56.

Guest, R. (2010), “Global Demographic Change, Carbon Emissions, the Optimal Carbon Price and Carbon Abatement”, *Global Economy Journal*, Volume 10, Issue 2, Article 8.

Gulati, S. (2005), “Free Trade and the Greening of Domestic Industry”, *Food and Resource Economics*, University of British Columbia.

Harbaugh, W., A. Levinson, and D. Wilson (2002), “Re-Examining Empirical Evidence for an Environmental Kuznets Curve”, *Review of Economics and Statistics*, Volume 84, Issue 3, pages 541-551.

Harberger, A. C. (1962) “The Incidence of the Corporate Income Tax”, *Journal of Political Economy*, Volume 70, pages 215-40.

Harold, C. and C.F. Runge (1993), "GATT and the Environment: Policy Research Needs", *American Journal of Agricultural Economics*, Volume 75, Issue 3, pages 789-793.

Hersch, J. and Viscusi, W.K. (2005), "Paying for Climate Change Policies in Europe", John M. Olin Center for Law, Economics, and Business, Discussion Paper no. 503, Harvard Law School, Cambridge, United States.

Hettige, H., R. Lucas, and D. Wheler (1992), "The Toxic Intensity of Industrial Production: Global Patterns, Trends and Trade Policy", *American Economic Review*, Volume 82, Issue 2, pages 478-481.

Hilton, H. and A. Levinson (1998), "Factoring the Environmental Kuznets Curve: Evidence from Automotive Lead Emissions", *Journal of Environmental Economics and Management*, Volume 35, Issue 2, pages 126-141.

Hornback, K. E. (1974), Orbit of Opinion: The Role of Age in the Environmental Movement's Attentive Public, 1968-1972, Ph.D. Dissertation, Michigan State University.

Islam, N. and Murray, S. (1992), *Trade and Sustainable Development*, Ottawa: Institute for Research on Public Policy and the International Institute for Sustainable Development, 71 pages.

Jaffe, A. B., Peterson, S. R., Portney, P. R., and Stavins, R. N. (1995), "Environmental Regulation and the Competitiveness of U.S. Manufacturing: What does the Evidence Tell Us?", *Journal of Economic Literature*, Volume 33, Issue 1, pages 132-162.

Johansen, L. (1960), *A Multi-Sector Study of Economic Growth*, Amsterdam: North Holland Pub. Co.

John, A. and Pecchenino, R. (1994), "An Overlapping Generations Model of Growth and The Environment", *The Economic Journal*, Volume 104, Issue 427, pages 1393-1410.

Jorgenson, D. W. (1984), "Econometric Methods for Applied General Equilibrium Analysis", In *Applied General Equilibrium Analysis*, ed. H. E. Scarf and J. B. Shoven, pages 139–203. Cambridge: Cambridge University Press.

Jorgenson, D. W. and Yun, K.-Y. (1990), "Tax Policy and U.S. Economic Growth", In *General Equilibrium Modeling and Economic Policy Analysis*, ed. L. Bergman, D. W. Jorgenson, and E. Zalai. Oxford: Basil Blackwell.

Kahn, M.E. (1998), "A Household Level Environmental Kuznets Curve", *Economics Letters*, Volume 59, Issue 2, pages 269-273.

Keller, W. and Levinson, A. (2003), “Pollution Abatement Costs and Foreign Direct Investment Inflows to U.S. States”, *Review of Economics and Statistics*, Volume 84, Issue 4, pages 691-703.

Knack, S. and Keefer, P. (1995), “Institutions and Economic Performance: Cross Country tests Using Alternative Institutional Measures”, *Economics and Politics*, Volume 7, pages 207-227.

Kohl, R. and P. O'Brien (1998), "The Macroeconomics of Ageing, Pensions and Savings: A Survey", OECD Economics Department Working Papers, No. 200, OECD Publishing.

Kriström, B. (2000), “Growth, Employment and the Environment”, *Swedish Economic Policy Review*, Volume 7, Issue 1, pages 155-184.

Kriström, B. and Riera, P. (1996), “Is the Income Elasticity of Environmental Improvements Less Than One?”, *Environmental and Resource Economics*, Volume 7, pages 45-55.

Kriström, S. (1998), “On a Clear Day, You Might See the Environmental Kuznets Curve”. mimeo.

Kuznets, S. (1937), *Natural Income and Capital Formation, 1919–1935*, New York: National Bureau of Economic Research.

Lenzen, M., Wier, M., Cohen, C., Hayami, H., Pachauri, S., and Schaeffer, R. (2006), “A Comparative Multivariate Analysis of Household Energy Requirements in Australia, Brazil, Denmark, India and Japan”, *Energy*, Volume 31, pages 181-207.

Leontief, W. W. (1941), “The Structure of American Economy, 1919–1929: An Empirical Application of Equilibrium Analysis”. Cambridge, Mass.: Harvard University Press.

Levinson, A. and Taylor, M. S. (July 2003), “Trade and the Environment: Unmasking the Pollution Haven Hypothesis”, Working Paper No. ueconwpa~04-04-04, Department of Economics, Georgetown University.

Liddle, B. (2001), “Free Trade and The Environment-Development System”, *Ecological Economics*, Volume 39, Issue 1, pages 21-36.

List, J. A., Millimet, D. L., Fredriksson, P. G., and Warren, W. (2004), “Effects of Environmental Regulations on Manufcaturing Plant Births: Evidence from a Propensity Score Matching Estimator”, *Review of Economics and Statistics*, Volume 58, Issue 4, pages 944-952.

Little, I. (1973), *A Critique of Welfare Economics*, 2nd edition, Oxford University Press, London.

Lopez, R. (1994), “The Environment as a Factor of Production: The Effects of Economic Growth and Trade Liberalization”, *Journal of Environmental Economics and Management*, Volume 27, Issue 2, pages 163-184.

Low, P. and Yeats, A. (1992), “Do dirty Industries Migrate?”, In *International Trade and the Environment*, Patrick Low, ed. Washington. DC: World Bank, pages 89-104.

Lowe, G. D. and Pinhey, T. K. (1982) “Rural-Urban Differences in Support for Environmental Protection”, *Rural Sociology*, Volume 47, pages 114-28.

Lucas, R., Wheeler, D., and Hettige, H. (1992), “Economic Development, Environmental Regulation and the International Migration of Toxic industrial Pollution: 1960-1988,” In Patrick Low (ed.), *International Trade and the Environment*, Washington, DC, pages 67-86, World Bank Discussion Paper 159.

MacKellar, F. L., A. Goujon, and C. Prinz (1995), “Population, Number of Households, and Global Warming”, *Popnet*, Volume27, pages 1-3.

Magnani, E. and Tubb, A. (2007), "The Link Between Economic Growth and Environmental Quality: Does Population Ageing Matter?", School of Economics at the University of New South Wales, Sydney, Australia, Discussion Paper: 2007/12

Magnani, E. and Tubb, A. (2007), "The Link Between Economic Growth and Environmental Quality: Does Population Ageing Matter?", School of Economics at the University of New South Wales, Sydney, Australia, Discussion Paper: 2007/12

Malkis, A. and Grasmick H. G. (1977), “Support for the Ideology of the Environmental Movement: Tests of Alternative Hypotheses”, *Western Sociological Review*, Volume 8, Issue 1, pages 25-47.

Mani, M. and Wheeler, D. (1997) “In Search of Pollution Havens? Dirty Industry in the World Economy, 1960-1995”, in Fredriksson, Per G., ed., *Trade, global policy, and the environment*, Discussion Paper, no. 402, World Bank, Washington, D.C., 1999, pages 115-28.

Manne, A. S. (1985), *Economic Equilibrium: Model Formulation and Solution Mathematical Programming Study 23*, Amsterdam: North-Holland

McConnell, K.E. (1997), “Income and the Demand for Environmental Quality”, *Environment and Development Economics*, Volume 2, Part 4, pages 383-400.

Meade, J. E. and Stone, J. R. N. (1941), “The Construction of Tables of National Income, Expenditure, Savings, and Investment”, *Economic Journal*, Volume 51, pages 216–33.

Meadows, D.H., Meadows, D.L., Randers, J., and Behrens, W.W. (1972), *The Limits to Growth*, London, Earth Island Limited.

Mercenier, J. and Srinivasan, T. N. (1994), *Applied general equilibrium and economic development*, Ann Arbor: University of Michigan Press.

Mercier, J., Mérette, M., Beausejour, L., and Hsueh, J. (2001), “A Multi-Region, Multi-Sector Dynamic Genereal Equilibrium Tax Model (DGETM)”, Manuscript.

Mohai, P. and Twight, B. W. (1987), “Age and Environmentalism: An Elaboration of the Buttel Model Using National Survey Evidence”, *Social Science Quarterly*, Volume 68, Issue 4, pages 798-815.

Naito, T. and Zhao, L. (2008), “Aging, transitional dynamics, and gains from trade”, Discussion Paper No. 215, Research Institute for Economics & Business Administration, Kobe University.

Nordstrom H. and W. Vaughan (1999), *Trade and the Environment*, World Trade Organization, Geneva, Switzerland

O’Neill, B.C. (2009), “Climate Change and Population Growth,” In Mazur, L. 2009, *A Pivotal Moment: Population, Justice and the Environmental Challenge*, Island Press, Washington, D.C.

O'Connell, J. (1982), *Welfare Economic Theory*, Auburn House Publishing, Boston.

O'Neill, B.C. and Chen, B.S. (2002), “Demographic Determinants of Household Energy Use in the United States”, *Population and Development Review*, Volume 28, pages 53-88.

Pacala, S. and R. Socolow (2007), “Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies”, *Science*, Volume 305, Issue 5686, pages 968-972.

Panayotou, T. (1993), “Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development”, Working Paper WP238 Technology and Employment Programme, Geneva: International Labor Office.

Panayotou, T. (2003), “Economic Growth and the Environment”, Paper prepared for and presented at the Spring Seminar of the United Nations Economic Commission for Europe, Geneva.

Panel on Policy Implications of Greenhouse Warming (1992), *Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base,* Washington, D.C.: National Academies Press, pages 811.

Pearson, P. (1994), "Energy, Externalities and Environmental Quality: Will Development Cure the Ills It Creates?", *Energy Studies Review*, Volume 6, Issue 3, pages 199-215.

Perroni, C. and Wigle, R. M. (1994), "International Trade and Environmental Quality; How Important are the Linkages?", *Canadian Journal of Economics*, Volume 27, Issue 3, pages 551-67.

Pigou, A. C. (1932), *The Economics of Welfare*, Fourth Edition, London: Macmillan and Co.

Rodrik, D. (1999), *The New Global Economy and Developing Countries: Making Openness Work*, Washington, DC. Overseas Development Council.

Rothman, S. (1998), "Environmental Kuznets Curves - Real Progress or Passing the Buck? A Case for Consumption - based approaches", *Ecological Economics*, Volume 25, Issue 2, pages 177-194.

Runge, C. F. (1998), "Emerging Issues at the Interface of Domestic and International Policy: Agricultural Trade and the Environment", WWF/OECD.

Satterthwaite, D. and D. Dodman (2009), "The Role of Cities in Climate Change", In *State of the World 2009: Into a Warming World*, Engelman, R., M. Renner and J. Sawin, eds., New York: Norton.

Scarf, H. E. (1967), "On the computation of equilibrium prices", In *Ten Economic Studies in the Tradition of Irving Fischer*, ed. W. J. Fellner, pages 207–30. New York: Wiley.

Scarf, H. E. and Hansen, T. (1973), *The computation of economic equilibria*, New Haven: Yale University Press.

Scarf, H. E. and Shoven, J. B. (1984), *Applied general equilibrium analysis*, Cambridge: Cambridge University Press.

Schipper, L. (1996), "Lifestyles and the environment: the case of energy", *Daedalus*, Volume 125, Issue 3, pages 113-138.

Selden, T.M. and Song, D. (1994), "Environmental Quality and Development: Is there a Kuznets Curve for Air Pollution Emissions*?", Journal of Environmental Economics and Management*, Volume 27, Issue 2, pages 147-162.

Selden, T.M., and D. Song (1995), "Neoclassical Growth, the J Curve for Abatement and the Inverted U Curve for Pollution", *Journal of Environmental Economics and Management*, Volume 29, pages 162-168.

Shafik, N. (1994), "Economic Development and the Environmental Quality: An Econometric Analysis", *Oxford Economic Papers*, Volume 46, pages 757-773.

Shafik, N. and Bandyopadhyay, S. (1977), "Economic Growth and Environmental Resources", *Journal of Environmental Economics and Management*, Volume 4, pages 1-24.

Srinivasan, T.N. and J. Bhagwati (1999), "Outward-Orientation And Development: Are Revisionists Right?", Center Discussion Paper, No. 806, Economic Growth Center, Yale University.

Stern, D.I. (1998), "Progress on the Environmental Kuznet Curve?", *Environment and Development Economics*, Volume 3, pages 173-196.

Stern, D.I. (2003), "The Environmental Kuznets Curve", International Society for Ecological Economics, Internet Encyclopaedia of Ecological Economics.

Stern, D.I. (2004), "The Rise and Fall of the Environmental Kuznet Curve", *World Development,* Volume 32, Issue 8, pages 1419-1439.

Stone, R. (1947), Measurement of National Income and the Construction of Social Accounts. Geneva: United Nations.

Stone, R. (1985), "The Disaggregation of the Household Sector in the National Accounts", In *Social Accounting Matrices: A Basis for Planning*, ed. G. Pyatt and J. I. Round, pages 145–85.Washington: The World Bank.

Stone, R. (1986), "The accounts of society", *Journal of Applied Econometrics*, Volume 1, pages 5–28.

Studenski, P. (1958), *The Income of Nations*, New York: New York University Press.

Tetsuo, O. (2004), "The Political Economy of Environmental Taxes with an Aging Population", *Environmental and Resource Economics*, Volume 30, Issue 2, pages 165-194.

Tetsuo, O. and YASUO, M. (2001), "Is Aging Harmful to the Environment?", *Environmental and Resource Economics*, Volume 20, Issue 2, pages 113–127.

Thimothy, J. K. (1996), "Social Accounting Matrices and Applied General Equilibrium Models", Working Paper 563, Federal Reserve Bank of Manneapolis Research Department.

Tobey, J.A. (1990), “The Effects of Domestic Environmental Policies on Patterns of World Trade: an Empirical Test”, *Kylos*, Volume 43, Issue 2, pages 191-209.

United Nations Population Fund, State of World Population (2009), Facing a Changing World: Women, Population and Climate. Available at: http://www.un.org.vn/index.php?option=com_content&view=article&id=995%3Afacing-a-changing-world-women-population-and-climate&catid=45%3Aunfpa-press-releases&Itemid=101&lang=en

Van Liere, K. D. and Dunlap, R. E. (1980), “The Social Bases of Environmental Concern: A Review of Hypotheses, Explanations and Empirical Evidence”, *Public Opinion Quarterly*, Volume 44, pages 181-97.

Verchère, A. (2003), “Développement durable et Rapports Nord-Sud dans un Modèle à Générations Imbriquées : Interroger le futur pour éclairer le présent”, *Recherches Économiques de Louvain* , Volume 69, pages 205-228.

Vlosky, D. A. and Vlosky, R. P. (1999), “Exploring Age-Related Environmental Attitudes in the Context of Wood Product Certification”, Working Paper No. 51, Louisiana State University Agricultural Center Baton Rouge, LA.

Wheeler, D. and D. Hammer (2009.), “The Economics of Population Policy for Carbon Emissions Reduction”, Working Paper, Washington, D.C.: Center for Global Development.

Wier, M., Lenzen, M., Munksgaard, J. and Smed, S. (2001), “Environmental effects of household consumption pattern and lifestyle”, *Economic Systems Research*, Volume 13, Issue 3, ages 259-274.

Xing, Y. and Kolstad, C. D. (2002), “Do Lax Environmental Regulations Attract Foreign Investment?”, *Environmental and Resource Economics*, Volume 21, Issue 1, pages 1-22.

Yamasaki, E. and Tominaga, N. (1997), “Evolution of an aging society and effect on residential energy demand”, *Energy Policy*, Volume 25, Issue 11, pages 903-912.