Environmental Policy and the Properties of Environmental Damages

Applications to economic growth and international environmental problems

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To my sister Eru because I have missed her all these years.

To my brother Iyob because I miss him and because he stood up for his beliefs no matter what the cost.

Abstract

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This thesis focus on three properties of environmental damages: variation across individuals, across sectors and geographical variation. The thesis consists of five articles, two are on long term growth and the environment, two are on international environmental problems and one is on growth and international environmental problems.

In Article I it is shown that under the assumption that pollution is a public bad, productivity of pollution has no effect on steady state growth rate. However, if the reach of pollution is limited then pollution is not purely public in character and the productivity of pollution has a positive impact on growth. In Article V population growth's positive and negative effects on pollution are examined.

In Article II the strategic aspect of self-protective activities to moderate environmental damages is analyzed. Self-protection is defined as decreasing own environmental damages without changing the level of pollution. Agents can through self-protection make strategic gains by decreasing their cost of abatement and still enjoy high level environmental quality as other agents are induced to increase their abetment. These gains are greatest when agents cooperate on abatement because cooperation leaves more room for strategic behavior to self-protection.

In Article III environmental policy of open countries trading polluting goods and polluted eco-services is investigated. Large economies choose strict or lax environmental policies depending on the relative value of eco-services and how this value changes due to changes in environmental policy. For small regional environmental problems where prices are exogenous, it is shown that a country's response to changes of the world price depend on the relative productivity of emissions within the region and the response of other countries.

In Article IV we look at a problem when countries concerned with the environment unilaterally abate in foreign countries because of low technological productivity levels in the latter countries and asymmetries in environmental damages. Sweden, financing sewage treatment plants in the baltic region to moderate eutrophication of the Baltic Sea, may be such an example.

Key words: Environmental damages, environmental policy, characteristics of bads, economic growth, population growth, strategic behaviors, self-protection, trade and the environment, transboundary pollution.

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Preface

I developed a particular interest in environmental economics during my undergraduate studies in the first half of the 90's thanks to a dynamic group working in that field at the Department of Economics at SLU. Years later, when Ing-Marie Green gave me the opportunity to start the PhD programme in economics with specialization on environmental issues, I never hesitated.

I am very grateful to my supervisors. Some months ago when research seemed meaningless and I was slowing down with my work Clas Eriksson asked me "Would it make any difference if I am tougher on you?". At that time I think those words were among the few that could have reached me. That is typical of Clas, he could always read me. He gave me the necessary input when I needed it. Through our collaboration on the first article he gave me inspiration and introduced me to academic writing. He also gave me the freedom to develop my own ideas while still keeping a great interest in my work. He quickly discovered weakness in my drafts and always gave me valuable advice and suggestions. Thank you Clas! I would also like to thank Ing-Marie Gren for believing in me and giving me the opportunity to start my PhD. Throughout, my graduated studies Ing-Marie has been a great support to me and she has continuously encouraged me. I am particularly grateful for her, as well as other's colleagues, moral support one year ago in a difficult time of my life.

Thanks to the group of graduated students at The Department of Economics at SLU for making my time as a Ph D student much more enjoyable. I am particularly indebted to Rob Hart. As a keen observer, Rob, has been a great resource to me. His comments are always right on target and have improved my thinking and writing. Functioning as an English dictionary, introducing and helping me with the computer package Latex he has saved me lots of time. Special thanks also to Ruben Hoffman, Mitesh Kataria, Dennis Collentine and Magnus Hennlock from whom I have gained a great deal through discussions and suggestions. Thanks also to Erik Fahlbeck, Peter Frykblom, Richard Furguson who, along with those already mentioned and many other graduated students, with interest have participated in one or more of my seminars at the department. Thanks, to Tomas Sjögren for valuable comments at my final seminar and to Christina Brundin for an excellent library service.

There also other people that deserve my gratitude. My first year in Uppsala I arranged a room to rent but was later refused the room because as the landlord expressed it 'I have to give priority to Swedish students'. Having no where to stay Yared Tekeste, Adiam and their daughter Malaika invited me to stay in their apartment and gave me the opportunity to start my academic carrier in their a warm and secure home. Thank you! Early in my undergraduate studies I got to know a group of students starting up an organization that later took the name of SUG (Studenter utan Gränser). Being part of this group made my academic life easier and full of interesting discussions and laughter. Thank you to all SUG people, and especially (in a rough order of appearance!) to Samuel Habteab, Rene Léon, Alicia Barczyk, Nesrin Aslan, Roland Madarász, Valenka Molina Vidal, Christine Schnabel, Josef el Mahdi, Cristoffer Lindgren, Nadine Gaib, Elin Asplund and Daniel Lindvall.

Among my fellow country men I often heard that 'a good freedom fighter building a nation must start by building up his family'. In that case the best freedom fighter I know is my mother. Knowing her, I have many times asked myself how

much love a heart can contain. She gives love to everybody even though her love is not returned. Her love and teaching to always do good no matter what others do is fundamental to me as it helps me to face each day in a positive manner. Thanks also to my brother Ghedlom that better than anyone of her children learned to be generous with his love and whatever he owns. My admiration goes also to my brother Iyob who was way ahead of us in any thinking that he did. He stood up for his beliefs against authorities, norms and traditions no matter what the cost. His curiosity and critical analysis would have made him a great researcher but he chose to deal with real problems rather than academic abstractions. Finally, I am grateful to my soul mate, my wife Malin. No words can express how much I owe her. Her love has constantly been feeding me with energy and helped me to overcome that which I believed was not possible to overcome. The fruit of our love is our son Iyob whom in these last months has been the source of so much joy, that I find it impossible to convey. His birth was a turning point in my life and I'm not sure that this PhD would have been finished if he had not been with me these last months of writing.

This thesis consists of five papers where the main theme is that the economic damages of pollution are more complicated than is often assumed in the literature. This idea later crystalized in the the title of this thesis. I am not sure this title fits all the articles but I found it to be the most appropriate of all the alternative that I could think of.

Ficre Zehaie,
Uppsala, August 2005.

Articles appended to the thesis

The thesis is based on the following articles, by Ficre Zehaie except where otherwise stated.

I Population Density,Pollution and Growth.
Clas Eriksson and Ficre Zehaie.

II The Strategic Role of Self-protection.

III Environmental Policy in Open Economies

IV Unilateral Actions Abroad to Reduce Inflowing Transboundary Pollution

V Is Population Growth Good for the Environment?
Clas Eriksson and Ficre Zehaie.

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Articles I–V

1 Introduction

The process of environmentally caused economic damages—or simply environmental damages—may be described as follows: Human activities generate emissions polluting the environment which then lands to economic damages. In the literature there is a tendency to overlook the difference between pollution of the environment and its economic consequences. To some extent this may be semantics as most environmental economist when they use the term pollution in fact mean its economic consequences. However, there seems to be more to it. In the theoretical literature on environmental economics it is often assumed that pollution is a public bad (or that environmental quality is a public good) and therefore affects all individuals.[1] This assumption is often interpreted as if all individuals are equally affected. Alternatively, the literature disregards variations in pollution. Thus, it may be problematic to use pollution as synonymous with the damages it causes. In reality environmental damages often varies across geographical areas, individuals or sectors of the economy even when pollution is public. For instance, global warming is predicted to increase sea water level and the damages upon individuals or firms vary depending on the distance to the sea and the altitude of the area where they are situated. Furthermore, the better the local infrastructure the lower the damages. In the case of ozone depleting chemicals, it is acknowledged that the ozone holes occur primarily in cold areas and therefore damages vary depending on where individuals live relative to the holes. Similarly, damages due to car emissions depend on individual's positions relative to heavily trafficked areas. In the two last cases individuals can protect themselves by solar blocks or air masks, both of which influence the variation across individuals. It is therefore reasonable to think that agents' choices between environmental quality and consumption goods are related to these variations, which in this thesis are described as properties of environmental damages. Most models make the common assumption that pollution is a public bad and ignore these variations. The main theme of this thesis is a more careful treatment of environmental damages.

The purpose of this thesis is to show that the properties of environmental damages need to be considered in order to efficiently design environmental policies. This is applied to two areas: economic growth and international environmental economics. Articles I and V consider how the reach of damages across individuals may affect long term economic choices. Article II examines agents' strategic behavior when they can decrease damages to their own benefit. Article III studies open economies' optimal behavior when damages vary across sectors that produce traded goods. Finally, Article IV deals with both economic growth and international environmental problems when damages vary across geographical areas.

First the properties of environmental damages considered in this thesis are presented, followed by a summery of each of the five articles included in the thesis are

[1] In this thesis we sometime use the terms individuals, firms and countries and sometimes the more general term agents to refer to any of the three terms.

summarized. In the final section conclusions are presented.

2 Environmental Damages

To capture some conceptual similarities of environmental damages it is necessary to disregard from at least some of its complexities. In environmental economics it is common to disregard from the many ways in which environmental damages may affect humans. In particular, this is often the case in the theoretical literature on growth and pollution (see for instance Keeler et al. (1972), Brock (1977), Tahvonen and Kuuluvainen (1993) and Bovenberg and Smulders (1995)) and the theoretical literature on international environmental problems(see for instance Markusen (1975), Copeland and Taylor (1990), Hoel (1992) and Barrett (1994)). However, in this thesis it is argued that the final impact of pollution on human welfare may show to have greater variations than is often acknowledged and affects environmental policy. In the following sections the different properties (types of variation) of environmental damages that are examined in this thesis are discussed.

2.1 Variation Across Individuals

In this thesis two types of variations across individuals are examined. In Article I variation across individuals occurs because the reach of pollution is limited and in Article II because agents can take self-protective measures to moderate damages.

If pollutants are not purely public the damages across individual will vary because one agents exposure to pollution will leave less pollution for other individuals. The crucial assumption is that pollutants are rival. A well known example of a private bad is a bag of garbage thrown into a neighbor's garden. An example of something between a public and private bad may be illustrated by the following case. If a a good available in the market contains some chemicals or dangerous micro organisms there is a given probability that a consumer will be affected. For each consumer that is affected, and given that the affected consumer does not himself affect other consumers, the probability that other consumers are affected decreases. Thus consumers are rivals in the bad but they are not fully rivals as the 'consumption' of the bad of one individual just decreases the probability that other consumers will be affected.

Furthermore, environmental damages across agents may vary because agents can take self-protective measures to moderate damages for given levels of pollution. For example, if global warming, as predicted, increases the frequency of bad weather, then countries can moderate damages through improvements in weather forecasting, monitoring systems and improvements in infrastructures. An other example of self-protection is individuals protecting themselves from hazardous solar rays by using solar blocks or clothing. Therefore the level of self-protection that each agent chooses will to some extent determine the level of damages harming the agent. Since the possibility of self-protection may differ among agents, for instance as a result of differences in income and technological levels, one should expect that environmental damages vary across individuals.

2.2 Variation Across Sectors

Some sectors of the economy are more likely to suffer from environmental damage than others. For example, emissions that may result in ecosystem degradation, reduces the flow of eco-services. Meanwhile, production in other sectors, given the level of technology, may be positively related to emission levels.

From a consumer's point of view degradation of the environment is often considered to be a public bad. However, from a producer's point of view, allowing higher emission levels may benefit production in some sectors while harming other sectors. Although this is well known in the literature most analyses of international environmental economics ignore such variations across sectors.

If environmental policy affects sectors of the economy in different ways, it will also affect the structures of the economies. Since the structure of an economy is closely connected to trade, it is interesting to investigate environmental policy when environmental damages vary across sectors in open economies.

2.3 Variation Across Regions

Environmental damages can vary across regions and this may be independent of where the sources of emissions are located. The extent to which emissions cause subsequent damages in a region depends upon factors such as its geographical location and the the ecology and the meteorology prevailing in the area. These factors determine the concentrations of emissions across a given region.

This is illustrated by the problem of eutrophication in the Baltic Sea. The Baltic Sea is bordered by nine countries: Sweden, Finland, Denmark, Germany, Poland, Lithuania, Latvia, Estonia and Russia. Sweden and Finland have much longer costs to the Baltic sea than the other countries and a higher proportions of their populations living around the costs. Furthermore, the highly populated areas in Sweden and Finland are in the archipelagos which are coastal regions with limited water exchange. Thus nutrient runoff in these areas is primarily local and only a smaller amount is transported off to the sea. On the other hand, open coasts such as those of Latvia and Poland, with high water exchange, are likely to cause a situation where nutrient losses from these countries lead to relatively low local pollution and conversely high transport to the sea proper. Thus nutrient loads to the Baltic Sea seem to have asymmetric characteristics.

It seems that eutrophication of the Baltic Sea is a concern primarily of Sweden and Finland. This is partly because a greater proportion of the population in these two countries lives around the costs and partly because asymmetries in the loads of nutrient tend to give higher environmental damage in the densely populated coastal areas of these two countries. Thus the average citizen of these countries is probably more concerned about eutrophication than the average citizen in the other countries.

3 Article I—Population Density, Pollution and Growth

In the theoretical literature of economic growth it is standard to assume that degradation of environmental quality has public bad characteristics, which is often interpreted as if every unit of pollution harms the entire population of the economy.[2] However, as we argue in the previous section, pollution may affect only a proportion of the population and the extent of exposure may be less than the aggregate pollution generated in the economy. This implies that the reach of pollution may be limited. In this paper we therefore investigate the conditions for sustainable growth when we take into consideration that the reach of pollution is limited. Sustainable growth is defined as a situation with per capita consumption growth and declining pollution. Allowing the characters of pollution to vary between the two extremes cases of a private bad and a public bad, population density emerges as an interesting factor for sustainable growth.

We introduce the concept of *perceived pollution* to capture that each individual's exposure to pollution is less than the total pollution produced in the economy. We define perceived pollution as aggregated pollution deflated with the size of population, weighted to account for the characteristics of pollution and the population density. The more private pollution is the greater the weight of population as deflator and the more will pollution be divided among the population. The more public pollution is the less is the weight of population size as deflator and the more will pollution be spread among the population. Therefore the characteristics of aggregate pollution is related to population density. This relation is introduced through the elasticity of perceived pollution with respect to population density *(EPD)*. The more responsive perceived pollution is to population density (i.e. the higher the *EPD*), the lower is the weight of population in deflating aggregate pollution and the more public is pollution.

We assume that there is a representative dynasty that maximizes utility and disregard from generational conflicts. We calculate optimal long term growth rates for two types of models: the traditional exogenous growth model and a semi-endogenous growth model. Consumers face a trade-off between, consumption and pollution. However, as opposed to the earlier literature, consumers pollution is less than aggregate pollution and is introduced in the model as *perceived pollution*. Following, Brock (1977), pollution is an input in the production function along with capital and labor. We assume that pollution is a flow pollution to hold the model simple. As Stokey (1998) has showed, assuming stock pollution will not change the results significantly, at least in the long term.

In the exogenous growth model the condition for sustainable growth can be described as a race between exogenous technological change and the drag on economic growth from the additional pollution resulting from a growing population. A large *EPD*—corresponding to higher responsiveness of perceived pollution to population

[2] See for example Keeler et al. (1972), Brock (1977), Tahvonen and Kuuluvainen (1993), Bovenberg and Smulders (1995), Michel and Rotillon (1995), Smulders and Gradus (1996), Stokey (1998) and Schou (2000).

density—reinforces the drag that pollution puts on economic growth. In this case society puts more resources into the environmental sector. A small *EPD* moderates the economic drag of population growth and corresponds to a situation where society puts less resources in the environmental sector.

In the semi-endogenous model technological change is determined within the model and is therefore an endogenous variable, but population growth is still exogenous. Population growth increases the supply of labor force in the economy and as such is the driving force for growth in a semi-endogenous model. Furthermore, low population density decreases the reach of pollution and thereby individuals' perceived pollution. Consequently, pollution contributes less to jeopardize sustainable growth. This is reversed if the reach of pollution is high. Then perceived pollution is high and pollution implies a stronger threat to sustainable growth. The more densely an area is populated the more difficult it is to achieve sustainable growth.

To summarize: the more public pollution is and the greater population density is the more difficult it is to achieve sustainable growth.

4 Article II—The Strategic Role of Self-protection.

In this paper self-protection from adverse environmental effects is examined as an alternative strategy to abatement. Self-protection decreases own damages for given levels of the activities generating the public bad while abatement decreases the activities generating public bads to reduce damages. Agents can therefore substitute an action that has private good characteristics (self-protection) for an action that has public good characteristics (abatement). It is important to understand strategic games of this kind as sometimes it may be difficult to solve public bad problems through abatement. For example, interventional environmental agreements on abatement need to be self-enforcing and it may difficult to sustain efficient levels of abatement. Therefore, protection may be an alternative option against pollution. In fact, protective action are considered as a possible strategy to meet global warming, see for instance IPCC (2001).

The existing literature on self-protection focuses on uncertainty (Ehrlich and Becker, 1972; Dionne and Eeckhoudt, 1985; Lewis and Nickerson, 1989; Immordino, 2003). Shogren and Crocker (1991) study how self-protection transfers or dilutes the public bad to other agents. Individuals' expenditures on self-protection has also been used to approximate the market value of environmental quality (Murdoch and Thayer, 1990; Baumol and Oates, 1988). Mendelsohn (2000) considers self-protection as the only instrument against global warming and finds the common result that government interventions tend to give non-optimal levels of self-protection and therefore these intervention are not cost efficient. Despite the obvious interrelation between abatement and protective activities there are no studies that investigate this interrelation except for Kane and Shogren (2000). They consider protective activities as an alternative policy to abatement and derive the optimality conditions under uncertainty and investigate how changes in risks change policy choices of

abatement and protection. As opposed to this paper, however, they do not analyze strategic issues.

The level of self-protection affects agents' vulnerability to pollution and thereby how much they abate. Since abatement is public, each agent's abatement level affects abatement levels of all other agents. Therefore an agent's choice of self-protection will affect his own as well as other agents' share of total abatement. Following the literature on investment as a strategic variable in the provision of public goods[3], a two-stage two-agents model, where agents in the first stage of the game choose the level of self-protection and in the second-stage they choose the level of abatement, is set up. In each stage agents maximize utility given a budget constraint. In the first stage income can be consumed or used for self-protection, while in the second stage it can be consumed or used for abatement. There may be three interesting scenarios to investigate. The first scenario is the noncooperative case when agent do not cooperate in any stage. The second scenario is the semi-cooperative case when agents cooperate in the second stage of the game on abatement but not in the first stage on self-protection. The third scenario is the full-cooperative scenario when countries cooperate in both stages.

In all scenarios, agents' choices of abatement and self-protection are determined by the relative sizes of their marginal costs. However, the strategic aspects of the problem twist the relative attractiveness of self-protection over abatement. For the non-cooperative and semi-cooperative scenarios it is shown that self-protection is substituted for abatement. Self-protection in addition to the direct benefit of protecting from damages, gives strategic advantages, which increases agents' incentives to use self-protection. Higher self-protection reduces own damages for a given level of abatement and thereby decreases own demand for abatement. Consequently, an agent that has taken self-protective measures decreases her share of abatement level and other agents respond by increasing their share of total abatement. Since abatement benefits all agents but has private costs an agent by her choice of the level of self-protection transfers more costs of abatement over to other agents.

The semi-cooperative scenario is an interesting case because it corresponds to the most common cases of regulation on environmental issues. Policy maker often regulate abatements or emissions levels but very little attention, if any, is given to self-protective activities. This in line with conventional economic theory where regulations on pubic goods may be Pareto improving while regulation on private goods in not. However, when self-protection is a substitute for abatement this not to be case. The reason is that agents can still free ride as they can affect the cooperative levels of abatements through the use of self-protection to their own benefits. Within a country it means that individuals can manipulate the social planner's solution such that the share of abatement they need to contribute with is decreased and that of the other individual is increased. In international environmental problems it means that countries can affect cooperative or bargaining outcomes such that the own contribution to abatement is decreased and that of the other countries is increased. Furthermore, it is shown that the greatest strategic advantages are to

[3]See for instance Copeland and Taylor (1990); Buchholtz and Konrad (1994); Stranlund (1996) and Aggarwal and Narayan (2004).

be found in the semi-cooperative scenario. The reason is that the levels of abatement when countries cooperate are higher as each country takes into consideration the positive externality of abatement. Thus, in addition to the strategic gains in the noncooperative case, self-protection gives an agent further strategic gains from the additional abatements due to cooperation.

Finally, the full cooperative scenario is investigated and it is shown that the level of self-protection is the lowest compared to the other two scenarios. The social planner in the full cooperation case is less willing to substitute self-protection for abatement because her opportunity cost of self-protection is the benefits abatement gives to all agents. This is to be compared to the opportunity cost of self protection for atomic agents which is only their own benefit of abatement.

Assuming that marginal cost of self-protection is negatively related to technology, countries with high technology of self-protection can easily lower own share of abatements and induce other countries to increase their shares of abatements. Thus when we consider self-protection in the non-cooperative and semi-cooperative scenarios technologically less advanced countries' share of abatement increases and that of high income countries is decreased. Note also that this result is strongest in the semi-cooperative case, which is the scenario that best describes the situation of most international environmental problems. This is interesting because the debate about international environmental problems often has a starting point where low income countries, corresponding to technologically less advanced countries, have low environmental concerns. For instance, the Kyoto Protocol is designed such that the global warming is primarily a responsibility of high income countries. However, as long as self-protective activities are not included in the protocol, the interest of high income countries may be limited. This may be one of the reasons why the agreed levels of GHG-reduction, already at early stage process of the protocol, were considered too small to stop global warming. This was for instance pointed out by Wigley (1998).

Until now very little attention has been directed towards self-protection in environmental issues. Earlier studies on self-protection, with focus on uncertainty, concluded that there is little support to ex-ante investments in self-protection.[4] However, in this paper it is shown that strategic aspects of environmental problems give reasons for ex-ante investments in self-protection when agents do not cooperate as well as when they cooperate on abatement.

5 Article III—Environmental Policy in Open Economies.

This paper examines international environmental problems when the use of environmental services are rival and are traded on the world market. It is found that environmental policy is crucially dependent on the relative market value of environmental services. Most of the literature investigating environmental policy in

[4]See Ehrlich and Becker (1972); Dionne and Eeckhoudt (1985); Lewis and Nickerson (1989) and Immordino (2003)

open economies model environmental problems as a general disutility to society. In the model used here, emissions result in ecosystem degradation (or a loss of biodiversity), which has an impact on the flow of ecosystem services, henceforth eco-services. Consequently, sectors of the economy in which production is closely connected to these eco-services will be harmed. These sectors may be agriculture, tourism, hydropower or sectors which harvest biological stocks such as timber and fish. The economic losses that may occur in these sectors are not public, because the output is rival in consumption. Thus, governments choosing environmental policy have to take into account these sector specific damages. This is especially important when open economies are considered, and services produced by the environmentally harmed sectors are traded in the world market.

In a world where most countries have signed free trade agreements, there are restrictions on direct support through trade policies such as export subsidies and tariffs to support domestic industries. Thus, environmental policy has emerged as an alternative way to channel this support. There are at least two potential ways in which environmental policy can be used to support the domestic economy. The first is that large economies can use environmental policies to change terms of trade in their favor. The second way to support the domestic economy is to make use of strategic aspects of environmental problems. Given that pollution is a public bad, the large economy, by a lax environmental policy, may force the foreign economy to pursue an environmentally conservative policy. This may favor the large economy's production sector at the expense of the foreign economy's production sector.

In the literature on environmental economics, analysis has primarily focused on whether or not environmental policy in a free trade regime will deteriorate the quality of the environment. Markusen (1975) and Raucher (1991) show that a large economy exporting polluted goods should have an environmentally protective policy to affect terms of trade in its own favor, while a large economy importing polluted goods should have lax environmentally policy to affect terms of trade to its own favor. Kennedy (1994); Barrett (1994); Ulph (1996) and Tanguay (2001) show that in a free trade regime countries with market power have strategic incentives to choose lax environmental policy. However, these results do not hold in general. Rausher (1994) and Benarroch and Thille (2001) show that general equilibrium effects in factor market may change these results. Furthermore, Copeland and Taylor (2005) show that the emission levels in a general equilibrium model with trade may be strategic complements, which implies that a lax environmental policy in one country induces lax environmental policy in other countries. In this case, the rationale for a strategically lax environmental policy is not longer valid. Thus, in general neither the terms of trade argument nor the strategic behavior argument support the hypothesis of lax environmental policy in a free trade regime.[5] However, Rausher (1994) and Benarroch and Thille (2001) and Copeland and Taylor (2005) give little attention to the conditions when the terms of trade or strategic behaviors improve or deteriorate the quality of the environment.

In this paper environmental policy is analyzed in a two-goods, two-country gen-

[5]There are also other arguments against lax environmental policies. See for instance Greaker (2003) for a recent contribution and Ulph (1997/1998) for a summary of the literature.

eral equilibrium model. There are two types of traded goods: eco-services and conventional goods. The production of the conventional good generates emissions that damage eco-services. Increasing exposure of emissions decreases the amount of services that the ecosystem can deliver, at an increasing rate, as the biodiversity falls and the amount of various species in the system decreases. Furthermore, it is assumed that eco-services are traded goods.[6] Given consumer choices of conventional goods and eco-services the social planner in each country maximizes a representative individual's indirect utility function with respect to environmental policy. The problem is solved for the cases of a benchmark small open economy, a small regional economy and large economy.

It is shown that environmental policy is more complex than what is portrayed in the literature. In the large economy case, rent seeking behaviors may result in increased or decreased domestic emission levels compared to the small economy case. The change in domestic emission levels depends on how eco-services are valued relative to conventional goods in the world market and whether the large economy is an importer or exporter of eco-services. The effects on total emission levels in the world will be moderate if, as in most cases, one country increases its emission levels when the other decreases its emission levels. However, for some range of the relative price, there are cases when both countries increase or both countries decrease emission levels. It is also of interest that the greater the difference in the productivity of emissions the greater the range of the price when emission levels in both countries go in the same direction.

In the small regional case, it is shown that an exogenous price shock induces the country with higher marginal productivity in eco-services to choose emission levels that occur together with more production of the good whose relative market value has increased. However, the other country must also take into account that its gains from free riding change and it therefore faces a trade-off between these two effects, and may increase or decrease its emission levels.

In this paper we show that the strategic incentives of countries, when involved in trade may be more intricate than the earlier literature has indicated. The main reason for our result is that this paper specifies environmental damages as sector specific rather than as a general disutility to consumers.

6 Article IV—Transboundary Pollution

This paper is built up around two observations about international environmental problems. The first is that often relatively wealthy countries give financial support to improvement of environmental quality in less wealthy countries when the environmental problem is international. For instance, a substantial proportion of abatements in low income countries in global environmental problems are financed by high income countries through multilateral funds. In addition to this, high income countries do bilaterally finance abatements in low income countries. One such case is Sweden, through environmental aid, financing abatements of nutrients loads to

[6] Ecosystem services may also be non-traded goods but these are not considered in this paper.

moderate eutrophication in the Baltic Sea. In most of the literature on international environmental problems it is assumed that countries are sovereign. This implies that the behavior of Sweden in the Baltic region and that of high income countries in low income countries are interpreted as altruistic behaviours. However, Hassler (2002), by studying how Swedish environmental aid is allocated in the Baltic states, showed that Sweden acts in self-interest. In this paper the sovereignty assumption is reinterpreted such that countries can act in other's territories as long as no harm is done to the host country, i.e. in this model unilateral abatements abroad are allowed.

The second observation is that environmental problems often are characterized by asymmetries, as discussed earlier. A common explanation for the difference in interests between high income and low income countries is that the demand for environmental quality is income related. Often environmental quality is assumed to be a luxury good and thereby high incomes countries' demand of environmental quality is higher than the demand in low income countries. This may explain why high income countries invest in the environmental sectors of low income countries. However, empirical evidence seems to suggest that environmental quality is a normal good which then questions the rationale for high income countries to finance abatements in low income countries. In this paper asymmetries in environmental problems are a further explanation for the behavior of high income countries. This is particularly evident in the case of eutrophication of the the Baltic Sea where Sweden, due to asymmetries in eutrophication, seems to be one of the most affected counties while Poland and the Baltic states are among those affected the least.

It seems that Sweden unilaterally abates in the Baltic regions and that high income countries often unilaterally abate in low income countries. In this paper it is investigated whether asymmetries in how pollution hits different geographical areas may explain these behaviors.

Unilateral improvement of environmental quality may be ineffective. Hoel (1991) and Buchholtz et al. (1998) have shown that if some countries or coalitions of countries take unilateral abatements other countries will free ride and decrease their abatements. Hoel (1992) shows that unilateral abatements may even increase total pollution levels. Heal (1993) shows that a unilateral abatement, caused by technology improvement, may decrease total pollution due to technology spill over effects. Unfortunately the free riding problem is true for unilateral abatements abroad as well. Therefore, unless there are technology spill over effects, these abatements may not improve environmental quality or the improvements are less than predicted.

However there may be conditions when unilateral abatements abroad may give the desired improvement in environmental quality. In particular if the asymmetries are the motives for the disinterests of some economies in some environmental problems it may be permanent.

If countries where abatement takes place are not concerned about the transboudary environmental problems and choose not to take any abatements at all then the problem is a concern of other environmentally more concerned countries alone. First the environmentally less concerned country are modelled. It is shown that if the asymmetries are high enough and the productivity parameter is low this country may end up in a corner solution where no abatement is undertaken. Given such

behavior, pollution generated in the environmentally less concerned country is a problem only to the environmentally more concerned country. Therefore, allowing the latter to abate abroad, its chooses abatement at home as well and abatement abroad. The optimal level of abatement abroad is found where marginal loss of utility from refraining from consumption is equal to the marginal value of decreasing transboundary emissions. In optimum the marginal decrease in transboundary pollution is inversely proportional to the marginal decrease in domestic productivity of emission. Thus if the productivity of emission at home is high a country is more willing to substitute domestic abatement with abatements aborad. Furthermore, it is found that there is a unique saddle point equilibrium. It is also shown that the equilibrium with countries allowed to abate abroad does not qualitatively differ from an equilibrium with no such possibilities. However, the equilibrium stock pollution decreases when the sovereignty assumption is less strictly interpreted.

7 Article V—Is Population Growth Good for the Environment.

In this paper we start from the observation that population growth may have positive as well negative effects in the environment. On the one hand, population growth may increase the environmental impact as more individuals increase aggregate demand. This causes a larger throughput of substances from the earth crust and the burden on our resource bases increases.

Population growth may however have positive effects on the environment. In the literature of growth it is for instance assumed that population growth stimulate production as more individuals create more ideas[7]. For instance in Jones (1995) a larger population means a larger number of gifted researchers, who produce more (useful) ideas. The ideas are transformed into innovations that make it possible to produce more with a given stock of production factors. In economics : it may contribute to technological progress, which can be beneficial for the environment.

Jones does not include environmental issues in his analysis, but his framework is easily amended to allow production to be an increasing function of the quantity of pollution that is allowed as a by-product of ordinary production[8]. We do this and obtain a model where some of the technological progress can be used to reduce the quantity of pollution generated, without reducing output. That is, technological progress can make production cleaner, and population growth contributes to this process.[9]

[7] A central feature, necessary for sustained growth, is that ideas/knowledge are non-rival, as opposed to rival production factors, such as capital and labor.

[8] Population growth is often ignored in the literature on environment and economic growth. Two interesting exceptions are however Keeler et al. (1972) and Gradus and Smulders (1993). However, they only include the negative effect of population growth.

[9] The literature on growth and pollution has of course used related models before (see Xepapadeas (2003) for a survey) but not, as far as we know, to analyze the problem we address in this paper. However, Dasgupta (2003) contains a brief informal discussion of the two roles of population growth that we analyze here.

Consequently, we have a model in which population growth has both negative and positive effects on the environment.[10] We derive and analyze a condition for when the positive effect is dominating. To simplify the exposition, we study the solution of the benevolent social planner's problem. We end this note by pointing out the limitations of the simplified model analyzed here, and suggest directions for further research.

8 Conclusions

The general message of this thesis is that when we think of environmental problems we often neglect the way these problems are transformed into damages. This is probably because there is a consensus that environmental quality (degradation of environmental quality) has public good (bad) characteristic, which is particularly evident in the theoretical literature of environmental and resource economics. In this thesis we show that the ways in which pollution is realized into economic damages has major implications for environmental policy. We focus on two areas of economics, namely long term growth and international environmental problems.

In a growth model aggregate pollution may be composed of many pollutants that may affect part or may reach the entire population. Therefore, assuming that the reach of pollution is limited, it is shown that productivity of pollution may be a determinant of the optimal steady state growth rate. The contribution of this factor decreases with population density. The higher the population density the higher is the reach of pollution and the more public pollution tends to be. Thus, it is shown that sustainable growth is easier to achieve if we acknowledge that the reach of pollution may be limited.

In international environmental problems, environmental policy is more complex if individuals can protect themselves from pollution. Self-protection decreases domestic damages for a given level of pollution and may be a substitute for abatement. An agent can, through self-protection, decreases her own abatement and induce other agents to increase their abatements. The agent has strategic gains because costs of abatement are private and benefits of abatements may be public. A second reason for the complexity of designing policy in international environmental problems is that environmental damages may be rivals. In such cases, environmental policy always harms some sector of the economy and favors other sectors. In this model the incentives to adopt a lax or strict environmental policy depend on the relative value of the goods produced in the harmed and benefited sectors and how policy may change this relative value. Finally, Article IV argues that it may be rational for some countries to unilaterally abate in a foreign economy if there are asymmetries in environmental damages and the foreign economy has low productivity.

[10] In Eriksson and Zehaie (2005) there are elements of the same phenomenon in a one-sector growth model. However, the mechanisms are easier to understand in the two-sector model that we analyze here.

8.1 Further Research

Based on new or the already existing empirical work it may be interesting to see if it is possible to find some regularity in the way pollution is realized as environmental damages. Some such research may already be going on but it is not fully incorporated into the theoretical literature on growth and the environment and the literature on international environmental problems.

An interesting extension of Article I and V may be to look closer at the population variables. In both articles population density is independent of population growth. However, it is more realistic to assume that population growth is related to population density. This way it is possible to capture the negative effects of a high population growth. An interesting other extension would be to endogenize population growth.

The articles included in this thesis mainly contain analyses of the social optimum, further interesting information may be gained by solving the models in decentralized settings. For instance, mechanism design would be interesting to investigate. In Article II it is suggested that the social planner's intervention in the market of self-protection may be Pareto improving. However, using market instruments such as taxes and subsidies probably would not be effective as agents may still act strategically, which would favor other instruments such as command and control.

It would be interesting to investigate the choice of self-protection and abatement in a dynamic model, in particular, in a model of research and development. The probability that new clean technologies may substitute the exiting technologies may support a temporary use of self-protection. Self-protection may also be of interest if the pollution is related to a non-renewable resource such as carbon dioxide emissions are related to oil.

The idea that environmental damages may be private and that environmental policy may have indirect effects on other sectors of the economy, as in Article III, may be extended to other areas of environmental theory. It would for instance be interesting to investigate the choice of dirty and clean technologies. It is also interesting to see how bargaining and cooperation may be affected when environmental policy has positive as well as negative effects on the domestic economy. An empirical application of the model in Article III would also be interesting. For instance, the starting point could be to study the relative prices of timber and environmental policy in Canada and Sweden.

In Article IV the obvious extension is the inclusion of capital in the model.

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