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Ph.D. Thesis

**THREE ESSAYS ON TRADE AND
BIODIVERSITY**

By

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FOREWORD

The whole journey to obtain a Ph.D is really a difficult but great experience for me. This difficult journey was made easy for me by many people. In this foreword I want to thank all those people for their contributions.

First I want to thank Almighty Allah for making me one of the few luckiest people on the earth to hold a Ph.D degree. Second, I am thankful to my parents Nurul Alam and Nazmun Nahar – without their hard work and encouragement - I would not be able to come so far.

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ABSTRACT OF THE THESIS

The thesis is motivated on the background of rapid biodiversity depletion around the world. Using a general equilibrium model, the first essay shows how free trade can have negative impacts on the biodiversity stock of the South due to missing markets. It also shows that free trade added with Southern rapid population growth and agricultural extensions are the main reasons of biodiversity loss. Demand side mechanisms like discounting of biodiversity depleting products and supply side mechanism like eco-friendly agricultural technologies can have a positive impact to decrease biodiversity loss. Essay two shows how absence of a market for ecosystem services causes depletion of biodiversity in the developing countries. In any period, the amount of land development in the south depends on how large the relative size of the southern younger generation in that period is, compared to the size of the maximum available land resources. Lack of any other assets in the South for old age savings, low land clearing cost and low discount rate causes biodiversity loss. There is scope of conserving biodiversity and the flow of ecosystem services by fiscal tools like land development fee or land tax and market creation through payment for ecosystem services. But these policies may deteriorate Southern terms of trade. Through a two period general equilibrium model with an open economy, paper three shows how bio-prospecting can help in the conservation of biodiversity and under what conditions it can fail. The paper shows that a systematic search process depending on prior information on the plant species and the health characteristics increases the success of bio-prospecting. Also a lower cost of the bio-prospecting process or manufacturing of drugs, a high probability of drug discovery, and a drug with a high benefit result in a higher royalty payment to the South and conservation of biodiversity. Strategic pricing by the bio-prospecting firms or marketing of only high benefit drugs ensure successful bio-prospecting schemes. A larger set of bio-prospected drugs may drive away the low-benefit drug firms out of market. The caveat is that bio-prospecting process may ignore Southern low-value diseases. The three essays of this thesis suggest that green consumerism, payment for ecosystem services or bio-prospecting scheme can be viable tools for biodiversity conservation. But the strong message in all the three essays is also that there is no one miracle tool that can save biodiversity. So a mix of market and non-market tools has to be used for the conservation of world's biodiversity.

CHAPTER 1

INTRODUCTION TO THE THESIS

Biodiversity loss is one of the gravest environmental concerns in the world now.¹ The Biodiversity resources in the world are decreasing at a very rapid rate.² According to the millennium ecosystem report, the last 50 years have seen the biggest biodiversity upheaval in human history. 'Over half the world's biomes (vegetation types) have experienced about 20-50% conversion to human use. The rates of change have been greatest in tropical and sub-tropical dry forests. Some 35% of mangroves and about 20% of corals have gone. A third of all amphibians, a fifth of mammals and an eighth of all birds are now threatened with extinction. It is thought 90% of the large predatory fish in the oceans have gone since the beginning of industrial trawling. And these are just the vertebrates - the species we know most about. Ninety percent of species, maybe more, have not even been catalogued by science yet.'³ Failure to internalize many aspects of the value of biodiversity in the market valuation system and lack of property rights for biodiversity rich resources are cited as the two main reasons for biodiversity losses. The market system often fails to reflect all the values of biodiversity. This market failure is encouraging alternative use of biodiversity rich land. The north is a net importer of biodiversity services and products⁴, and it has an ever-growing consumption pattern⁵, whereas the south is a net exporter and it has high population growth and poverty. As, the product and services generated by biodiversity are not properly priced in the world market; the biodiversity rich south is hurt most. It does not have the option to abandon

¹ Millenium Ecosystem Assessment (2005).

² Same as above.

³ Same as above.

⁴ For example, 'More than one-half of global forest products imports by value are accounted for by Europe, and over 25 percent of the remaining imports are to Canada, Japan and the United States (FAO, 1994).'Barbier (1995).

⁵ One of the main reasons of biodiversity destruction 'is the competitive growth, the high standard of living and the specific development pattern in the developed capitalist countries' Liodakis (2000).

the present growth path of the economy that over-exploits its biodiversity resources unless the market failure problem is corrected.

The thesis was motivated on this backdrop of rapid biodiversity loss. It also takes into account the fact that the world is moving very fast towards a free trade regime. We explain the biodiversity loss problem in a north south general equilibrium free trade framework. The three papers in the thesis deal with green consumerism, ecosystem services and bio-prospecting respectively.

All three papers have some general assumptions and a framework. We consider a world in which there are two countries – called country 1 (the North) and country 2 (the South), respectively. Each of these countries produces two goods from labor and land – one of the products is labor-intensive and the other is land-intensive. We assume that in each country, part of the land endowment has already been developed and is ready for use as input in the production process; the remaining part is still in a state of wilderness, and must be cleared before being used as a factor of production. We assume that all the land in the North has been developed. In the South, the wilderness region is rich in biological diversity and part or all of this region can be cleared and used for the production of other goods or conserved.

In this thesis, biodiversity is measured by a proxy – undeveloped land in the South. We assume that only the South has biodiversity resource stock and this stock is located in the undeveloped land of the Southern countries. We are using undeveloped land as the proxy for biodiversity for several reasons. Firstly, there is definitional ambiguity and lack of consensus among academics on the unit of measurement of biodiversity resources⁶. Secondly, a spatial scale can capture the ecosystem functions of biodiversity better. Thirdly, it is very difficult to capture all the aspects of biodiversity like the direct and indirect use value, the option value, bequest value, the existence value, the cultural, aesthetic, religious, spiritual and social values. Due to this valuation problem, it is better

⁶ 'There is no agreement on what exactly biodiversity means. It can refer to genetic diversity, to species diversity or to the diversity of environments or habitats.'<http://www.redpath-museum.mcgill.ca/Qbp/2.About%20Biodiversity/theory.html>

to use a spatial measure like undeveloped land than the number of species. Fourthly, if we think biodiversity as an irreversible resource stock which has many unknown potential still not discovered, then spatial scale will be a better safeguard from the conservation point of view. Fifth, with thousands of species available in the world, the marginal value may be so small that it may not be economically efficient to conserve the species. For example, the value of biodiversity as a source of new drugs may be very small.⁷ If we rely on the economic principle of valuation of biodiversity, we may wait to conserve till the extreme end when the biodiversity stock is very small. For all these reasons, it is better to preserve biodiversity in a spatial scale to preserve its enormous unknown potentials.

In all three models of the thesis, we use homothetic utility functions which eliminates the income effect of trade and the 'Environmental Kuznet's Curve'. We eliminated the income effect of trade to reflect the current reality. According to 'Environmental Kuznets Curve' (EKC), the natural resource degradation of any country follows an inverted U shaped curve. When the per capita income is low, the country faces increasing biodiversity degradation. But with increased income, the degradation reaches a maximum and then starts decreasing due to the change in preference pattern. But the 'Environmental Kuznets Curve' may not be appropriate for the economies of the Southern Least Developed Countries (LDCs). The inverted U shaped resource degradation path emerges if the growth of demand for environmental quality is greater than the growth of the demand for other goods. But in the LDCs, the free trade driven growth of the economy increases the demand for other consumption goods at a faster rate. So, usually the LDCs remain on the upward sloping portion of the EKC curve. Reaching the peak of the EKC can take much time and a high level of per capita income. But the time the LDCs will reach that income level and the peak of the EKC, their natural resource base may already be extinct. Also the inverted U shaped relation does not work very well for biodiversity and ecosystems. 'The inverted U shaped relations have been uncovered for emissions of pollutants, not resource stocks. The relation is less likely to hold wherever the feedback effects of resource stocks are significant, such as those involving soil and its

⁷ Simpson et al. (1996).

cover, forests, and other ecosystems.’⁸ In the developing countries the feedback effects are strong due to the socio-economic conditions.

Using a general equilibrium model, chapter 2 shows how free trade can have negative impacts on the biodiversity stock of the South under green consumerism. For the last 25 years, the world is moving towards a free trade regime and the concern for the impact of free trade on natural resources is increasing⁹. There is debate among the environmentalists and the economists on the impact of trade on welfare and biodiversity. ‘They (the environmentalists) worry that trade will expand the scope of market failures, put added strain on the environment and lead to degradation of natural resource stocks in the long run’¹⁰, which in turn will decrease the welfare of the society. On the other hand many economists think that free trade will improve welfare if there are no distortions in the market. According to them, increased trade may only have negative impact on natural resources like biodiversity when there is presence of market distortion, property right problems, externality problems, valuation problems or absence of market for non-market values of natural resources.

The model in this chapter uses the concept of international trade in vertically differentiated products. There are two types of agricultural products – one produced in the South that clears biodiversity rich land and hence is perceived as a lower quality product by the green consumers and the other produced in the North that does not clear land and is assumed of higher quality. Under free trade these quality differentiated goods are traded in the international market. Inclusion of a discount factor for biodiversity destroying products captures the Northern green consumer’s current trend of differentiating between certified and non-certified goods and readiness to pay a premium for the better quality good that destroys less biodiversity. But this type of discounting does not show that the green consumers value the biodiversity or get utility just from the

⁸ Arrow, Kenneth and others (1995).

⁹ ‘Many environment groups have argued, and we agree, that the pattern of trade has helped accelerate environmental degradation worldwide. It has accelerated the depletion of natural resources as countries in the South extract raw materials and use land resources for export crops.’Khor, Martin in Third World Network Features, <http://www.sunsonline.org/trade/areas/envirom/02230394.htm>

¹⁰ Karp et al. 2001.

conservation of biodiversity in the South and are ready to pay for it.¹¹ In this model, we elaborate the impact of this green discounting on land conversion.

The chapter derives some very important results that may help to find out proper instruments and mechanisms for biodiversity conservation. First, we find that free trade increases the clearing of undeveloped land in the South and in that way destroys biodiversity. But at the same time free trade also increases the welfare of the Northern and Southern consumers after opening up for trade. Second, the terms of trade of the South rise with increasing land development even with the Northern green consumer's preference related discounting of the Southern agricultural goods. In case of very large scale land development, the terms of trade may reverse and the South may become a net importer of the agricultural goods. Third, if the Southern consumers also become sensitive towards biodiversity loss, their utility decreases with opening up the economy for free trade. Fourth, if the situation is more realistic and there are two types of consumers in the North – one is the 'green' consumers who are sensitive to biodiversity loss and the other is the 'gray' consumers who are insensitive to the biodiversity loss like the Southern consumers, free trade destroys more biodiversity. Fifth, as the income share of the 'green' consumers increases in the North, the biodiversity loss decreases. Sixth, even with the absence of trade, only Southern population growth can decrease the stock of biodiversity. Free trade puts an added pressure on this trend. Under free trade, population increase of the North also increases biodiversity loss. But the population increase in the South affects the biodiversity at a greater extent than the population increase in the North. Lastly, if there is some technology that decreases the use of land in the Southern agriculture and if the North subsidizes that technology, the biodiversity loss decreases. This transfer increases the utility of the Southern consumers, but decreases the utility of the Northern consumers.

The chapter provides support for the concern of anti-globalization activists that free trade depletes world's biodiversity stock when there is no market for the biodiversity resources

¹¹ Biodiversity as a source of utility was used by Cabo (1999) and Caviglia-Harris et.al. (2003). The later authors tried to incorporate demand side policies to ensure sustainable use of natural resources.

itself. Biodiversity resources provide different goods and services that often do not have any market. For example, ecosystem services are produced by the biodiversity rich land that increases the productivity of the agricultural sector, but the sector does not pay for it. There are other non-use values (e.g. species, carbon sink etc.) of the 'undeveloped land' which has no market. The market for many of these non-use values is global and the South alone can not create this market and correct this distortion. Due to absence of market for these services and products of the biodiversity rich land, the opportunity cost of their alternative use in agriculture becomes high and causes land clearing. Also when developing countries can not monetize the value of the conserved biodiversity they have no other alternatives but to deplete their rich biodiversity resource stock to feed the current population though it may hurt the future generation of these countries in particular and the world at large.

The chapter also provides support to the concern of environmental and resource economists that even without trade, the unsustainable population growth alone can deplete biodiversity resources. Environmentalists' concern about economic scale relative to resource availability, the 'ecological footprint'¹² concept explained by Wackernagel and Rees (1996)¹³ is supported by this model. Free trade added with Southern rapid population growth and agricultural extensions pushes the 'ecological footprint' of the South and causes rapid biodiversity loss.

Demand side mechanisms like discounting of biodiversity depleting products and supply side mechanism like eco-friendly agricultural technologies can have a positive impact to decrease biodiversity loss. But, only discounting southern agricultural product and not caring about the biodiversity resources directly, may not conserve the biodiversity at the end. If the Northern green consumers really care about biodiversity loss in the South, it should affect their utility and biodiversity should be an argument in their utility function. In that situation, their valuation of Southern biodiversity can be measured and they

¹² 'A measure of the 'load' imposed by a given population on nature. It represents the land area necessary to sustain current levels of resource consumption and waste discharge by that population.'

www.pce.govt.nz/reports/pce_reports_glossary.shtml

¹³ Wackernagel and Rees (1996).

should be willing to pay for the conservation of biodiversity in the South equal to that value. Not valuing biodiversity directly and only discounting differentiated product like this model can only slow down the depletion of biodiversity stock, but can not stop it fully.

The chapter leads to the conclusion that the biodiversity rich developing countries should diversify with respect to domestic production and trade. They need to decrease their dependence on export of natural resource and agricultural products and diversify their export towards manufacturing products. Green activism like avoiding consumption of biodiversity depleting goods or anti-globalization activism like blocking free trades or free market activism like leaving everything to the hand of market does not work in the long run. If the green consumers really care about the existence of biodiversity, they should be ready to pay a premium for its existence too. If as a citizen of the globe, we value biodiversity as a global public good that has to be conserved, we have to act as global citizens too. The efforts like the global environmental fund should be the principal mechanism to conserve biodiversity stock of the world.

The conclusion in chapter 2 points out that countries should try to create markets for different goods and services provided by the biodiversity rich land. This conclusion leads to the third chapter. Biologically diverse land provides many economic and non-economic services to human society.¹⁴ One of such service is the *ecosystem services* that help to improve the productivity of the agricultural sector. These services include photosynthesis, soil generation and preservation, pollination of crops, recycling of nutrients, filtering of pollutants and waste assimilation, flood control, climate moderation, operation of the hydrological cycle, disturbance regulation, biological control (Costanza et al. 1997; Folke et al. 1996). ‘In ecosystem terms, ecosystems are fundamental ‘factors of production’’ (Barbier et al. 1994; Jansson et al. 1994). But these contributions of biologically diverse land are not reflected in the market system. Ecosystem functions

¹⁴ Daily, G.C. (ed.) (1997).

have strong public goods characteristics which are often undervalued in the private producer's production process.

The 3rd chapter presents a general equilibrium model of North-South trade with overlapping generation to explain the long run dynamics of land conversion when ecosystem services contributes in agricultural productivity. Inclusion of ecosystem services in the production process as a weak complement imposes a limit to the growth of the agricultural production. At extreme situations when the amount of biodiversity rich land reaches a critical limit, the marginal productivity of land in agriculture becomes negative. The chapter proposes land taxes, land development fee and ecosystem fee as policy tools to internalize the contribution of ecosystem services.

The model in this chapter helps us to state some very important propositions and results. First, the chapter explains the long run dynamics of the land clearing sector. It shows that whether all the land in the South will be cleared or not depends on how large the relative size of the upper bound of the southern younger generation is, compared to the size of the maximum available land resources in the South. In the same way, in any period t , whether the land clearing sector will be active or not depends on how large the relative size of the southern younger generation in that period is, compared to the size of the maximum available land resources in the South in that period. As there are no other alternative real assets other than land available in the South, the old generation only depends on the land market to gain assets for old-age security. With population growth, it puts added pressure on the land clearing sector and speeds up biodiversity destruction through land development. But whether the land clearing sector will be active or not depends on the relative size of the younger generation. It explains the current reality of the biodiversity rich South. Third, the chapter shows if per unit land clearing cost is high enough, then no new land will be cleared in the South.

Fourth, the chapter finds if the discount factor in the South is low enough (which is equivalent to a high discount rate) and if the population pressure is not large enough then no new land will be added to the stock of developed land in the South at the end of period

t. This finding is in contrast with the popular Hotelling's conclusion that high discount rate leads to resource depletion. The difference in conclusion is due to land being the only real asset for savings, availability of cleared land for future generation only and the model being built on a general equilibrium context, rather than a central planner context.

Fifth, the chapter also shows if the ecosystem services are highly valuable, then the competitive equilibrium is not efficient as too much land is developed in the South. Sixth, though the tools for paying for the ecosystem services like land development fee, land tax and ecosystem fee may help in the conservation of the biodiversity rich undeveloped land, it can also affect the Southern terms of trade adversely.

As the lack of alternative assets is one major reason of biodiversity loss in the South, the creation of alternative real asset market like stronger bond markets, increased ownership access of physical capital or income generation system for the older generation are keys to decrease biodiversity destruction in the South. Alternative earning and employment opportunities other than land clearing can also slow down destruction of biodiversity.

One of the conclusions of chapter three is to look for alternative measures like bio-prospecting or eco-tourism to create economic values from the conservation effort. That led to the fourth chapter which models the bio-prospecting as a search for new drugs.

In the early development of medicines, higher plants have played a vital role in providing biologically active compounds for producing pharmaceuticals. With the advent of synthetic chemical design, the role of plant-based agents in the development of new and clinically effective pharmaceutical products declined significantly. In the last two decades, there was a resurgence of interest in the potential of the chemical compounds manufactured by higher plants to provide proto-types for new pharmaceuticals, agrochemicals, and consumer products. The tropical forests in developing countries, which house the large majority of the world's estimated 422, 000 plant species¹⁵,

¹⁵ <http://www.plant-talk.org/stories/28bramw.html>

represent a potentially unlimited pool of novel structures – if discovered – as blueprints for the development of marketable drugs.

To serve as a pool of novel structures, which constitute the target of the bio-prospecting process, these higher plants must be protected. There are direct costs of biodiversity protection. Because land has alternative uses, such as housing development or food production, there is also an opportunity cost involved in maintaining tropical forests as reservoirs of biodiversity. An economic analysis must take into consideration all these costs, and the conservation of biodiversity can only be justified if there are sufficient benefits to warrant its conservation. Because the knowledge about a species and the bio-chemicals it manufactures might serve as the basis for discovering and developing marketable drugs, the developing countries with tropical forests charge a price for the right to bio-prospect or claim a share of the profits made by these pharmaceutical companies. In chapter 4, we present an economic model in which the bio-prospecting process, its costs, and its benefits, as well as the opportunity cost of biodiversity conservation are formalized. Most of the existing models that attempt to measure the value of biodiversity – whether in terms of the revenues generated by tourism activities or in terms of the monetized value of the medicinal plants the biodiversity houses – adopt the partial-equilibrium approach. The model of this chapter, in contrast, is formulated from a general equilibrium perspective in a two-country trade framework.

In their struggle for survival, plants manufacture biologically active compounds – known as secondary metabolites – to defend themselves against insects, herbivores, diseases, and harsh environmental conditions. Each species has a unique profile of secondary metabolites, and it is in this pool of bio-chemicals that bio-chemical compounds with the desired medicinal properties can be discovered through bio-prospecting activities.

The search for novel biochemical structures by a bio-prospecting firm is systematic, not random. A bio-prospecting program consists of three stages. In the first stage, the plants whose secondary metabolites are expected to have the desired bio-chemical activity are identified. Shaman, a pharmaceutical company, employs a network of ethno-botanists

and physicians to seek out plant remedies used by generations of native populations.¹⁶ Specific plants that are related to plants with proven bio-chemical activity might also be the target of a systematic investigation. Samples of the identified plants are then collected and screened for the desired novel bio-chemical structures. Each of these steps just described takes time and involves enormous costs. At the end of each step, the results are evaluated and the bio-prospecting program might be terminated – and all the resources spent up to this point wasted – if it is judged that the leads turn out not to be as promising as expected. Principe (1991) used the National Institute of Health experience with the screening process in bio-prospecting and arrived at an estimate that from 1000 to 10,000 chemicals must be evaluated before a lead is found. In the second stage, the leads are used to develop a drug with the desired properties. The drug thus designed must not be toxic to the patient, and the development stage involves many clinical trials. If the clinical trials are satisfactory and if the drug is not too expensive to produce, then the pharmaceutical company can embark on the last stage of the bio-prospecting process: marketing the drug. According to McChesney (1996), on average it takes about 10 years and costs between 100 and 225 million dollars to discover, develop, and bring to the market a new drug.

The chapter contains a two-period model of trade between the North and the South in which the bio-prospecting – to find plants for pharmaceutical products – of wilderness land is modeled as a search process. The chapter shows that conservation of biodiversity through bio-prospecting can be a viable tool with some caveats. Lower cost of bio-prospecting and drug production, higher quality of the drug (e.g. treats high ‘disutility’ disease or not), number of drugs innovated and lower amount of royalty payment ensure a successful bio-prospecting and the corresponding biodiversity conservation. But there are some caveats of this search process. Depending on the number of drugs invented and the price and demand of these drugs, the bio-prospecting contract may or may not hold. The drug companies may ignore any of the southern specific diseases which do not create enough demand. So, bio-prospecting may be one of the feasible options for biodiversity

¹⁶ Conte, Lisa A. (1996).

conservation due to the systematic search, pricing strategy, drug importance and royalty payment scheme, but may not be a strong or only option.

The rest of the thesis is laid out as the following: chapter 2 presents the essay titled – ‘International Trade and Its Impact on Biodiversity’, chapter 3 presents the essay titled – ‘Land Conversion, Ecosystem Services and Biodiversity Conservation’, chapter 4 presents the essay titled – ‘Bio-Prospecting, Land Development and Biological Diversity Under Free Trade’ and chapter 5 presents some concluding remarks and future research extensions.

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CHAPTER 2

INTERNATIONAL TRADE AND ITS IMPACT ON BIOLOGICAL DIVERSITY

1. INTRODUCTION

For the last 25 years, the world is moving towards a free trade regime.¹⁷ At the same time the concern for the impact of free trade on natural resources is increasing.¹⁸ There is debate among the environmentalists and the economists on the impact of trade on welfare and biodiversity. Environmentalists “worry that trade will expand the scope of market failures, put added strain on the environment and lead to degradation of natural resource stocks in the long run” (Karp *et al.* (2001)), which in turn will decrease the welfare of both import and export countries. On the other hand many economists argue that free trade will improve social welfare and rectify environmental externalities through income effects provided markets function efficiently, property rights over biodiversity resources are well defined and non-market values of natural resources are accounted for in the production process.

The fact that most of the world’s biodiversity rich land lies in the populated and poor South makes the situation even worse. The biodiversity rich South is already overburdened to meet the demand of their own population for biodiversity derived goods

¹⁷ Numerous regional free trade agreements and evolution of WTO is moving the world towards a more free trade regime.

¹⁸ ‘Many environment groups have argued, and we agree, that the pattern of trade has helped accelerate environmental degradation worldwide. It has accelerated the depletion of natural resources as countries in the South extract raw materials and use land resources for export crops.’Khor, Martin in Third World Network Features, <http://www.sunsonline.org/trade/areas/envirnm/02230394.htm>

(such as agricultural products, timber and non timber forest products), while free trade, it is argued, adds further pressure to over use and over exploit biodiversity resources.

On the other hand, as incomes grow in northern countries, their consumers are displaying an increasingly stronger preference for so called 'green products'. Eco-labelled and certified fair-trade products are gaining wider acceptance and increasing their market share as a significant proportion of northern consumers are willing to pay a premium price for such products. Similar to the quality differentiated goods in the manufacturing sector there is an emergence of many quality differentiated goods from the agricultural sector. The quality differentiating characteristic of such goods is not in their taste or appearance but rather in the 'environment friendly' process with which they were produced.

Over the last decade several papers have explained the complex relationship between trade and renewable natural resources. A significant part of this literature has shown that institutional and market failures in resource intensive countries lead to over-exploitation of these resources and in a decrease in social welfare. For example, North-South trade models developed by Chichilinsky (1994), Brander and Taylor (1997b, 1998), Karp *et al.* (2001) show how a resource intensive country may over-exploit its biodiversity resources when it fails to define and enforce property rights over these resources. Habitat destruction by land conversions and agriculture are indicated as other main causes for the loss of biodiversity around the world (e.g. Reid *et al.* (1989); Southgate *et al.* (1991); Swallow (1990); Barbier *et al.* (1994); Smulders *et al.* (2004)). Several other papers (e.g.

Swanson (1994); Barbier and Schulz (1997)) develop models that describe the impact of trade and land conversion on a country's natural resource base and its exports. In these models, the property rights in the south are weakly-defined while the resource sector produces an exporting product and competes with the agricultural sector. Recently, Polasky et al. (2004) constructed a model where consumers of both import and export countries have identical tastes and are equally concerned about biodiversity loss but the relative endowments of biodiversity vary between countries. The model again shows how trade liberalisation may lead to overexploitation of biodiversity resources and decrease social welfare. Smulders *et al.* (2004) constructed a model with three sectors: manufacturing, agricultural and resource extraction. In their model agriculture and resource extraction compete for the same habitat area while land has poorly defined property rights. Their model shows how free trade leads to overexploitation of the resource base and a short term welfare gain due to reduced search cost for the resource good.

The current chapter complements and contributes to this growing literature on trade and renewable natural resources. In particular we develop a model in a static general equilibrium context that shows that even under growing 'green consumerism', free trade when combined with agricultural and population growth can lead to the depletion of biodiversity resources. The model uses the concept of international trade in vertically differentiated products which is in line with the work of Dixit (1979), Dixit and Norman (1978), Flam and Helpman (1982), Copeland and Kotwal (1995) on vertical differentiation of product quality. The framework in this chapter considers the case where

there are two types of agricultural products – one produced in the South that requires the conversion of biodiversity rich land and is, hence, perceived as a lower quality product by green consumers and the other produced in the North that does not require such conversion and is assumed to be of higher quality. Under conditions of free trade these quality differentiated goods are traded in the international market. By including in our model a discount factor for ‘biodiversity depleting’ products we incorporate in the analysis the Northern green consumer’s current trend of differentiating between certified and non-certified goods and their readiness to pay a premium for the better quality good that destroys less biodiversity. But this type of discounting does not show that the green consumers value the biodiversity or get utility just from the conservation of biodiversity in the South and are ready to pay for it.¹⁹ In this model, we elaborate the impact of this green discounting on land conversion.

The chapter derives some very important results that may contribute towards designing appropriate policy instruments and mechanisms for biodiversity conservation. First, it finds that free trade increases the clearing of undeveloped land in the South and in that way may lead to further destruction of biodiversity. But at the same time it is shown that free trade also increases the welfare of the Northern and Southern consumers depending on how high is the northern consumer’s discount factor for southern agricultural products. Secondly, the terms of trade of the South rises with increasing land development even when their agricultural goods are discounted by Northern green

¹⁹ Biodiversity as a source of utility has been used by Cabo (1999) and Caviglia-Harris *et al.* (2003). The latter authors tried to incorporate demand side policies to ensure sustainable use of natural resources.

consumers. Yet, in the case of large-scale land development, the terms of trade may reverse and the South may become a net importer of agricultural goods. Third, if the Southern consumers also become sensitive towards biodiversity loss, their utility decreases with trade liberalization with an absence of income effect. Fourth, when considering a more realistic situation of two types of consumers in the North – ‘green’ consumers which are sensitive to biodiversity loss and ‘grey’ consumers which are indifferent (similar to Southern consumers), free trade may destroy even higher amount of biodiversity rich land. Fifth, we show that as the income share of ‘green’ consumers increases in the North, biodiversity loss may decrease. Sixth, the model suggests that in the absence of free trade, only Southern population growth can decrease the stock of biodiversity. Free trade puts an added pressure on this trend. Furthermore, under free trade, population growth in the North may also lead to enhanced rates of biodiversity loss. But, the population growth in the South affects biodiversity to a greater extent than does the population growth in the North. Lastly, we show that if there is a subsidized technology from the North that may decrease the use of land in the agricultural sector in the South then biodiversity loss may be decreased. Though, this transfer increases the welfare of the Southern consumers, it decreases the welfare of Northern consumers.

The structure of the chapter is as follows. Section 2 describes the model while Section 3 explains the impact of free trade on biodiversity. Section 4 discusses the impact of trade on biodiversity when there are two types of consumers in the North – ‘green’ and ‘grey’. Section 5 explains the impact of population growth on biodiversity. Section 6 discusses the impact of a Northern subsidized on the South and how it can reverse the trend of land

conversion induced biodiversity loss. Section 7 provides the results of some sensitivity analysis for different parameters of the model. Finally, Section 8 concludes with the policy insights derived from the model.

2. THE MODEL

2.1. Technologies

Consider a world in which there are two countries – called country 1 (the North) and country 2 (the South), respectively. Each of these countries produces two goods – one manufacturing good, called good 1, and one agricultural good, called good 2, from labor and land. In what follows the countries will be indexed by $i, i=1,2$, and the goods by $j, j=1,2$. In each country, the industries producing the two goods are assumed to be perfectly competitive.

For each i and each j , let

$$(1) \quad Y_{ij} = \min \left[\frac{L_{ij}}{\ell_{ij}}, \frac{A_{ij}}{a_{ij}} \right]$$

be the technology for producing good j in country i . In (1), Y_{ij}, L_{ij} , and A_{ij} denote, respectively, the output of good j produced in country i , the labor input, and the land input, respectively, used to produce this output. Also, ℓ_{ij} and a_{ij} are two positive constants representing, respectively, the labor input and the land input required to produce one unit of the good in question.

The labor endowment and the land endowment of country i are denoted by $\bar{L}_i$ and $\bar{A}_i$, respectively. In each country, part of the land endowment has already been developed and is ready for use as input in the production process; the remaining part is still in a state of wilderness, and must be cleared before being used as a factor of production. Let A_i be the amount of land in country $i, i=1,2$, that has already been cleared and is currently

available for use as input in the production process. We shall assume that all the land in the North has been developed, i.e., $A_1 = \bar{A}_1$. In the South, the wilderness region, with area $\bar{A}_2 - A_2$, is rich in biological diversity and part or all of this region can be cleared and used for food production or conserved. We assume that the value of logging through land clearing is minimal and so is not included in our model. The undeveloped land in the South has clearly defined property rights and we can assume either state or private ownership. The form of ownership does not change the results of the model qualitatively. In this model biodiversity is measured by a proxy – undeveloped land in the South. Due to definitional ambiguity, lack of consensus among academics on the unit of measurement of biodiversity resources,²⁰ and difficulties to capture all aspects of the value of biodiversity - it is better to use spatial measure like ‘undeveloped land’ as a proxy for biodiversity rather than using the number of species. Also as biodiversity is an irreversible resource stock, the spatial scale is a better safeguard from the conservation point of view.²¹ The biodiversity rich ‘undeveloped land’ in this model does not produce any products. It can only produce agricultural products after it is developed. Therefore, there is no competition for the undeveloped land from any other sectors.

We shall also assume that the total amount of labor needed to clear ΔA_2 units of wilderness land in the South is

$$(2) \quad C(\Delta A_2) = \gamma_0 + \gamma_1 \Delta A_2 + \frac{1}{2} \gamma_2 (\Delta A_2)^2,$$

where $\gamma_0, \gamma_1, \gamma_2$ are positive parameters. Thus if ΔA_2 unit of wilderness land is cleared, the total amount of land offered for rent in the South will be $A_2 + \Delta A_2$.

²⁰ ‘There is no agreement on what exactly biodiversity means. It can refer to genetic diversity, to species diversity or to the diversity of environments or habitats.’<http://www.redpath-museum.mcgill.ca/Qbp/2.About%20Biodiversity/theory.html>

²¹ For more detailed reasons see chapter 1, pages 2-3.

2.2. Preferences

In what follows, we shall assume that the land input used in the manufacturing sector comes from the stock of developed land. The land input in the agricultural sector comes from what is left of the stock of developed land and, possibly, from part of the wilderness land after it has been cleared. Consumers in the North who are sensitive to this biodiversity loss will discount the benefits of the agricultural goods produced in the South when these goods are produced by converting wilderness land into agricultural land. Therefore, the utility of the northern consumers is affected not only by the amount of these goods but also by the damage inflicted on the biodiversity by their production. We assume that the consumers have perfect information about the place of production of the agricultural good. To capture these ideas, we shall assume that the preferences of a consumer in the North are represented by the following utility function:

$$(3) \quad u_1(x_{11}, x_{12}^1, x_{12}^2) = x_{11}^{1-\alpha_1} \left[x_{12}^1 + \left(1 - \frac{\varepsilon_1 \Delta A_2}{A_2 - A_2}\right) x_{12}^2 \right]^{\alpha_1}.$$

In (3), x_{11} represents the amount of the manufacturing good consumed by a consumer in the North, while x_{12}^1 and x_{12}^2 represents, respectively, the amount of the agricultural good whose origin is from the North and the amount of the agricultural good whose origin is from the South that such a consumer purchases. Also, ε_1 and α_1 are two parameters in the range (0,1). As can be seen from (3), the expression $\left[1 - \frac{\varepsilon_1 \Delta A_2}{A_2 - A_2}\right]$ represents the weight assigned to one unit of the agricultural good produced in the South. Note that when $\Delta A_2 = 0$, there is no further biodiversity loss, and the agricultural goods produced in the South are considered to be of the same quality as those produced in the North. This weight declines linearly as more and more new land is brought into production and is equal to $(1 - \varepsilon_1)$ when all the wilderness land is converted into agricultural land. This discounts factor comes from the ‘guilt feeling’ of the Northern consumers as they feel that by consuming the biodiversity depleting Southern agricultural product they are indirectly providing incentive to the depletion of biodiversity. Inclusion of such discount

factor captures the Northern green consumer's current trend of differentiating between certified vs. non-certified and fair-trade vs. regular products. But this type of discounting does not show that the green consumer values the biodiversity as a product or service itself or gets utility just from the conservation of biodiversity in the South.

As for consumers in the South, the preferences of each of them are represented by the following utility function:

$$(4) \quad u_2(x_{21}, x_{22}^1, x_{22}^2) = x_{21}^{1-\alpha_2} \left[x_{22}^1 + \left(1 - \frac{\varepsilon_2 \Delta A_2}{A_2 - A_2}\right) x_{22}^2 \right]^{\alpha_2},$$

where x_{21} , x_{22}^1 , and x_{22}^2 represent, respectively, the consumption of the manufacturing good, the consumption of the agricultural goods produced in the North, and the consumption of the agricultural goods produced in the South. Also, ε_2 and α_2 are two positive parameters strictly less than 1. As specified by (4), the preferences of consumers from the South are allowed to be different from those of consumers from the North. First, consumers from the North and consumers from the South might have different preferences about biodiversity loss. We shall assume that $\varepsilon_2 < \varepsilon_1$, i.e., consumers in the South care less about biodiversity loss than consumers in the North. Second, their preferences between the manufacturing and agricultural goods are also allowed to be different when $\alpha_1 \neq \alpha_2$. We also assume that the elasticity of substitution of the agricultural good (i.e. its contribution to the utility) is lower than the manufacturing good in both the regions or, $\alpha_2 < 0.5$, but the elasticity of substitution of agricultural goods is greater in the South than the North i.e. $\alpha_1 < \alpha_2$.

2.3. Profit Maximization

Let $p_j^i, i=1,2, j=1,2$, be the price of good j whose origin is in country i . Because the manufacturing sector in the South is not assumed to damage the environment, the same price must apply to the manufacturing goods produced in both the North and the South; that is, $p_1^1 = p_1^2 = p_1$. However, if some of the wilderness area in the South is converted

into agricultural land to grow food, we might have $p_2^1 \neq p_2^2$. Also, let ω_i and r_i denote, respectively, the wage rate and the rental rate of land in country $i, i = 1, 2$.

For each i and each j , the representative firm in sector j of country i solves the following profit maximization problem:

$$(5) \quad \max_{(L_{ij}, A_{ij})} [p_j^i Y_{ij} - \omega_i L_{ij} - r_i A_{ij}]$$

As for the competitive firms that hire labor to convert wilderness land into agricultural land in the South, they solve the following profit maximization problem:

$$(6) \quad \max_{\Delta A_2} [r_2 \Delta A_2 - \omega_2 C(\Delta A_2)],$$

where, we recall, ΔA_2 represents the part of the wilderness area cleared to be used as input in the production of the agricultural goods.

2.4. Utility Maximization

The representative consumer in the North solves the following utility maximization problem:

$$(7) \quad \max_{(x_{11}, x_{12}^1, x_{12}^2)} x_{11}^{1-\alpha_1} \left[x_{12}^1 + \left(1 - \frac{\varepsilon_1 \Delta A_2}{A_2 - A_2}\right) x_{12}^2 \right]^{\alpha_1}$$

subject to the following budget constraint:

$$(8) \quad p_1 x_{11} + p_2^1 x_{12}^1 + p_2^2 x_{12}^2 - m_1 = 0,$$

where m_1 represents her income. The solution of this utility maximization problem is simple. First, observe that a fraction of income equal to α_1 will be spent on the agricultural goods and the remaining fraction to the manufacturing goods. More precisely, the demand for the manufacturing goods is given by

$$(9) \quad x_{11} = \frac{(1-\alpha_1)m_1}{p_1},$$

and the demands for the agricultural goods from the North and from the South are given, respectively, by

$$(10) \quad x_{12}^1 = \frac{\alpha_1 m_1}{p_2^1}, \quad x_{12}^2 = 0 \text{ if } p_2^1 \left(1 - \frac{\varepsilon_1 \Delta A_2}{A_2 - A_2}\right) < p_2^2,$$

$$(11) \quad x_{12}^1 = 0, \quad x_{12}^2 = \frac{\alpha_1 m_1}{p_2^2} \text{ if } p_2^1 \left(1 - \frac{\varepsilon_1 \Delta A_2}{A_2 - A_2}\right) > p_2^2,$$

$$(12) \quad x_{12}^1 + \left(1 - \frac{\varepsilon_1 \Delta A_2}{A_2 - A_2}\right) x_{12}^2 = \frac{\alpha_1 m_1}{p_2^1} \text{ if } p_2^1 \left(1 - \frac{\varepsilon_1 \Delta A_2}{A_2 - A_2}\right) = p_2^2.$$

The representative consumer in the South solves the following utility maximization problem:

$$(13) \quad \max_{(x_{21}, x_{22}^1, x_{22}^2)} x_{21}^{1-\alpha_2} \left[x_{22}^1 + \left(1 - \frac{\varepsilon_2 \Delta A_2}{A_2 - A_2}\right) x_{22}^2 \right]^{\alpha_2}$$

subject to the following budget constraint:

$$(14) \quad p_1 x_{21} + p_2^1 x_{22}^1 + p_2^2 x_{22}^2 - m_2 = 0,$$

where m_2 is this consumer's income. The solution of this utility maximization problem is given by

$$(15) \quad x_{21} = \frac{(1 - \alpha_2) m_2}{p_1},$$

$$(16) \quad x_{22}^1 = \frac{\alpha_2 m_2}{p_2^1}, \quad x_{22}^2 = 0 \text{ if } p_2^1 \left(1 - \frac{\varepsilon_2 \Delta A_2}{A_2 - A_2}\right) < p_2^2,$$

$$(17) \quad x_{22}^1 = 0, \quad x_{22}^2 = \frac{\alpha_2 m_2}{p_2^2} \text{ if } p_2^1 \left(1 - \frac{\varepsilon_2 \Delta A_2}{A_2 - A_2}\right) > p_2^2.$$

$$(18) \quad x_{22}^1 + \left(1 - \frac{\varepsilon_2 \Delta A_2}{A_2 - A_2}\right) x_{22}^2 = \frac{\alpha_2 m_2}{p_2^1} \text{ if } p_2^1 \left(1 - \frac{\varepsilon_2 \Delta A_2}{A_2 - A_2}\right) = p_2^2.$$

2.5 Autarkic Equilibrium

First we will look into the autarkic equilibrium. In autarky, the economies are closed and they consume what they produce domestically. By a price system we mean a list $\mathcal{P} = ((p_j^i)_{j=1}^2, \omega_i, r_i)_{i=1}^2$, and by an allocation we mean a list $\mathcal{A} = ((Y_{ij}, L_{ij}, A_{ij})_{j=1}^2)_{i=1}^2, (X_{i1}, X_{i2})_{i=1}^2$. For the South, ΔA_2 is added in this list. A pair $(\mathcal{P}, \mathcal{A})$ is said to constitute equilibrium if the following conditions are satisfied:

First, for each i and each j , the production plan (Y_{ij}, L_{ij}, A_{ij}) maximizes the profit of the representative firm in sector j of country i when the price system $\mathcal{P}$ prevails.

Second, ΔA_2 is the part of the wilderness area converted to agricultural land in the South when the price system $\mathcal{P}$ prevails.

Third, (X_{i1}, X_{i2}) is the consumption bundle that maximizes the utility of the representative consumer in country $i, i=1,2$, subject to the aggregate budget constraint. More precisely, (X_{i1}, X_{i2}) is the solution of the problem constituted by (7) and (8), where the income of the representative consumer in country 1 is given by

$$(19) \quad m_1 = GDP_1 = p_1^1 Y_{11} + p_2^1 Y_{12}$$

For simplicity and without loss of generality, we assume that $\varepsilon_2 = 0$, i.e., consumers from the south are totally insensitive to biodiversity loss.

Then the solutions are:

$$(20) \quad x_{11} = \frac{(1 - \alpha_1)m_1}{p_1^1},$$

$$(21) \quad x_{12} = \frac{\alpha_1 m_1}{p_2^1},$$

(X_{21}, X_{22}) is the solution of the problem constituted by (13) and (14), where the income of the representative consumer in country 2 is given by

$$(22) \quad m_2 = GDP_2 = p_1^2 Y_{21} + p_2^2 Y_{22}$$

The solutions are:

$$(23) \quad x_{21} = \frac{(1 - \alpha_2)m_2}{p_1^2},$$

$$(24) \quad x_{22} = \frac{\alpha_2 m_2}{p_2^2},$$

Fourth, the following market-clearing conditions must hold for the North and South:

$$(25) \quad Y_{i1} = \frac{(1 - \alpha_i)(p_1^i Y_{i1} + p_2^i Y_{i2})}{p_1^i},$$

$$(26) \quad Y_{i2} = \frac{\alpha_i (p_1^i Y_{i1} + p_2^i Y_{i2})}{p_2^i},$$

$$(27) \quad \bar{L}_1 = Y_{11} \ell_{11} + Y_{12} \ell_{12},$$

$$(28) \quad \bar{L}_2 = Y_{21} \ell_{21} + Y_{22} \ell_{22} + C(\Delta A_2),$$

$$(29) \quad A_1 = a_{11} Y_{11} + a_{12} Y_{12},$$

$$(30) \quad A_2 + \Delta A_2 = a_{21} Y_{21} + a_{22} Y_{22}.$$

In what follows, we consider an equilibrium under which the output of each sector in each country is positive, i.e., $Y_{ij} > 0, i = 1, 2, j = 1, 2$. Because the technology in each sector is linear, profit maximization implies that the representative firm in each sector makes zero profits. The zero profit conditions are expressed by the following equations:

$$(31) \quad p_j^i = \omega_i \ell_{ij} + r_i a_{ij}, i = 1, 2, j = 1, 2.$$

Furthermore, in the South, wilderness land will be cleared until the marginal cost of land clearing is equal to the rental rate of land, i.e.,

$$(32) \quad r_2 = \omega_2 (\gamma_1 + \gamma_2 \Delta A_2) \text{ and,}$$

$$(32 \text{ A}) \quad r_2 = \omega_2 (\gamma_2 \Delta A_2), \text{ assuming } \gamma_1 = 0.$$

For the South, equations (22), (23), (24), (25), (26), (28), (30), (31), (32) constitute a system of 9 equations in 9 unknowns: $p_j^2, j = 1, 2, \omega_2, r_2, \Delta A_2, Y_{2j}, j = 1, 2, X_{21}, X_{22}$. Due to Walras' law, only 8 of these equations are independent. Choosing the wage rate in the South as the numeraire, we will have 8 independent equations in 8 unknowns, which can be solved to find the equilibrium of this autarky in the South.

For the North, equations (19), (20), (21), (25), (26), (27), (29), (31) constitute a system of 8 equations in 8 unknowns: $p_j^1, j = 1, 2, \omega_1, r_1, Y_{1j}, j = 1, 2, X_{11}, X_{12}$. Due to Walras' law, only 7 of these equations are independent. Choosing the wage rate in the North as the numeraire, we will have 7 independent equations in 7 unknowns, which can be solved to find the equilibrium of this autarky in the North.

Although the model can be solved algebraically, the large number of parameters makes it difficult to interpret the results. Therefore, we have tried to solve the model numerically

by assuming some reasonable values for the parameters that characterize the model.²² Numerical solutions are useful because they reveal a number of important results of the model. For simplicity and without loss of generality, we assume that $\varepsilon_2 = 0$, i.e., consumers from the south are totally insensitive to biodiversity loss and that $\gamma_0 = \gamma_1 = 0$. Also, we assume that the technology used by the agricultural good is land intensive and the one by the manufacturing good is labor intensive. It costs more to produce agricultural good in the North i.e. the North uses more per unit labor and land to produce the agricultural good than the South. In the same line of argument, we assume that it costs more to produce manufacturing good in the South.

The assumptions above implies that the South has a comparative advantage to produce the agricultural good and the North has a comparative advantage to produce the manufacturing good. It is reflected through the prices of the two goods in the North and South in Autarky shown in the table below.

TABLE 1
AUTARKY PRICES OF THE AGRICULTURAL AND MANUFACTURING GOODS

	Price of Agricultural Good	Price of Manufacturing Good
North	0.55	0.40
South	0.14	0.43

The above table clearly shows that under Autarky, the price of the agricultural good is lower in the South than the North and the price of the manufacturing good is lower in the North than the South. So, when the two economies will open up for trade, South will export agricultural good and North will export manufacturing good.

²² The values used for the parameters are listed in table 10 in the appendix.

2.6. General Equilibrium under Free Trade

When the two economies are opened up for free trade, the world markets will clear. The solution procedure will be similar as before except that few more variables and equations will be added in the system of general equilibrium.

Now we assume that two types of good 2 are produced. One is from the South that destroys biodiversity in the process of production and the other one is from the North. These are denoted by $(X_{i2}^1 \& X_{i2}^2)$ respectively. $(X_{i1}, X_{i2}^1, X_{i2}^2)$ is the consumption bundle that maximizes the utility of the representative consumer in country $i, i=1,2$, subject to the aggregate budget constraint. More precisely, $(X_{i1}, X_{i2}^1, X_{i2}^2)$ is the solution of the problem constituted by (7) and (8), where the income of the representative consumer in country 1 is given by

$$(33) \quad m_1 = GDP_1 = p_1^1 Y_{11} + p_2^1 Y_{12},$$

Here the solutions are:

$$(34) \quad x_{11} = \frac{(1 - \alpha_1)m_1}{p_1^1},$$

$$(35) \quad x_{12}^1 + (1 - \frac{\varepsilon_1 \Delta A_2}{A_2 - A_2})x_{12}^2 = \frac{\alpha_1 m_1}{p_2^1},$$

and $(X_{21}, X_{22}^1, X_{22}^2)$ is the solution of the problem constituted by (13) and (14) where the income of the representative consumer in country 2 is given by

$$(36) \quad m_2 = GDP_2 = p_1^2 Y_{21} + p_2^2 Y_{22}$$

The solutions are:

$$(37) \quad x_{21} = \frac{(1 - \alpha_2)m_2}{p_1^2},$$

$$(38) \quad x_{22}^1 + (1 - \frac{\varepsilon_2 \Delta A_2}{A_2 - A_2})x_{22}^2 = \frac{\alpha_2 m_2}{p_2^2},$$

Also, the following world market-clearing conditions must hold:

$$(39) \quad Y_{11} + Y_{21} = \frac{(1-\alpha_1)(p_1^1 Y_{11} + p_2^1 Y_{12})}{p_1^1} + \frac{(1-\alpha_2)(p_1^2 Y_{21} + p_2^2 Y_{22})}{p_1^2},$$

$$(40) \quad Y_{12} = X_{12}^1 + X_{22}^1,$$

$$(41) \quad Y_{22} = X_{12}^2 + X_{22}^2,$$

Equations (27) to (32) must also hold for this free trade case. Like before, we consider an equilibrium under which the output of each sector in each country is positive, i.e., $Y_{ij} > 0, i = 1, 2, j = 1, 2$.

As the manufacturing good produced in the South is assumed not to be harmful to the biodiversity, its price must be identical to the price of the manufacturing goods produced in the North. Hence

$$(42) \quad p_1^1 = p_1^2.$$

In general equilibrium, if the North imports the agricultural goods produced in the South, then we must have

$$(43) \quad p_2^1 \left(1 - \frac{\varepsilon_1 \Delta A_2}{A_2 - A_2}\right) = p_2^2.$$

When (43) holds, (12) applies for the representative consumer in the North, and we have

$$(44) \quad X_{12}^1 + \left(1 - \frac{\varepsilon_1 \Delta A_2}{A_2 - A_2}\right) X_{12}^2 = \frac{\alpha_1 (p_1^1 Y_{11} + p_2^1 Y_{12})}{p_2^1}.$$

Also, when (43) holds, (17) will apply for the representative consumer in the South due to the assumption $\varepsilon_2 < \varepsilon_1$, and we have

$$(45) \quad X_{22}^1 = 0,$$

$$(46) \quad X_{22}^2 = \frac{\alpha_2 (p_1^2 Y_{21} + p_2^2 Y_{22})}{p_2^2}.$$

Together, equations (33), (34), (36), (37), (39) to (41), (27) to (32), (42) to (44) and (46) constitute a system of 17 equations in 17 unknowns:

$p_j^i, i = 1, 2, j = 1, 2, \omega_i, i = 1, 2, r_i, i = 1, 2, \Delta A_2, Y_{ij}, i = 1, 2, j = 1, 2, X_{12}^1, X_{12}^2, X_{22}^1, X_{22}^2$. Due to Walras' law, only 16 of these equations are independent. Choosing the wage rate in the

South as the numeraire, we will have 16 independent equations in 16 unknowns, which can be solved to find the equilibrium of this two-country world.

In the same fashion as the autarky solution and with the same assumptions, we have tried to solve the model numerically by assuming some reasonable values for the parameters that characterize the model. We found some very interesting results through these solutions.

3. IMPACT OF TRADE ON BIODIVERSITY

3.1. From Autarky to Free Trade

There is a dominant view among the environmentalists that free trade degrades the environment and accelerates biodiversity loss.²³ The model can be simulated to find out if this viewpoint can be supported. In the numerical solutions, we compute the amount of new agricultural land cleared by labor in the South and used in food production. The following table shows the result for different levels of population or labor force.

TABLE 2
CHANGE IN THE AMOUNT OF CLEARED LAND UNDER AUTARKY AND FREE TRADE
FOR DIFFERENT SIZES OF POPULATION

Variables	$L_2 = 1.5$		$L_2 = 2$	
	Autarky	Free Trade	Autarky	Free Trade
ΔA_2	0.1729	1.3370	0.6394	1.6486
U_2	3.3217	3.6021	4.3153	4.5112
U_2/L_2	2.2145	2.4014	2.1577	2.2556
U_1	5.5509	6.7349	5.5509	6.5491
U_1/L_1	1.8503	2.2449	1.8503	2.1830
P_2	0.11	0.18	0.14	0.19

Note: In the above table,

L_2 = The size of the labor force in the South

ΔA_2 = The change in agricultural land or the amount of cleared land

U_2 = The total utility of the Southern consumers

U_2/L_2 = The per capita utility of the Southern consumers

P_2 = The price of the agricultural good

²³ 'Many environment groups have argued, and we agree, that the pattern of trade has helped accelerate environmental degradation worldwide. It has accelerated the depletion of natural resources as countries in the South extract raw materials and use land resources for export crops.'Khor, Martin in Third World Network Features, <http://www.sunsonline.org/trade/areas/envirnm/02230394.htm>

The results from the above table clearly show that the amount of cleared land increases as the South moves from autarky to free trade for both the population sizes. It supports the much-proclaimed view of the environmentalists that free trade increases biodiversity loss. The result is quite intuitive. As the South has a competitive advantage in agricultural goods, it will export these goods as the economy opens up for trade. In autarky, the South was producing food only to feed its own people, but now it will also produce food for exports. This increases the pressure on land resources. Due to the absence of market for any other values of biodiversity rich land, to produce more agricultural goods, the South clears the untouched biodiversity-rich land and brings it into agriculture. Also, as the utility of Southern consumers is not sensitive to biodiversity loss, moving from autarky to free trade increases both total and per capita utility in spite of the increase in biodiversity loss. This increase in utility provides an incentive for the South to push for more export by clearing more land and in the process causing biodiversity loss. Observe that the price of the agricultural good rises when the economy moves from autarky to free trade.

For the North, both the gross and per capita utility of the Northern consumers increase as it moves from autarky to free trade. It is obvious, as they can now consume more agricultural good at a lower price. But it is also important to note that both the gross and per capita utility of the Northern consumers decrease in free trade as the population in the South increases. This is due to the population growth induced increase in biodiversity loss in the South which in turn affects the utility of the Northern consumers.

3.2. The Impact of Positive Environmental Sensitiveness of the Southern Consumers

In the model above we assumed that the Southern consumers are insensitive to the loss of biodiversity i.e. we assumed that $\varepsilon_2 = 0$. But instead if we assume that $\varepsilon_2 > 0$, there will be an impact on the utility of the Southern consumers. The solutions for the variables will be the same as before. But a positive sensitiveness of the Southern consumers for the biodiversity loss will decrease the gross and per capita utility of the Southern consumers. This result is very straight forward. As the Southern consumers also now care about the loss of biodiversity and as free trade increases the loss of biodiversity, the utility of the

Southern consumers decreases more than the case when they had no sensitivity towards biodiversity loss. This is shown by table 3 below.

TABLE 3
IMPACT OF POSITIVE ENVIRONMENTAL SENSITIVITY OF THE SOUTHERN CONSUMERS
ON THEIR UTILITY

ε_2	$U_2 [Autarky]$	$U_2 [Free Trade]$
0.00	4.3153	4.5112
0.15	4.1775	4.1394
0.25	4.0854	3.8915

It is interesting to see in the above table that, both in Autarky and free trade, the gross utility of the Southern consumer's decreases as their sensitivity towards biodiversity loss increases. When the South moves from autarky to free trade and the Southern consumers have positive sensitivity towards biodiversity loss (i.e. $\varepsilon_2 > 0$), the gross utility of the Southern consumers decreases even more. It implies that free trade may decrease both the utility of the Southern consumers and the stock of biodiversity if the Southern consumers are sensitive to biodiversity loss. If the sensitivity of the Southern consumers become highly positive and $\varepsilon_2 > \varepsilon_1$, then the South may lose the comparative advantage in agricultural goods and start importing it from the North.

3.3 The Impact of Biodiversity Loss on the Terms of Trade

The model assumes that Northern consumers are sensitive to biodiversity loss and these preferences are reflected in their utility function. The consumption of the agricultural good produced in the South, which destroys biodiversity, is discounted by the northern consumers through the discount factor $(1 - \frac{\varepsilon_1 \Delta A_2}{A_2 - A_2})$. Also, when the Northern consumers purchase both the agricultural goods produced at home and the agricultural good produced in the South, then we have: $p_2^1 (1 - \frac{\varepsilon_1 \Delta A_2}{A_2 - A_2}) = p_2^2$, according to (43).

Now the terms of trade for the South is given by the ratio of the price of the exported good over the price of the imported good, i.e.,

$$(47) \quad P^* = \frac{P_2^2}{P_1^2} = \frac{l_{22} + a_{22}\gamma_2\Delta A_2}{l_{21} + a_{21}\gamma_2\Delta A_2}$$

Differentiating the above terms of trade with respect to ΔA_2 provides the following expression:

$$(47A) \quad \frac{\partial P^*}{\partial \Delta A_2} = \frac{\gamma_2(a_{22}l_{21} - a_{21}l_{22})}{(l_{21} + a_{21}\gamma_2\Delta A_2)^2}$$

As by assumption, $a_{22} > a_{21}$ and $l_{21} > l_{22}$, so, $\frac{\partial P^*}{\partial \Delta A_2} > 0$.

Results from the sensitivity analysis confirm the above relation. It can be seen from (47A) that the terms of trade increases with rise in ΔA_2 . So, even with the green consumer's discounting of the southern agricultural product, the southern terms of trade increases with increase in land clearing. This works as an incentive to clear more land in the South. But with large scale land clearing, the price of the southern agricultural product may increase enough to reverse the pattern of trade in agricultural goods and the South may become a net importer of the agricultural good.

4. TWO TYPES OF CONSUMERS IN THE NORTH

In this section, we extend the model to the case in which there are two types of consumers in the North. One type, called the “green” is sensitive to biodiversity loss and the other type, called the “gray” is indifferent to biodiversity loss. Furthermore, the later is assumed to behave like the Southern consumers who are also insensitive to biodiversity loss. We assume that, $\alpha_2 = \alpha_{2gray}$. The greens are assumed to constitute a fraction, θ ($0 < \theta < 1$), of the Northern population. The size of the grays, as a fraction of the total

population is thus equal to $1-\theta$. To concentrate on the question of how different preferences for biodiversity affect biodiversity loss, we shall assume that all the Northern consumers, except their different preferences for biodiversity, have the same income. Furthermore, the utility functions of the two types of consumers in the North are given by:

$$(48) \quad u_{1green}(x_{1green,1}, x_{1green,2}^1, x_{1green,2}^2) = [x_{1green,1}]^{1-\alpha_{1green}} \left[x_{1green,2}^1 + \left(1 - \frac{\varepsilon_1 \Delta A_2}{A_2 - A_2}\right) x_{1green,2}^2 \right]^{\alpha_{1green}}$$

$$(49) \quad u_{1gray}(x_{1gray,1}, x_{1gray,2}^1, x_{1gray,2}^2) = [x_{1gray,1}]^{1-\alpha_{1gray}} \left[x_{1gray,2}^1 + \left(1 - \frac{\varepsilon_1 \Delta A_2}{A_2 - A_2}\right) x_{1gray,2}^2 \right]^{\alpha_{1gray}}$$

The budget constraint of a green Northern consumer and the budget constraint of a gray Northern consumer are given, respectively, by -

$$(50) \quad p_1 x_{1green,1} + p_2^1 x_{1green,2}^1 + p_2^2 x_{1green,2}^2 - \theta m_1 = 0.$$

$$(51) \quad p_1 x_{1gray,1} + p_2^1 x_{1gray,2}^1 + p_2^2 x_{1gray,2}^2 - (1-\theta)m_1 = 0.$$

The world market clearing conditions provides that,

$$p_2^1 \left(1 - \frac{\varepsilon_1 \Delta A_2}{A_2 - A_2}\right) = p_2^2.$$

The solutions to this maximization problem for the green consumers will be as the following. The demand for the manufacturing goods will be -

$$(52) \quad x_{1green,1} = \frac{(1-\alpha_{1green})\theta m_1}{p_1},$$

And the demand for the agricultural goods from the North and from the South is:

$$(53) \quad x_{1green,2}^1 + \left(1 - \frac{\varepsilon_1 \Delta A_2}{A_2 - A_2}\right) x_{1green,2}^2 = \frac{\alpha_{1green} \theta m_1}{p_2^1}.$$

As from the world market clearing condition we get, $p_2^1 > p_2^2$ and the gray consumers in the North are insensitive to biodiversity loss, they will only consume agricultural goods exported from the South as it is cheaper to them. So, their utility maximization will provide demand for the manufacturing and agricultural goods as the following:

$$(54) \quad x_{1gray,1} = \frac{(1-\alpha_{1gray})(1-\theta)m_1}{p_1},$$

$$(55) \quad x_{1gray,2}^2 = \frac{\alpha_{1gray}(1-\theta)m_1}{p_2^2}.$$

With these new utility maximizing quantities we can get a different set of solutions for this two consumer group case. The results that we get through the numerical solutions for this extension of the model are interesting and support our previous claim. The following table shows the comparative picture of the key variables under autarky, free trade and free trade with two types of Northern consumers.

TABLE 4
CHANGE IN THE AMOUNT OF CLEARED LAND UNDER AUTARKY, FREE TRADE AND
FREE TRADE WITH TWO TYPES OF NORTHERN CONSUMERS

Variables	$L_2 = 2$		
	Autarky	Free Trade	Free Trade with Two Groups
ΔA_2	0.6394	1.6486	1.7894
U_2	4.3153	4.5112	4.5623
U_2/L_2	2.1577	2.2556	2.2812
P_2^2	0.14	0.19	0.21
P_2^2 / P_1^2	-	0.43	0.44

The above table also clearly establishes our previous claim that biodiversity loss through clearing of land increases if a country moves from autarky to free trade. It even increases further if a portion of the northern consumers is insensitive to biodiversity loss. Both the total and per capita utility in the south increases from autarky to - free trade to - free trade with two groups of northern consumers. South's comparative advantage in agricultural products is the reason behind this. Also the price of good 2 and the terms of trade for the South increase from free trade to free trade with two types of Northern consumers. Both of the above two events work as incentives for the Southern economies to clear more land and increase the export of agricultural goods.

Next we look at the case when the income share of the Northern green consumers increases. Table 4 shows, as the income share of the 'green consumers' in the North

becomes larger, the clearing of land and in the process, biodiversity loss decreases further. It implies that only preference related discounting of the northern consumers could slow down the biodiversity loss in the south. As more northern consumers discount the southern agricultural goods, the biodiversity loss slows down in the south. But this is true only if there is no population growth in the south.

TABLE 5
DIFFERENT INCOME LEVELS OF 'GREEN CONSUMERS' ($L_2 = 2$)

Different Values of θ	ΔA_2
0.5	1.8239
0.6	1.7894
0.7	1.7546

5. IMPACT OF POPULATION GROWTH ON BIODIVERSITY

We can also get important insight from the above models on the impact of population growth on biodiversity. It is a popular claim that rapid population growth in the South is a major cause of global biodiversity decline. As the population grows in the South, they try to feed the increased population by clearing more land which is biodiversity rich and bringing it into agriculture. Our results support this claim.

TABLE 6
IMPACT OF SOUTHERN POPULATION GROWTH

Variables	Autarky		Free Trade		Free Trade with two groups	
	$L_2 = 1.5$	$L_2 = 2$	$L_2 = 1.5$	$L_2 = 2$	$L_2 = 1.5$	$L_2 = 2$
ΔA_2	0.1729	0.6394	1.3370	1.6486	1.4864	1.7894
U_2	3.3217	4.3153	3.6021	4.5112	3.6666	4.5623
U_2/L_2	2.2145	2.1577	2.4014	2.2556	2.4444	2.2812
P_2^2	0.11	0.14	0.18	0.19	0.19	0.21
P_2^2 / P_1^2	-	-	0.397	0.43	0.41	0.44

Table 6 shows that in all three cases - autarky, free trade and free trade with two groups of Northern consumers - as population size increases, the amount of cleared land also increases which in the process increases biodiversity loss. Population growth joined with free trade make the situation worse and population growth joined with free trade with two northern consumer groups make the situation worst. Also under both the cases of free trade, the total utility of the South and its terms of trade improve with population increase. These two factors work as an incentive to increase the export of agricultural goods and causes more land clearing. But at the same time the per capita utility declines with population increase in the South and it should also be taken into account by the South. So, population increase may bring growth in total utility of Southern consumers and improve the trade scenario for the South, but it is accompanied with per capita utility decline and biodiversity losses. The two later trends may deteriorate the national welfare in the long run.

Not only the population increase in the South, but the population increase in the North can also create pressure on biodiversity and increase its loss. Though the Northern consumers are sensitive to biodiversity loss, yet with increased population, their demand for agricultural good will increase and they will import more of the Southern agricultural good. This will help to expand the agricultural sector in the South and it will clear more untouched land which will eventually increase biodiversity loss.

TABLE 7
IMPACT OF NORTHERN POPULATION GROWTH

Variables	Free Trade		
	$L_I = 3$	$L_I = 3.5$	$L_I = 4$
ΔA_2	1.6486	1.9131	2.1729
U_2	4.5112	4.6108	4.7226
U_2/L_2	2.2556	2.3054	2.3613
P_2^2 / P_1^2	0.43	0.45	0.47

It is evident from the results presented in table 7. Also note that with population increase in the North, the gross and per capita utility of the Southern consumers and the terms of trade of the South increase too. This will again work as an incentive for further expansion of the Southern agricultural sector and increase biodiversity loss.

Biodiversity loss increases most if the population in both the North and South increases. It is evident from table 8. If we compare columns 2 to 3, only the Northern population increases and the amount of cleared land increase from 1.6486 to 1.9131. Between columns 2 and 4, only the Southern population increases and the amount of cleared land increases from 1.6486 to 1.9457. So, more land is cleared for an increase in population in the South than in the North. Finally if we compare columns 2 and 5, both the Southern and Northern population increases and the amount of cleared land are highest in this case. It implies that population increase is one of the main reasons for biodiversity loss. Also under free trade, biodiversity is destroyed more in the case of population increase in the South than population increase in the North.

TABLE 8
IMPACT OF BOTH NORTHERN AND SOUTHERN POPULATION GROWTH

Variables	$L_1 = 3$ $L_2 = 2$	$L_1 = 3.5$ $L_2 = 2$	$L_1 = 3$ $L_2 = 2.5$	$L_1 = 3.5$ $L_2 = 2.5$
ΔA_2	1.6486	1.9131	1.9457	2.2019
U_2	4.5112	4.6108	5.3565	5.4395
U_2/L_2	2.2556	2.3054	2.1426	2.1758
P_2^2 / P_1^2	0.43	0.4507	0.4536	0.48

6. IMPACT OF SUBSIDY

We make a final extension of the model, to find the impact of a subsidy on biodiversity and on the utilities of the Northern and the Southern consumers. The model will be same as the ‘free trade’ case with a minor extension. We assume that the North provides a

lump-sum subsidy of the amount ‘T’ to the South. This subsidy ‘T’ is subtracted from the Northern GDP and added to the Southern GDP. We further assume that this subsidy is used by the South to improve technological efficiency in the agricultural sector, so that less amount of per unit land is used to produce the agricultural good. In this way it decreases land clearing in the South and decreases biodiversity loss. It is reflected through the following equation that is added to the model.

$$(56) \quad a_{22} = \delta - \sigma \cdot \ell_0$$

where δ & σ are two parameters and $\ell_0 = T / \omega_2$ i.e. it is the amount of labor used to invent new technology that uses lower amount of land in the agricultural sector. Using this extra assumption if we solve the model we find interesting results. The results are summarized in table 9.

TABLE 9
IMPACT OF SUBSIDY

Variables	Amount of Subsidy		
	T = 0.05	T = 0.08	T = 0.11
ΔA_2	1.2811	1.2445	1.2053
U_2	3.6937	3.7488	3.8040
U_1	6.7296	6.7275	6.7261

The results above clearly show that under free trade, if a subsidy is provided from the North to the South that improves the land use efficiency in the South, the amount of land cleared in the South decreases and so is the biodiversity loss. It also increases the gross utility of the Southern consumers. But the Northern consumers’ gross utility decreases.

7. SENSITIVITY ANALYSIS

We have run some sensitivity analysis to get more insight on the affect of different parameters on the model. The results are presented in the appendix. The following are the major conclusions from the sensitivity analysis.

- i. The amount of cleared land is lower when the size of total land is smaller in the South.
- ii. Land clearing is also sensitive to the amount of available developed land in the South. With a higher amount of developed land, the amount of cleared land, price of good '2' and the terms of trade for the South become smaller. But the opening up of the economy clears more land with a higher amount of developed land.
- iii. Both the terms of trade and the amount of cleared land are smaller with a higher level of land use efficiency either in the North or in the South.
- iv. With a higher level of the elasticity of substitution for consumption of good 2, the amount of cleared land is also larger. But the impact of Northern consumer's α_1 is greater than the Southern consumer's α_2 .
- v. A larger value of discount factor results in corresponding smaller levels of cleared land and terms of trade.
- vi. The differences in the amount of cleared land for two different population levels are lower for the free trade scenario. It implies that the scale effect of population growth on the land clearing activities is dampened by the green consumerism under free trade.

8. POLICY IMPLICATIONS AND CONCLUSION

This chapter has lent support to some of the concerns of anti-globalization activists that when there is no market for the biodiversity resources itself, free trade may deplete the world's biodiversity. Biodiversity resources provide different goods and services that often do not have any market. For example, ecosystem services that are produced by biodiversity rich land increase the productivity of the agricultural sector and yet that sector does not pay for them. There are other non-use values (e.g. carbon sequestration) associated with 'undeveloped land' which also have no market. In fact the market for

many of these non-use values is global in nature and scope which implies that the South alone can not correct for the distortion generated from the missing market problem. Due to absence of markets for these services and products derived from biodiversity rich land, the opportunity cost of their alternative use in agriculture becomes significant and causes land clearing. Further, when developing countries can not monetize the value of the conserved biodiversity they have no other alternatives but to deplete their rich biodiversity resource stock in order to meet the subsistence needs of the current population, even though this may be welfare decreasing for the future generations in these countries as well as for the world at large.

On the other hand, the chapter has also provided support to the concerns of environmental and resource economists that even without trade, unsustainable population growth alone can deplete biodiversity resources. Further, the 'ecological footprint'²⁴ concept explained by Wackernagel and Rees (1996)²⁵ is also supported by this model. Free trade coupled with Southern rapid population growth and agricultural expansion can augment the 'ecological footprint' of the South leading to rapid biodiversity loss.

Demand-side mechanisms like discounting of biodiversity depleting products and supply side mechanisms such as eco-friendly agricultural technologies can have a positive impact to decrease biodiversity loss. But, merely discounting southern agricultural products and not being concerned about the biodiversity resources directly, may not

²⁴ 'A measure of the 'load' imposed by a given population on nature. It represents the land area necessary to sustain current levels of resource consumption and waste discharge by that population.'
www.pce.govt.nz/reports/pce_reports_glossary.shtml

²⁵ Wackernagel and Rees (1996).

provide sufficient incentives for biodiversity conservation in the long run. If Northern 'green' consumers really care about biodiversity loss in the South, then biodiversity should be an argument in their utility function. In such a case, their valuation of Southern biodiversity can be measured and they should be willing to pay for the conservation of biodiversity in the South equal to that value. Not valuing biodiversity directly and only discounting differentiated products as shown in this model can only slow down the depletion of biodiversity stock, but cannot provide a more sustainable long term solution.

The above discussion leads to the conclusion that policy planners should try to create markets for the different goods and services provided by biodiversity rich lands. For example, they may further explore alternative markets such as bio-prospecting or eco-tourism in order to appropriate economic values for the conservation of the biodiversity stock. Also the biodiversity rich developing countries have to diversify with respect to domestic production and trade. They need to decrease their dependence on export of natural resources and agricultural products and diversify their export towards manufacturing products. Above all, if consumers in all regions of the world really care about the existence of biodiversity, they should be prepared to pay a premium for the conservation and provision of this global public good. Hence, institutions such as the Global Environmental Fund should become the principle mechanisms for the conservation of biodiversity.

APPENDIX A

TABLE 10
DIFFERENT SIZES OF SOUTHERN TOTAL LAND

	$\bar{A}_2 = 5$	$\bar{A}_2 = 4.5$	$\bar{A}_2 = 4$
ΔA_2	1.6486	1.6372	1.6179
U_2/L_2	2.2556	2.2536	2.2504
U_1/L_1	2.1830	2.1577	2.1195
p_2 / p_1	0.4269	0.4259	0.4241

TABLE 11
DIFFERENT SIZES OF SOUTHERN DEVELOPED LAND

	$A_2 = 2$	$A_2 = 2.5$	$A_2 = 3$
ΔA_2 (Autarky)	0.63941	0.317	1.4572×10^{-16}
ΔA_2 (Free Trade)	1.6486	1.3881	1.1316
$[\Delta A_2$ (Free Trade) - ΔA_2 (Autarky)]	1.0092	1.0711	1.13159
U_2/L_2	2.2556	2.3267	2.3754
U_1/L_1	2.1830	2.218	2.241
P_2 (Autarky)	0.138	0.119	0.1
P_2 (Free Trade)	0.199	0.183	0.168
$[P_2$ (Free Trade) - P_2 (Autarky)]	0.061	0.064	0.068
p_2 / p_1	0.4269	0.4024	0.3771

TABLE 12
DIFFERENT SOUTHERN LAND EFFICIENCY

	$a_{22} = 0.3$	$a_{22} = 0.28$	$a_{22} = 0.26$	$a_{22} = 0.24$
ΔA_2	1.6486	1.5707	1.4808	1.3767
U_2/L_2	2.2556	2.2722	2.2868	2.2988
U_1/L_1	2.1830	2.2142	2.2486	2.2869
p_2 / p_1	0.4269	0.4061	0.3854	0.365

TABLE 13
DIFFERENT NORTHERN LAND EFFICIENCY

	$a_{12} = 0.40$	$a_{12} = 0.38$	$a_{12} = 0.36$	$a_{12} = 0.34$
ΔA_2	1.6486	1.6323	1.6139	1.5931
U_2/L_2	2.2556	2.2528	2.25	2.2462
U_1/L_1	2.1830	2.1869	2.1912	2.1959
p_2 / p_1	0.4269	0.4254	0.4237	0.4218

TABLE 14
DIFFERENT VALUES OF α_2 , α_1

	$\alpha_2 = 0.4$ $\alpha_1 = 0.3$	$\alpha_2 = 0.3$ $\alpha_1 = 0.3$	$\alpha_2 = 0.3$ $\alpha_1 = 0.4$
ΔA_2	1.6486	1.4260	1.78
U_2/L_2	2.2556	2.2528	2.2331
U_1/L_1	2.1830	2.1869	2.1449
p_2 / p_1	0.4269	0.4254	0.4386

TABLE 15
DIFFERENT SOUTHERN POPULATION SIZES

Variables	$L_2 = 1.5$		$L_2 = 2$		Difference	
	Autarky	Free Trade	Autarky	Free Trade	Autarky	Free Trade
ΔA_2	0.1729	1.3370	0.6394	1.6486	0.4665	0.3116
U_2	3.3217	3.6021	4.3153	4.5112	0.9936	0.9091
U_2/L_2	2.392	2.4014	2.1577	2.2556	-0.2343	-0.1364
P_2	0.11	0.18	0.14	0.19	0.03	0.01
p_2 / p_1	-	0.394	-	0.422	-	0.028

TABLE 16
DIFFERENT DISCOUNT FACTORS

	$\varepsilon_1 = 0.4$	$\varepsilon_1 = 0.5$	$\varepsilon_1 = 0.6$
ΔA_2	1.6486	1.6341	1.6179
U_2/L_2	2.2556	2.2531	2.2504
U_1/L_1	2.1830	2.1513	2.1195
p_2 / p_1	0.4269	0.4256	0.4241

APPENDIX B

TABLE 17
PARAMETER VALUES USED FOR NUMERICAL SIMULATION

Parameter and Values
$l_{11} = 0.3$
$a_{11} = 0.1$
$l_{12} = 0.15$
$a_{12} = 0.4$
$l_{21} = 0.4$
$a_{21} = 0.2$
$l_{22} = 0.1$
$a_{22} = 0.3$
$\alpha_1 = 0.3$
$\alpha_2 = 0.4$
$\alpha_{1_{green}} = 0.3$
$\alpha_{1_{gray}} = 0.4$
$\theta = 0.6$
$\varepsilon_1 = 0.4$
$\bar{A}_2 = 5$
$A_1 = 1.5$
$L_1 = 3$
$A_2 = 2$
$L_2 = 2$

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CHAPTER 3

LAND CONVERSION, ECOSYSTEM SERVICES AND BIODIVERSITY CONSERVATION

1. INTRODUCTION

Biologically diverse land provides many economic and non-economic services to the human society. One of such services is the *ecosystem services* that help to improve the productivity of the agricultural sector. These services include photosynthesis, soil generation and preservation, pollination of crops, recycling of nutrients, filtering of pollutants and waste assimilation, flood control, climate moderation, operation of the hydrological cycle, disturbance regulation, biological control (Costanza et al. (1997), Folke et al. (1996)). In ecosystem terms, ecosystems are fundamental ‘factors of production’ (Barbier et al. (1994), Jansson et al. (1994)). But these contributions of biologically diverse land are not reflected in the market system. Ecosystem functions have strong public goods characteristics, and so are often undervalued in the private sector’s production process. According to Costanza et al. (1997), “because ecosystem services are not fully captured in the market or adequately quantified in terms comparable with economic services and manufactured capital, they are often given too little weight in policy discussions.” Failure to include ecological benefits of biodiversity rich land results in higher level of deforestation (Barbier and Burgess (1997)). Empirical evidence also confirms that ecosystem services are needed for agricultural production.²⁶

Very few models have been developed to include ecosystem services in the production process. Folke et al. (1996) considered *ecosystem* as a natural capital and as a primary input in the production process. Bulte et al. (2002) modeled *the flow of ecosystem services* as a geometric Brownian motion to capture the trend and uncertainty aspects of

²⁶ Regmi and Weber (2000) report that crop yields have continuously been decreasing over time, largely caused by heavy top soil losses which is prevented by ecosystem services. They also report evidence that a loss of 3.9 inches of top soil reduced yield by 52% in West Africa.

ecosystem services. Huang and Smith (1998) and Pattanayak and Butry (2003) have modeled *the flow of ecosystem services* as a weak complementary factor to the production process.

In this paper, to analyze the pattern of land conversion and biodiversity loss, we formulate a North-South trade model that includes the *flow of ecosystem services* in the agricultural production function of the South as a weak complement. Choosing ecosystem services as a weak complement makes the production positive even when all the biodiversity is lost. Furthermore, to capture the dynamics of land conversion, ecosystem services, and savings, the model is set in the framework of overlapping generations. The model thus formulated is meant to explain how the absence of asset markets other than land affects the pattern of land conversion in the South. Inclusion of ecosystem services in the production process imposes a limit on the growth of agricultural production. In extreme situations – when the amount of biodiversity rich land reaches a critical threshold – the marginal productivity of land in agriculture becomes negative. Currently, there are various efforts around the world to create markets for ecosystem services or to use fiscal tools to conserve biodiversity rich land to ensure the flow of ecosystem services. For example, Costa Rica has instituted a system of environmental service payments made to the private owners of conserved land. In Europe, the US, and Canada, tools such as land taxes, land development fees, and payments for set aside lands, are used for land conservation purposes. The chapter proposes some instruments to capture the value of ecosystem services.

Many other factors also explain the current destruction of biological diversity. A major dividing line in the debate on the causes of the biodiversity destruction separates the camp that emphasizes population and poverty factors as the causes of biodiversity loss from the camp that attributes the loss of biodiversity to market and institutional factors failure. See, for example, Angelsen (1999). This chapter – by emphasizing population and poverty factors as well as market and institutional factors – contributes to explaining how factors from both camps cause biodiversity destruction. Poverty in this chapter is represented in the form of low labor productivity. Institutional and market factors are

represented by the absence of any real assets market other than developed land and absence of market for ecosystem services.

The structure of the paper is as follows. Section 2 describes the model. The definition of competitive equilibrium is given in Section 3. The properties of the competitive equilibrium are discussed in Section 4. Policies for internalizing the value of ecosystem services are discussed in Section 5. Some concluding remarks are given in Section 6.

2. THE MODEL

2.1. *Technologies*

Time is discrete and denoted by $t, t = 0, 1, \dots$. There are two countries – called country 1 (the North) and country 2 (the South), respectively. Each of these countries produces two goods – one manufacturing good, called good 1, and one agricultural good, called good 2 – from labor (L) and land (A). Agricultural good is land intensive and the manufacturing good is labor intensive. We also assume that South is abundant in land and North is abundant in labor. So, South has a comparative advantage in agricultural goods and North has a comparative advantage in manufacturing goods. When they open up for trade, they trade according to their comparative advantage. In what follows the countries will be indexed by $i, i = 1, 2$, and the goods by $j, j = 1, 2$.

Let $A_i^{\max}$ be the land endowment of country i . In each country, part of the land endowment has already been developed and is ready for use as input in the production process. The remaining part is still in a state of wilderness and must be cleared before being used as a factor of production. Let $A_{i,t}$ denote the stock of land already developed and available as an input for production at the beginning of period t in country i . We shall assume that all the land in the North has been developed, i.e., $A_{1,t} = A_1^{\max}, t \geq 0$. In the South, the wilderness land is rich in biological diversity and provides *ecosystem services*, and part of this region can be cleared in any period for use as input in food

production in the following period. In the South, the area of wilderness land that remains at the beginning of period t is $A_2^{\max} - A_{2,t}$.

In each country, three classes of economic agents coexist in each period t : a young generation, an old generation, and competitive firms. In each period $t, t=0,1,\dots$, the demographic structure of country $i, i=1,2$, is represented by the list $(N_{i,t}^0, N_{i,t}^1)$, where $N_{i,t}^0$ and $N_{i,t}^1$ denote, respectively, the size of the young generation and the size of the old generation in that country in period t . The evolution of $(N_{i,t}^0, N_{i,t}^1)$ through time is taken to be exogenous. An individual lives two periods, first as a young person, and then as an old person. The individual works when she is young, and retires when she is old. In any period and in each country, the stock of developed land is owned by the old generation of that period. The assumption of the model is that there are no other asset markets in the South that the old generation can use to generate old-age income. So, it is only through the land she owns that an old individual provides for her old-age consumption. A young individual owns no assets, except for one unit of time that she supplies inelastically to the labor market. Part of her labor income is spent on current consumption, and the remaining part – her saving – is used to acquire developed land at the end of the period. It is through this amount of land thus acquired that a young individual provides for her old-age consumption.

Let $a_{2,t}$ denote the amount of land cleared in the South in period t . It is assumed that wilderness land is cleared by perfectly competitive firms with the help of labor and that the total amount of labor inputs needed to clear a_2 units of land is given by

$$(1) \quad \Gamma(a_2) = \gamma a_2,$$

where γ is a positive parameter. We shall assume that the wilderness land cleared during period t is offered for sale to the young generation at the end of that period. The stock of developed land available for use in production at the beginning of the next period in the South is then described by the following difference equation:

$$(2) \quad A_{2,t+1} = A_{2,t} + a_{2,t}, \quad A_{2,0} \text{ is given.}$$

In each period t , the manufacturing good in country i is produced according to the following Cobb-Douglas production function:

$$(3) \quad Y_{i,1,t} = A_{i,1,t}^{1-\beta_{i,1}} L_{i,1,t}^{\beta_{i,1}},$$

where $Y_{i,1,t}$, $A_{i,1,t}$, and $L_{i,1,t}$ denote, respectively, the output of the manufacturing good, the land input, and the labor input – all in period t – used to produce the manufacturing good in country $i, i=1,2$. Also, $0 < \beta_{i,1} < 1, i=1,2$, is a parameter.

As for the agricultural sectors, the output of the agricultural good produced in the North is assumed to be given by

$$(4) \quad Y_{1,2,t} = A_{1,2,t}^{1-\beta_{1,2}} L_{1,2,t}^{\beta_{1,2}},$$

where $Y_{1,2,t}$, $A_{1,2,t}$, and $L_{1,2,t}$ denote, respectively, the output of the agricultural good, the land input, and the labor input – all in period t – used to produce the agricultural good in the North. Also, $0 < \beta_{1,2} < 1$, is a parameter.

In the South, the stock of wilderness land is assumed to provide a *flow of ecosystem services* to the agricultural sector in this region. These ecosystem services can be considered as *inputs which complement the traditional factors of production* used in the agricultural sector in the South. More precisely, the output of the agricultural good in the South in any period t is given by the following production function:

$$(5) \quad Y_{2,2,t} = \frac{1}{1 + e^{-\mu(A_2^{\max} - A_{2,t})}} A_{2,2,t}^{1-\beta_{2,2}} L_{2,2,t}^{\beta_{2,2}}.$$

In (5), $Y_{2,2,t}$ represents the output of the agricultural good produced in the South; $A_{2,2,t}$ and $L_{2,2,t}$ denote, respectively, the inputs of land and labor used in the production of the agricultural good. Also, $0 < \beta_{2,2} < 1$ is the parameter that characterizes the elasticity of the output of the agricultural good with respect to the labor input, and $\mu > 0$ is the parameter that characterizes the ecosystem services contributed by the remaining wilderness land to the production of the agricultural goods. In (5), the ecosystem services are represented by the expression $[1/(1 + e^{-\mu(A_2^{\max} - A_{2,t})})]$. Observe that the value of

ecosystem services rises with the amount of undeveloped land but at a decreasing rate. Furthermore, the output of agricultural good is not reduced to zero even if all the wilderness land is developed. Hence ecosystem services can be considered as weak complements of the essential inputs – land and labor – in the production of the agricultural goods.

2.2. Preferences

Consider a young individual who lives in country i in period t . A lifetime consumption plan for such an individual is a list $((x_{i,1,t}^0, x_{i,2,t}^0), (x_{i,1,t+1}^1, x_{i,2,t+1}^1))$, where $x_{i,j,t}^0$ denotes her consumption of good j in period t , when she is young, and $x_{i,j,t+1}^1$ denotes her consumption of good j in period $t+1$, when she is old. Her discounted lifetime utility is then given by

$$(6) \quad u_i(x_{i,1,t}^0, x_{i,2,t}^0) + \delta_i u_i(x_{i,1,t+1}^1, x_{i,2,t+1}^1),$$

where $u_i(x_{i,1}, x_{i,2})$ is the single-period utility function in terms of the manufacturing good and the agricultural good consumed in that period. Also, $\delta_i, 0 < \delta_i < 1$, is the factor used to discount utility. In what follows, the single-period utility function for an individual in country i is assumed to have the following form:

$$(7) \quad u_i(x_{i,1}, x_{i,2}) = \text{Log} x_{i,1} + \alpha_i \text{Log} x_{i,2},$$

where $0 < \alpha_i < 1$, is a parameter.

2.3. The Price System

Let $\omega_{i,t}$ and $r_{i,t}$ denote, respectively, the wage rate and the rental rate of land that prevail in period t in country i . Also, we denote by $p_{i,j,t}$ the price of good j that prevails in period t in country i . As for land, we shall let $q_{i,t}$ be the price at which land can be bought and sold at the end of period t in country i . By a price system we mean an infinite sequence $\mathcal{P} = ((p_{i,1,t}, p_{i,2,t}, \omega_{i,t}, r_{i,t}, q_{i,t})_{i=1}^2)_{t=0}^\infty$.

2.4. Cost Minimization in the Manufacturing Sector and in the Agricultural Sector

Let $\mathcal{P} = \left((p_{i,1,t}, p_{i,2,t}, \omega_{i,t}, r_{i,t}, q_{i,t})_{i=1}^2 \right)_{t=0}^{\infty}$ be a price system. In period t , the cost function of the representative firm that produces the manufacturing good in country i is obtained by solving the following cost minimization problem:

$$(8) \quad \min_{(A_{i,1,t}, L_{i,1,t})} r_{i,t} A_{i,1,t} + \omega_{i,t} L_{i,1,t}$$

subject to

$$(9) \quad Y_{i,1,t} = A_{i,1,t}^{1-\beta_{i,1}} L_{i,1,t}^{\beta_{i,1}}.$$

The solution of the cost minimization problem constituted by (8) and (9) is well known and is given by

$$(10) \quad A_{i,1,t}(\mathcal{P}, Y_{i,1,t}) = \left(\frac{1-\beta_{i,1}}{\beta_{i,1}} \right)^{\beta_{i,1}} r_{i,t}^{-\beta_{i,1}} \omega_{i,t}^{\beta_{i,1}} Y_{i,1,t}$$

and

$$(11) \quad L_{i,1,t}(\mathcal{P}, Y_{i,1,t}) = \left(\frac{1-\beta_{i,1}}{\beta_{i,1}} \right)^{-(1-\beta_{i,1})} r_{i,t}^{1-\beta_{i,1}} \omega_{i,t}^{-(1-\beta_{i,1})} Y_{i,1,t}.$$

Furthermore, the cost function in period t of the representative firm that produces the manufacturing good in country i is given by

$$(12) \quad C_{i,1,t}(\mathcal{P}, Y_{i,1,t}) = \left[\left(\frac{1-\beta_{i,1}}{\beta_{i,1}} \right)^{\beta_{i,1}} + \left(\frac{1-\beta_{i,1}}{\beta_{i,1}} \right)^{-(1-\beta_{i,1})} \right] r_{i,t}^{1-\beta_{i,1}} \omega_{i,t}^{\beta_{i,1}} Y_{i,1,t}.$$

Similarly, in period t , the cost function of the representative firm that produces the agricultural good in country 1 is obtained by solving the following cost minimization problem:

$$(13) \quad \min_{(A_{1,2,t}, L_{1,2,t})} r_{1,t} A_{1,2,t} + \omega_{1,t} L_{1,2,t}$$

subject to

$$(14) \quad Y_{1,2,t} = A_{1,2,t}^{1-\beta_{1,2}} L_{1,2,t}^{\beta_{1,2}}.$$

The solution of the cost minimization problem constituted by (13) and (14) is given by

$$(15) \quad A_{1,2,t}(\mathcal{P}, Y_{1,2,t}) = \left(\frac{1 - \beta_{1,2}}{\beta_{1,2}} \right)^{\beta_{1,2}} r_{1,t}^{-\beta_{1,2}} \omega_{1,t}^{\beta_{1,2}} Y_{1,2,t}$$

and

$$(16) \quad L_{1,2,t}(\mathcal{P}, Y_{1,2,t}) = \left(\frac{1 - \beta_{1,2}}{\beta_{1,2}} \right)^{-(1-\beta_{1,2})} r_{1,t}^{1-\beta_{1,2}} \omega_{1,t}^{-(1-\beta_{1,2})} Y_{1,2,t}.$$

Furthermore, in period t the cost function of the representative firm that produces the agricultural good in the North is given by

$$(17) \quad C_{1,2,t}(\mathcal{P}, Y_{1,2,t}) = \left[\left(\frac{1 - \beta_{1,2}}{\beta_{1,2}} \right)^{\beta_{1,2}} + \left(\frac{1 - \beta_{1,2}}{\beta_{1,2}} \right)^{-(1-\beta_{1,2})} \right] r_{1,t}^{1-\beta_{1,2}} \omega_{1,t}^{\beta_{1,2}} Y_{1,2,t}.$$

In period t , the cost function of the representative firm that produces the agricultural good in the South is obtained by solving the following cost minimization problem:

$$(18) \quad \min_{(A_{2,2,t}, L_{2,2,t})} r_{2,t} A_{2,2,t} + \omega_{2,t} L_{2,2,t}$$

subject to

$$(19) \quad Y_{2,2,t} = \frac{1}{1 + e^{-\mu(\bar{A}_2 - A_{2,t})}} A_{2,2,t}^{1-\beta_{2,2}} L_{2,2,t}^{\beta_{2,2}}.$$

The solution of the cost minimization problem constituted by (18) and (19) is given by

$$(20) \quad A_{2,2,t}(\mathcal{P}, Y_{2,2,t}) = \left(\frac{1 - \beta_{2,2}}{\beta_{2,2}} \right)^{\beta_{2,2}} r_{2,t}^{-\beta_{2,2}} \omega_{2,t}^{\beta_{2,2}} Y_{2,2,t} \left(1 + e^{-\mu(\bar{A}_2 - A_{2,t})} \right)$$

and,

$$(21) \quad L_{2,2,t}(\mathcal{P}, Y_{2,2,t}) = \left(\frac{1 - \beta_{2,2}}{\beta_{2,2}} \right)^{-(1-\beta_{2,2})} r_{2,t}^{1-\beta_{2,2}} \omega_{2,t}^{-(1-\beta_{2,2})} Y_{2,2,t} \left(1 + e^{-\mu(\bar{A}_2 - A_{2,t})} \right)$$

Furthermore, in period t , the cost function of the representative firm that produces the agricultural good in the South is given by

$$(22) \quad C_{2,2,t}(\mathcal{P}, Y_{2,2,t}) = \left[\left(\frac{1 - \beta_{2,2}}{\beta_{2,2}} \right)^{\beta_{2,2}} + \left(\frac{1 - \beta_{2,2}}{\beta_{2,2}} \right)^{-(1-\beta_{2,2})} \right] r_{2,t}^{1-\beta_{2,2}} \omega_{2,t}^{\beta_{2,2}} Y_{2,2,t} \left(1 + e^{-\mu(\bar{A}_2 - A_{2,t})} \right)$$

2.5. Lifetime Utility Maximization

Consider a young individual in the country i in period t . She solves her lifetime utility maximization problem by maximizing (6) subject to the following inter-temporal budget constraint:

$$(23) \quad p_{i,1,t+1}x_{i,1,t+1}^1 + p_{i,2,t+1}x_{i,2,t+1}^1 = \frac{\omega_{i,t} - p_{i,1,t}x_{i,1,t}^0 - p_{i,2,t}x_{i,2,t}^0}{q_{i,t}}(r_{i,t+1} + q_{i,t+1}).$$

Observe that the left side of (23) represents the expenditures on the two goods in period $t+1$, when the individual is old. On the right side of (23), $[\omega_{i,t} - p_{i,1,t}x_{i,1,t}^0 - p_{i,2,t}x_{i,2,t}^0]/q_{i,t}$ represents her savings – in the form of land – at the end of period t . The right side of (23) thus represents the income of the individual from her land ownership in period $t+1$, when she is old.

The optimal lifetime plan for a young individual in country i in period t is given by:

$$(24) \quad \begin{aligned} x_{i,1,t}^0(\mathcal{P}) &= \frac{\omega_{i,t}(r_{i,t+1} + q_{i,t+1})}{(1 + \alpha_i)(1 + \delta_i)p_{i,1,t}(r_{i,t+1} + q_{i,t+1})}, \\ x_{i,2,t}^0(\mathcal{P}) &= \frac{\alpha_i \omega_{i,t}(r_{i,t+1} + q_{i,t+1})}{(1 + \alpha_i)(1 + \delta_i)p_{i,2,t}(r_{i,t+1} + q_{i,t+1})}, \\ x_{i,1,t+1}^1(\mathcal{P}) &= \frac{\delta_i \omega_{i,t}(r_{i,t+1} + q_{i,t+1})}{(1 + \alpha_i)p_{i,1,t+1}(1 + \delta_i)q_{i,t}}, \\ x_{i,2,t+1}^1(\mathcal{P}) &= \frac{\alpha_i \delta_i \omega_{i,t}(r_{i,t+1} + q_{i,t+1})}{(1 + \alpha_i)p_{i,2,t+1}(1 + \delta_i)q_{i,t}}, \\ \ell_{i,t+1}(\mathcal{P}) &= \frac{\delta_i \omega_{i,t}}{(1 + \delta_i)q_{i,t}}. \end{aligned}$$

Note that in (24) the amount of land that she acquires at the end of period t – as a real asset to provide for her old-age consumption in period $t+1$ – is denoted by $\ell_{i,t+1}(\mathcal{P})$.

As for an old individual in country i in period t , she solves the following simple one-period utility maximization problem:

$$(25) \quad \max_{(x_{i,1,t}^1, x_{i,2,t}^1)} \text{Log} x_{i,1,t}^1 + \alpha_i \text{Log} x_{i,2,t}^1$$

subject to

$$(26) \quad p_{i,1,t}x_{i,1,t}^1 + p_{i,2,t}x_{i,2,t}^1 = \ell_{i,t}(r_{i,t} + q_{i,t}).$$

Note that in the old-age budget constraint (26) $\ell_{i,t}$ denotes the amount of land owned by an individual of the old generation in country i in period t . The solution of the utility maximization problem constituted by (25) and (26) is given by

$$(27) \quad \begin{aligned} x_{i,1,t}^1(\mathcal{P}, \ell_{i,t}) &= \frac{\ell_{i,t}(r_{i,t} + q_{i,t})}{(1 + \alpha_i)p_{i,1,t}}, \\ x_{i,2,t}^1(\mathcal{P}, \ell_{i,t}) &= \frac{\alpha_i \ell_{i,t}(r_{i,t} + q_{i,t})}{(1 + \alpha_i)p_{i,2,t}}. \end{aligned}$$

3. DEFINITION OF COMPETITIVE EQUILIBIRUM

Let $\mathcal{P} = \left((p_{i,1,t}, p_{i,2,t}, \omega_{i,t}, r_{i,t}, q_{i,t})_{i=1}^2 \right)_{t=0}^{\infty}$ be a price system. An allocation induced by the price system $\mathcal{P}$ is an array

$$\mathcal{A} = \left(\begin{aligned} &\left(\left(\ell_{i,0}, x_{i,1,0}^1(\mathcal{P}, \ell_{i,0}), x_{i,2,0}^1(\mathcal{P}, \ell_{i,0}) \right), \right. \\ &\left(x_{i,1,t}^0(\mathcal{P}), x_{i,2,t}^0(\mathcal{P}), x_{i,1,t+1}^1(\mathcal{P}), x_{i,2,t+1}^1(\mathcal{P}), \ell_{i,t+1}(\mathcal{P}) \right)_{t=0}^{\infty}, \\ &\left. \left((Y_{i,j,t}, A_{i,j,t}(\mathcal{P}, Y_{i,j,t}), L_{i,j,t}(\mathcal{P}, Y_{i,j,t}))_{j=1}^2 \right)_{t=0}^{\infty} \right) \\ &\left(\left(\ell_{2,0}, x_{2,1,0}^1(\mathcal{P}, \ell_{2,0}), x_{2,2,0}^1(\mathcal{P}, \ell_{2,0}) \right), \right. \\ &\left(x_{2,1,t}^0(\mathcal{P}), x_{2,2,t}^0(\mathcal{P}), x_{2,1,t+1}^1(\mathcal{P}), x_{2,2,t+1}^1(\mathcal{P}), \ell_{2,t+1}(\mathcal{P}) \right)_{t=0}^{\infty}, \\ &\left. \left((Y_{2,j,t}, A_{2,j,t}(\mathcal{P}, Y_{2,j,t}), L_{2,j,t}(\mathcal{P}, Y_{2,j,t}))_{j=1}^2, (a_{2,t}, \Gamma(a_{2,t})) \right)_{t=0}^{\infty} \right) \end{aligned} \right),$$

where the production plan $(Y_{i,j,t}, A_{i,j,t}(\mathcal{P}, Y_{i,j,t}), L_{i,j,t}(\mathcal{P}, Y_{i,j,t}))_{i=1,2, j=1,2, t=0,1,\dots}$, maximizes the profits in period t of the representative firm producing good j in country i and the production plan $(a_{2,t}, \Gamma(a_{2,t}))$ maximizes the profits of the representative firm that clears wilderness land in the South. Observe that in $\mathcal{A}$ the stock of land owned by an old individual of period 0 in country i is $\ell_{i,0}$ which is also equal to $A_{i,0}/N_{i,0}^1$. The three elements of the list $(\ell_{i,0}, x_{i,1,0}^1(\mathcal{P}, \ell_{i,0}), x_{i,2,0}^1(\mathcal{P}, \ell_{i,0}))$ represents, respectively, the land owned by an old individual of time 0 in country i , her consumption of the manufacturing good, and her consumption of the agricultural good. As for the list

$(x_{i,1,t}^0(\mathcal{P}), x_{i,2,t}^0(\mathcal{P}), x_{i,1,t+1}^1(\mathcal{P}), x_{i,2,t+1}^1(\mathcal{P}), \ell_{i,t+1}(\mathcal{P}))$, its first two elements represent, respectively, the consumption of the manufacturing good and the consumption of the agricultural good of a young individual of period t in country i . The next two elements represent her consumption of the manufacturing good and her consumption of the agricultural good, respectively, when she is old. The last element, namely $\ell_{i,t+1}(\mathcal{P})$, represents her saving under the form of land.

The pair $(\mathcal{P}, \mathcal{Q})$, is said to constitute *a competitive equilibrium under free trade* if the following conditions are satisfied.

First, for $t = 0, 1, \dots$, the following market-clearing conditions must hold in the North:

$$(28) \quad A_l^{\max} = A_{l,1,t}(\mathcal{P}, Y_{1,1,t}) + A_{l,2,t}(\mathcal{P}, Y_{1,2,t}),$$

$$(29) \quad N_{l,t}^0 = L_{1,1,t}(\mathcal{P}, Y_{1,1,t}) + L_{1,2,t}(\mathcal{P}, Y_{1,2,t}),$$

$$(30) \quad A_l^{\max} = N_{l,t}^0 \ell_{l,t+1}(\mathcal{P}).$$

Observe that (28) represents the equilibrium condition of the market for land at the beginning of period t in the North. In this equilibrium condition, we recall that $A_l^{\max}$ is the supply of land; while $A_{l,1,t}(\mathcal{P}, Y_{1,1,t})$ and $A_{l,2,t}(\mathcal{P}, Y_{1,2,t})$ denote, respectively, the demand for land by the representative firm in the manufacturing sector and the demand for land by the representative firm in the agricultural sector. As for (29), it represents the equilibrium condition in the labor market at the beginning of period t in the North. Finally, (30) represents the equilibrium condition on the market for land – as an asset – at the end of period t . Here, $\ell_{l,t+1}(\mathcal{P}) = \delta_i \omega_{l,t} / (1 + \delta_i) q_{l,t}$ is the demand for land – as an investment asset to provide for old-age consumption – by a young individual in period t in the North.

Second, for $t = 0, 1, \dots$, the following market-clearing conditions must hold in the South:

$$(31) \quad A_{2,t} = A_{2,1,t}(\mathcal{P}, Y_{2,1,t}) + A_{2,2,t}(\mathcal{P}, Y_{2,2,t}),$$

$$(32) \quad N_{2,t}^0 = L_{2,1,t}(\mathcal{P}, Y_{2,1,t}) + L_{2,2,t}(\mathcal{P}, Y_{2,2,t}) + \Gamma(a_{2,t}),$$

$$(33) \quad A_{2,t+1} = N_{2,t}^0 \ell_{2,t+1}(\mathcal{P}),$$

where

$$(34) \quad A_{2,t+1} = A_{2,t} + a_{2,t}, \quad A_{2,0} \text{ is given.}$$

Observe that (31) represents the equilibrium condition of the market for land at the beginning of period t in the South. In (31), we recall that $A_{2,t}$ is the stock of developed land available at the beginning of period t ; while $A_{2,1,t}(\mathcal{P}, Y_{2,1,t})$ and $A_{2,2,t}(\mathcal{P}, Y_{2,2,t})$ denote, respectively, the demand for land by the representative firm in the manufacturing sector and the demand for land by the representative firm in the agricultural sector – both at the beginning of period t in the South. As for (32), it represents the equilibrium condition in the labor market at the beginning of period t in the South. On the left side of (32), $N_{2,t}^0$ represents the labor supply; while on the right side of (32), $L_{2,1,t}(\mathcal{P}, Y_{2,1,t})$, $L_{2,2,t}(\mathcal{P}, Y_{2,2,t})$, and $\Gamma(a_{2,t})$ represent, respectively, the demand for labor by the representative firm in the manufacturing sector, the demand for labor by the representative firm in the agricultural sector, and the demand for labor by the representative firm in the wilderness land clearing sector – all in period t in the South. Finally, (33) represents the equilibrium condition on the market for land – as an asset market – at the end of period t , with (34) describing the dynamics of the stock of developed land generated by the profit-maximizing behavior of the representative firm that clears wilderness land in the South. Here, recall that $a_{2,t}$ is the amount of land cleared during period t and is available for sale as an investment asset at the end of that period, and $\ell_{2,t+1}(\mathcal{P})$ is the demand for land – as an investment to provide for their old-age consumption – by the young generation in the South at the end of period t .

Third, the following conditions must hold on the international markets for the manufacturing and agricultural goods.

$$(35) \quad p_{1,j,t} = p_{2,j,t} = p_{j,t}$$

and

$$(36) \quad Y_{1,j,t} + Y_{2,j,t} = N_{1,t}^0 x_{1,j,t}^0 + N_{2,t}^0 x_{2,j,t}^0 + N_{1,t}^1 x_{1,j,t}^1 + N_{2,t}^1 x_{2,j,t}^1, \quad (j = 1, 2).$$

Condition (35) asserts that under free trade the prices of each commodity are the same in the North and the South, while condition (36) asserts that on the international market for each good demand is equal to supply.

4. PROPERTIES OF THE COMPETITIVE EQUILIBRIUM

4.1 *Equilibrium in the Land-Clearing Sector*

Let $(\mathcal{P}, \mathcal{A})$ be a competitive equilibrium. In what follows, we shall choose the wage rate in each period in the South as the numeraire; that is, we set $\omega_{2,t} = 1, t = 0, 1, \dots$. Because the technology of wilderness land clearing is linear, the following condition must hold in equilibrium:

$$(37) \quad q_{2,t} \leq \gamma \omega_{2,t} = \gamma.$$

Furthermore, when the inequality in (37) is strict, no wilderness land clearing activities will be carried out in the South.

Now according to (24), the demand for land by a young Southerner at the end of period t is

$$(38) \quad \ell_{2,t+1}(\mathcal{P}) = \frac{\delta_2 \omega_{2,t}}{(1 + \delta_2) q_{2,t}} = \frac{\delta_2}{(1 + \delta_2) q_{2,t}}.$$

Note that the second equality in (38) has been obtained by using the assumption that wage rate in any period in the South is the numeraire. The aggregate demand for land by the young generation in the South at the end of period t is thus equal to $\frac{N_{2,t}^0 \delta_2}{(1 + \delta_2) q_{2,t}}$. On

the other hand, the amount of land held by the old generation in the South in period t is

$A_{2,t}$. If no new land is added to the stock of developed land at the end of period t , then in equilibrium we must have

$$(39) \quad A_{2,t} = \frac{N_{2,t}^0 \delta_2}{(1 + \delta_2) q_{2,t}},$$

from which we obtain the following expression for the equilibrium price of land at the end of period t :

$$(40) \quad q_{2,t} = \frac{N_{2,t}^0 \delta_2}{(1 + \delta_2) A_{2,t}}.$$

Now when no wilderness land clearing activities are carried out, the price of land must be less than or equal to its production cost. Thus, in any period during which no new land is added to the stock of developed land we must have

$$(41) \quad q_{2,t} = \frac{N_{2,t}^0 \delta_2}{(1 + \delta_2) A_{2,t}} \leq \gamma.$$

Observe that the inequality in (41) will only hold if $N_{2,t}^0$ is not too high relative to $A_{2,t}$, i.e., if the number of young individuals in the South in period t is not too high relative to the stock of developed land existing at the beginning of the period. This inequality will

not hold if $\frac{N_{2,t}^0 \delta_2}{(1 + \delta_2) A_{2,t}} > \gamma$, in which case the excessive demand for land as an investment

asset to provide for their old-age consumption by the young generation in the South at the end of period t will trigger wilderness land clearing activities in that period. The amount of wilderness land cleared during period t , namely $a_{2,t}$, depends on how much wilderness land remains. If there is much wilderness land remaining, then the amount of newly developed land will be just enough to raise supply to the point where the price of land is equal to the production cost of wilderness land clearing.

Under such a scenario, $a_{2,t}$ will satisfy the following condition:

$$(42) \quad \frac{N_{2,t}^0 \delta_2}{(1 + \delta_2)(A_{2,t} + a_{2,t})} = \gamma.$$

On the other hand, if the population explosion is severe, say $N_{2,t}^0$ is so high that

$$(43) \quad \frac{N_{2,t}^0 \delta_2}{(1 + \delta_2) A_2^{\max}} \geq \gamma,$$

then all the remaining wilderness land will be cleared during period t , i.e., $a_{2,t} = A_2^{\max} - A_{2,t}$, and the equilibrium price of land in the South at the end of period t is

$$(44) \quad q_{2,t} = \frac{N_{2,t}^0 \delta_2}{(1 + \delta_2) A_2^{\max}}.$$

Observe that the right side of (44) will be higher than γ if $N_{2,t}^0$ is high. Under such a scenario, the wilderness land clearing sector will make positive profits in clearing the remaining wilderness land. The following proposition summarizes the preceding discussion.

PROPOSITION 1: *Recall that $A_{2,t}$ is the stock of developed land available at the beginning of period t in the South and that $N_{2,t}^0$ is the size of the Southern young generation in that period.*

(a) *If $\frac{N_{2,t}^0 \delta_2}{(1 + \delta_2) A_{2,t}} \leq \gamma$, then no new land will be added to the stock of developed land*

in the South at the end of period t , and the price of land at the end of this period

will be given by $q_{2,t} = \frac{N_{2,t}^0 \delta_2}{(1 + \delta_2) A_{2,t}}$.

(b) *On the other hand, if $\frac{N_{2,t}^0 \delta_2}{(1 + \delta_2) A_{2,t}} > \gamma$, then the wilderness land clearing operation*

in the South will be active and the amount of wilderness land cleared during

period t depends on whether or not $\frac{N_{2,t}^0 \delta_2}{(1 + \delta_2) A_2^{\max}} < \gamma$. Furthermore,

(b1) *if $\frac{N_{2,t}^0 \delta_2}{(1 + \delta_2) A_2^{\max}} < \gamma$, then the amount of new developed land in period t*

is given by $a_{2,t} = \frac{N_{2,t}^0 \delta_2}{(1 + \delta_2) \gamma} - A_{2,t}$, and the price of land at the end of period

t in the South will be $q_{2,t} = \gamma$. On the other hand,

(b2) if $\frac{N_{2,t}^0 \delta_2}{(1 + \delta_2) A_2^{\max}} \geq \gamma$, then all the remaining wilderness land in the South will be developed in period t , and the price of land at the end of this period will be given by $q_{2,t} = \frac{N_{2,t}^0 \delta_2}{(1 + \delta_2) A_2^{\max}} \geq \gamma$.

The following proposition follows directly from Proposition 1.

PROPOSITION 2: Let $\bar{N}_2^0 = \sup_t N_{2,t}^0$ be the upper bound on the size of the population in the South and $\bar{A}_2$ be the long-run stock of developed land in the South.

(a) If $\frac{\bar{N}_2^0 \delta_2}{(1 + \delta_2) A_2^{\max}} < \gamma$, then the equilibrium stock of developed land in the long run in the South is given by $\bar{A}_2 = \frac{\bar{N}_2^0 \delta_2}{(1 + \delta_2) \gamma}$, and the equilibrium price of land in the long run is given by $\bar{q}_2 = \gamma$.

(b) On the other hand, if $\frac{\bar{N}_2^0 \delta_2}{(1 + \delta_2) A_2^{\max}} \geq \gamma$, then in the long run all the wilderness land in the South will be developed, i.e., $\bar{A}_2 = A_2^{\max}$, and the equilibrium price of land in the long run in the South, assuming that $\lim_{t \rightarrow \infty} N_{2,t}^0 = \bar{N}_2^0$, is $\bar{q}_2 = \frac{\bar{N}_2^0 \delta_2}{(1 + \delta_2) A_2^{\max}}$.

The above two propositions show that whether land will be cleared or not in the South depends on the relative size of the young people to the available developed land. Also the amount of land to be cleared depends on the relative size of the young people to the maximum amount of land available.

4.2 Absence of Asset Markets

The model we formulate reflects the current realities in the South. As financial institutions are not well developed in the South, there are no other assets other than developed land that are available to the old generation: developed land is the only asset that can provide income for an old individual's consumption. Thus land is the only form of saving available to a young individual of any period. So, in any period if the size of the young generation in the South is relatively larger than the available developed land, the demand for developed land pushes the land price high enough to activate the land-clearing sector. In this way the lack of alternative real assets other than developed land coupled with a growing population are the causes of biodiversity loss in the South, as suggested by the analysis in Section 4.1. The following corollary follows from the preceding discussion and Propositions 1 and 2.

COROLLARY 1: Due to the absence of any other real asset market other than the land market, a large young generation in any period increases the demand for developed land and pushes the land price above the land clearing cost, i.e., $\frac{N_{2,t}^0 \delta_2}{(1 + \delta_2) A_{2,t}} > \gamma$, which makes the land-clearing activities profitable and contributes to the loss of biodiversity.

4.3 Impact of Land-Clearing Cost

Another important result follows from the equilibrium conditions of the land-clearing sector. According to (41), land-clearing activities will not be carried out when the price of land is less than or equal to its production cost. The implication of this inequality is that the land-clearing activities depend on the unit cost of land clearing. If the unit cost of land clearing, namely γ , is high enough to exceed the price of land, $q_{2,t}$, then land-clearing activities will not take place.

The cost of clearing undeveloped land may be high for the following reasons.

- if the undeveloped land is remote and inaccessible due to geographical and natural barriers
- if there is no natural or man-made access like trails and roads to the undeveloped land area or if it takes too much time to reach to the clearing site
- if the weather conditions and the ecosystem of the undeveloped land are stressful and harmful to human health
- if there are natural conditions like soil erosion, weeds, pests, salinity, water-clogging, flooding, etc. that makes it difficult to transform the wilderness land into good agricultural land.

All the above factors can push the land clearing cost high enough to make (41) hold with strict inequality and cause land-clearing activities to be suspended and biodiversity rich areas to be preserved. The following corollary summarizes the preceding discussion.

COROLLARY 2: *If the per unit land clearing cost, γ , is high enough so that*

, $\frac{N_{2,t}^0 \delta_2}{(1 + \delta_2) A_{2,t}} \leq \gamma$, holds, then no new land will be added to the stock of developed land in the South at the end of period t .

4.4. Impact of the Discount Rate on the Land-Clearing Market

To analyze the influence of the discount rate on the land-clearing activities in the South, let us rewrite the inequality in (41) – which holds when land-clearing activities are not carried out – as follows:

$$(45) \quad \frac{A_{2,t}}{N_{2,t}^0} \geq \frac{1}{\gamma(1 + 1/\delta_2)}.$$

The left side of (45) is the developed land labor ratio in period t . The lower this ratio is, the lower will be the output per worker in that period. This ratio is thus an index of the poverty of the South in period t . The right side of (45) is increasing of the discount factor δ_2 . Observe that a lower discount factor induces a rise in current consumption and reduces saving for old-age consumption, which a fortiori means a lower demand for developed land as investment. Usually when there is extreme poverty in the South it is reflected by the low labor productivity. But at the same time extreme poverty makes the current consumption more important and consumers become highly impatient. This impatience is reflected by a high discount rate. Low labor productivity also decreases the savings of the young generation and the demand for developed land. Thus (45) is likely to hold if there is extreme poverty in the South and if the Southern population is extremely impatient. Low productivity decreases the value of the left hand side of (45), but at the same time as discount rate increases, the value of the right hand side also decreases. These two simultaneous events hold (45).

The impact of the discount rate is rather puzzling given the conventional wisdom on the impact of a high discount rate on the destruction of biodiversity. In the literature on exhaustible resources, it is well known that a rise in the discount rate tilts the pattern of consumption toward the present, causing the resources to be depleted sooner. In the context of biodiversity loss, this result takes the form of converting wilderness land into agricultural land at a faster rate. It implies that the urgency of satisfying the current needs may lead to faster land clearing in the South. But the conclusion in this chapter is different from the above. On the other hand, Pearce and Turner (1990), Pearce (1991)

stated that the demand for “natural resource use.....in any country is ambiguous.” Rowthorn and Gardner (1999) concluded that “in a neoclassical growth model with developed land as an input and with preferences that value species, a high discount (rate) favors species.” Our result is in line with these conclusions in a different context in which savings take the form of developed land. As there is a one period lag in the use of developed land, the high discount rate and low labor income for low labor productivity lead to the fulfillment of current consumption demand, not future land demand. If the time gap of availability of developed land is lower and it can be used for the current consumption, then this impact of discount rate on biodiversity will not hold. Another explanation may be that perhaps the seeming paradox arises from the fact that most researchers in the literature looked at the problem from the perspective of a central planner. The model we formulate is a dynamic general equilibrium model, not one of central planning.

The following corollary summarizes the impact of impatience on the loss of biodiversity.

COROLLARY 3: If the discount factor in the South, δ_2 , is low enough (which is equivalent to a high discount rate) and if the population pressure is not large enough so that

$$\frac{A_{2,t}}{N_{2,t}^0} \geq \frac{1}{\gamma(1+\delta_2)}$$

holds, then no new land will be added to the stock of developed land in the South at the end of period t .

4.5 Impact of Ecosystem Services on Land Conservation

To analyze the impact of ecosystem services on the agricultural sector, let us differentiate (5) with respect to $A_{2,t}$ to obtain

$$(46) \quad \frac{1}{Y_{2,2,t}} \frac{\partial Y_{2,2,t}}{\partial A_{2,t}} = -\frac{\mu}{1 + e^{\mu(A_2^{\max} - A_{2,1,t} - A_{2,2,t})}} + \frac{1 - \beta_{2,2}}{A_{2,2,t}}.$$

Observe that on the right side of (46) the term $(1 - \beta_{2,2})/A_{2,t}$ is strictly decreasing from infinity to $(1 - \beta_{2,2})/A_2^{\max}$ as $A_{2,2,t}$ rises from 0 to $A_2^{\max}$. As for the term $\mu/[1 + e^{\mu(A_2^{\max} - A_{2,1,t} - A_{2,2,t})}]$, it is strictly rising from $\mu/[1 + e^{\mu(A_2^{\max} - A_{2,1,t})}]$ to $\mu/2$ as $A_{2,2,t}$ rises from 0 to $A_2^{\max} - A_{2,1,t}$.

Let

$$(47) \quad \bar{A}_{2,1} = \lim_{t \rightarrow +\infty} A_{2,1,t}$$

and

$$(48) \quad \bar{A}_{2,2} = \lim_{t \rightarrow +\infty} A_{2,2,t}.$$

Then if μ is high, i.e., if ecosystem services are valuable, we will have

$$(49) \quad -\frac{\mu}{1 + e^{\mu(A_2^{\max} - \bar{A}_{2,1} - \bar{A}_{2,2})}} + \frac{1 - \beta_{2,2}}{\bar{A}_{2,2}} < 0,$$

i.e., the marginal productivity of developed land is negative, which means that too much land in the South is cleared, and the level of ecosystem services obtained are sub-optimal. We summarize the results just obtained in the following proposition:

PROPOSITION 3: *If the ecosystem services are extremely valuable, then the competitive equilibrium is not efficient because too much land is developed in the South.*

5. POLICIES FOR INTERNALIZING THE VALUE OF ECOSYSTEM SERVICES AND CONSERVING BIODIVERSITY

5.1. Policy Tools

Although ecosystem services are valuable to the Southern economy, especially to the agricultural sector in this region, there is no market for them. If a market can be created

for the conservation of undeveloped land and if agricultural producers pay for its conservation, it will serve as an indirect market for the ecosystem services. Due to the weak complementarities of the ecosystem services and non-point nature of the users, this market has to be institutionalized by the government. There may be different types of policy tools that can be used. Currently, around the world governments are trying to implement different tools to create markets for ecosystem services.

Land Development Fee

According to Corollary 2, land-clearing activities will not be carried out if the cost of land development is high enough. By imposing a land development fee, the government can effectively raise the land-clearing cost and conserve land and the flow of ecosystem services. If the land development fee is set high enough, then no new land will be developed.

Tax on Developed Land

Another tool the government of the South can use is to impose a tax on the demand for developed land. That will shift the demand curve for developed land to the left and keep the biodiversity-rich land conserved. The tax revenues can then be used to monitor the undeveloped land and the rest can be redistributed among the population.

Fees on Agricultural Production and Payments for Ecosystem Services

As there is no direct market for ecosystem services, the government can work as a middle-man to create an indirect market for it. If payment for ecosystem services is institutionalized, the undeveloped land will also be considered as an income-generating asset that can be used to provide for old-age consumption. In this manner, the saving portfolio of an old individual will consist of both developed and undeveloped land. Furthermore, in order for a young individual to put her saving in both developed and undeveloped land, the rates of return to these assets must be equal. If we denote the price of undeveloped land by E_t and the fees for ecosystem services per unit of developed land used in the agricultural sector by $\sigma_{2,t}$, then the following condition must hold.

$$(50) \quad \frac{r_{2,t+1} - \sigma_{2,t+1} + q_{2,t+1}}{q_{2,t}} = \frac{E_{2,t+1}}{E_{2,t}}.$$

It implies that the per dollar net income from developed land has to be equal to the per dollar income from undeveloped land.

5.2. *Impact on Terms of Trade, land conversion and ecosystem services*

In this model, land investment is driven by the saving behavior of the successive generations, not by trade. Even when two countries trade with each other, the saving behavior of the residents in the two countries is not changed due to trade. This is like the overlapping generation model of saving in which the long-run capital stock depends on the rate of time preference.

Trade between the North and South in this model rather promotes the conservation of biodiversity rich land. As South exports land intensive agricultural products, opening up for trade decreases the relative income of the laborers and they can save less and demand less land.

Both the land development fee and the tax on developed land will increase the price of developed land. The payment for ecosystem services will add an extra cost to the users of developed land. The Southern comparative advantage in producing agricultural products at a lower cost may be affected by these policy tools. When the land development fee, land tax, or ecosystem fee is high enough, the Southern effort to internalize the value of ecosystem services by these tools may adversely affect its comparative advantage in agricultural goods and reverse the patterns of trade. Also when ecosystem services are highly valuable, the southern cost of agricultural products may become very high and reverse the terms of trade for the South. Both these events can make the South a net importer of the agricultural products.

6. CONCLUSION

The model in this paper helps us to derive some very important propositions and results. The paper explains some of the realities that the biodiversity-rich developing countries currently confront.

First, the paper explains the long-run dynamics of the land clearing sector. It shows that whether all the land in the South will be cleared or not depends on how large the ultimate size of the Southern younger generation relative to the ultimate land resources in the South. In the same way, in any period t , whether the land-clearing sector will be active or not depends on the size of the Southern younger generation relative to the available developed land in the South in that period. As there are no available alternative real assets other than land in the South, the old generation can only use the land market to obtain assets for old-age security. With population growth, there is added pressure on the land-clearing sector, which accelerates the destruction of biodiversity through land development.

Second, the paper shows that if the land-clearing cost is high enough, then no new land will be cleared in the South.

Third, it is the pressure generated by a population explosion that is at the source of biodiversity loss, not a high rate of discount. Our result agrees with Pearce & Turner (1990), Pearce (1991) and Rowthorn & Gardner (1999), who suggest that a high discount rate may help in conservation of biodiversity.

Fourth, although land development fees, land tax, and ecosystem fee may help in the conservation of the biodiversity-rich undeveloped land, it can decrease the welfare of the Southern consumers when the population increases over time.

The results of this paper have important policy implications. To the Southern workers, land clearing is a form of investment as other benefits of biodiversity-rich land are very

low or not valued at all in the market system. As decreasing productivity only takes place after a substantial loss of biodiversity-rich land, there is no incentive for creating a market for undeveloped land and its ecosystem services. Hence the government has to use fiscal tools or create markets through institutional mechanisms. Politically, these mechanisms may be hard to implement as they might lower the welfare of the Southern consumers.

The model also shows that the absence of markets for real assets – other than developed land – in the South encourages land clearing. So, the creation of alternative real asset markets, such as the bond market, the stock market (for ownership of physical capital), or an income-generating system for the older generation are keys to reduce biodiversity loss in the South. Alternative earning and employment opportunities other than land clearing can also slow down destruction of biodiversity.

The results of the paper also imply that naturally, geographically, and biologically remote areas of the biodiversity-rich land would probably be safe for the near short run due to very high cost of land development. Development of access facilities, such as roads and other forms of communication should be avoided for highly biodiversity-rich areas, known as the “hot-spots.”

We should probably look for more pro-active measures, too. Alternative measures, such as bio-prospecting or eco-tourism, to create economic values for conservation efforts should be taken. The biodiversity-rich developing countries have to diversify with respect to alternative asset generation, employment, and earning opportunities. Also, the non-marketed public-good type values of biodiversity resources have to be paid in some format to keep them conserved. The transfer schemes, such as the global environmental fund, should be one of the principal mechanisms to conserve the biodiversity stock of the world.

Further extension of the model can be carried out by including the evolution of the biodiversity resources, ecosystem services, and the population. The extensions may

provide richer and more realistic results than the current model. Inclusion of the dynamics of the land clearing activity might be another extension. Also, further insight can be gained by introduction of different policy tools. These extensions are left for future research.

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CHAPTER 4

BIO-PROSPECTING, LAND DEVELOPMENT, AND BIOLOGICAL DIVERSITY UNDER FREE TRADE

1. INTRODUCTION

In the early development of medicines, higher plants have played a vital role in providing biologically active compounds for producing pharmaceuticals. With the advent of synthetic chemical design, the role of plant-based agents in the development of new and clinically effective pharmaceutical products declined significantly. In the last two decades, there was a resurgence of interest in the potential of the chemical compounds manufactured by higher plants to provide proto-types for new pharmaceuticals, agrochemicals, and consumer products. The tropical forests in developing countries, which house the large majority of the world's estimated 422, 000 plant species²⁷, represent a potentially unlimited pool of novel structures – if discovered – as blueprints for the development of marketable drugs.

To serve as a pool of novel structures, which constitute the target of the bio-prospecting process, these higher plants must be protected. There are direct costs of biodiversity protection. Because land has alternative uses, such as housing development or food production, there is also an opportunity cost involved in maintaining tropical forests as reservoirs of biodiversity. An economic analysis must take into consideration all these costs, and the conservation of biodiversity can only be justified if there are sufficient benefits to warrant its conservation. Because the knowledge about a species and the biochemicals it manufactures might serve as the basis for discovering and developing marketable drugs, the developing countries with tropical forests have a legitimate claim on the profits made by these pharmaceutical companies. In this chapter, we present an

²⁷ <http://www.plant-talk.org/stories/28bramw.html>

economic model in which the bio-prospecting process, its costs, and its benefits, as well as the opportunity cost of biodiversity conservation are formalized. Now most models that attempt to measure the value of biodiversity – whether in terms of the revenues generated by tourism activities or in terms of the monetized value of the medicinal plants the biodiversity houses – adopt the partial-equilibrium approach. The model of the present chapter, in contrast, is formulated from a general equilibrium perspective in a two-country trade framework.

The chapter is organized as follows. In Section 2, the model is presented. A numerical example, which illustrates the main properties of the model, is given in Section 3. Section 4 presents results from the numerical simulation and states some propositions. Section 6 contains some concluding remarks.

2. THE MODEL

In the model we build, economic activities take place over two periods – called period 0 and period 1. There are two countries called the North (N) and the South (S), respectively, and they are indexed by $i, i = N, S$. There are two types of goods in the model: a consumption good and a number of drugs. The consumption good is produced from land and labor in both the North and the South. However, drugs are only produced by pharmaceutical companies in the North. Pharmaceutical companies in the North also carry out bio-prospecting programs, using plant samples obtained from the biodiversity resources of the South to search for new drugs. It is assumed that labor is the only input used in bio-prospecting and in drug manufacturing.

Let $\bar{A}_i$ be the land endowment of country $i, i = N, S$. In each country, part of the land endowment has already been developed and is ready for use as input in the production process. The remaining part is still in a state of wilderness and must be cleared before being used as a factor of production. The area of the developed land available for food production in country i in period 0 is denoted by $A_{i,0}$. We shall assume that all the land

in the North has been developed, i.e., $A_{N,0} = \bar{A}_N$. In the South, the area of wilderness land that houses its biodiversity resources at the beginning of period 0 is thus given by $\bar{A}_S - A_{S,0}$. This wilderness land is rich in biological diversity and can be conserved or cleared in any period for use as input in food production.

2.1. The Consumption Good Sector

Each country produces a consumption good – taken to be the numéraire and labeled good y – from land and labor according to the following Cobb-Douglas technology:

$$(1) \quad Y_i = H_i A_i^{\beta_i} L_i^{1-\beta_i}, \quad (i = N, S),$$

where A and L denote, respectively, the land and labor input. Also, H_i is a positive constant that represents the technological level of country i , and β_i is a parameter strictly between 0 and 1.

Consider a period in which the representative firm that produces the consumption good in country i faces the rental rate of land r_i and the wage rate ω_i . The representative firm solves the following profit maximization problem:

$$(2) \quad \max_{(A,L)} H_i A_i^{\beta_i} L_i^{1-\beta_i} - r_i A_i - \omega_i L_i.$$

The following first-order conditions characterize, respectively, the land and labor inputs that maximize profit:

$$(3) \quad \beta_i H_i A_i^{\beta_i-1} L_i^{1-\beta_i} - r_i = 0.$$

and

$$(4) \quad (1 - \beta_i) H_i A_i^{\beta_i} L_i^{-\beta_i} - \omega_i = 0.$$

2.2. The Pharmaceutical Sector

At the beginning of period 0 there exist already n_0 drugs which are labeled drug 1, drug 2, ..., and drug n_0 . We shall let $J_0 = \{1, 2, \dots, n_0\}$ denote the set of drugs that exist at the

beginning of period 0. Also, we let $J = \{1, \dots, n_0, n_0 + 1, \dots, n\}$, with n being a positive integer greater than n_0 , denote the set of the totality of drugs – already discovered or potentially might be discovered. In what follows, we shall denote the price of drug j by $p_j, j \in J$. To simplify the exposition, we shall assume that each drug has a specific use in fighting a specific disease. More specifically, we assume that there are n diseases, and that drug j can only be used to treat disease $j, j = 1, \dots, n$. That is, an individual afflicted with disease j derives no benefits from drug $j', j' \neq j$. The model can easily be extended to include drugs that are similar and can be used to treat the same disease. Drugs in such a group are differentiated products in the sense that they have similar medicinal properties, but might be differentiated according to advertising or popularity of use recommended by physicians. Bio-prospecting activities are carried out during period 0, and their outcomes are only known at the end of this period. The set of drugs that are available for production at the beginning of period 1 is denoted by J_1 , with $J_0 \subset J_1 \subset J$. Note that J_1 includes both J_0 and the set of newly discovered drugs $J_1 - J_0$.

2.2.1. *The Bio-prospecting Process*

In their struggle for survival, plants manufacture biologically active compounds – known as secondary metabolites – to defend themselves against insects, herbivores, diseases, and harsh environmental conditions. Each species has a unique profile of secondary metabolites, and it is in this pool of bio-chemicals that bio-chemical compounds with the desired medicinal properties can be discovered through bio-prospecting activities.

The search for novel biochemical structures by a bio-prospecting firm is systematic, not random. A bio-prospecting program consists of three stages. In the first stage, the plants whose secondary metabolites are expected to have the desired bio-chemical activity are identified. Shaman, a pharmaceutical company, employs a network of ethno-botanists

and physicians to seek out plant remedies used by generations of native populations.²⁸ Specific plants that are related to plants with proven bio-chemical activity might also be the target of a systematic investigation. Samples of the identified plants are then collected and screened for the desired novel bio-chemical structures. Each of these steps just described takes time and involves enormous costs. At the end of each step, the results are evaluated and the bio-prospecting program might be terminated – and all the resources spent up to this point wasted – if it is judged that the leads turn out not to be as promising as expected. Principe (1991) used the National Institute of Health experience with the screening process in bio-prospecting and arrived at an estimate that from 1000 to 10,000 chemicals must be evaluated before a lead is found. In the second stage, the leads are used to develop a drug with the desired properties. The drug thus designed must not be toxic to the patient, and the development stage involves many clinical trials. If the clinical trials are satisfactory and if the drug is not too expensive to produce, then the pharmaceutical company can embark on the last stage of the bio-prospecting process: marketing the drug. According to McChesney (1996), on average it takes about 10 years and costs between 100 and 225 million dollars to discover, develop, and bring to the market a new drug.

2.2.2. *Pharmaceutical Firms and the Search for New Drugs*

Recall that the set of drugs that already exist at the beginning of period 0 is $J_0 = \{1, \dots, n_0\}$. The pharmaceutical companies that own the patents for these drugs are assumed to be distinct, and each of these firms owns exactly one drug.²⁹ Recall also that the set of drugs – existing or yet to be discovered – is $J = \{1, \dots, n_0, n_0 + 1, \dots, n\}$. We shall assume that in period 0 there are $n - n_0$ other pharmaceutical companies, with each company engaging in a bio-prospecting program in the South to find a new drug.

²⁸ Conte, Lisa A. (1996): “Sharman Pharmaceuticals’ Approach to Drug Development,” in *Medicinal Resources of the Tropical Forests*, ed. by Michael J. Ballick, Elaine Elisabetsky, and Sarah A. Laird, Columbia University Press, New York, pp. 94-100.

²⁹ It is simple to extend our model to the case of pharmaceutical companies marketing more than one drug or the case of several pharmaceutical companies manufacturing the same or similar drugs. In the latter case, the same drugs marketed by different pharmaceutical companies can be considered as differentiated products.

Presumably, for each $j \in J - J_0$, the pharmaceutical company that searches for drug j among the flora of the South has won the right – before period 0 and over numerous competitors – to obtain plant samples from the government of the South to screen for desired bio-chemical compounds. In exchange for these plant samples, a bio-prospecting company often pays up front a lump sum and promises to pay royalties in the future if its bio-prospecting program results in a marketable drug. The company, under this scenario, owns the intellectual property right to the novel bio-chemical structure it has discovered. Competition among bio-prospecting firms will drive the net expected payoff – the profits that remain after royalties have been paid in the production stage minus the lump sum payment and the bio-prospecting costs – of obtaining the right for using the biodiversity of the South down to zero. We shall ignore the lump sum payment and assume that the bio-prospecting firm that discovers a marketable drug, say drug j , pays the country from the South a royalty of τ_j , which is a percentage of the price of the drug. Now the pharmaceutical companies that produce the drugs that exist at the beginning of period 0 do not have to pay royalties for these drugs. Hence without any loss in generality we can let $\tau_j = 0, j \in J_0$. Under this convention, τ_j represents the royalty paid by the manufacturer of drug j for any $j \in J$.

As discussed in sub-section 2.2.1, bio-prospecting is a long and costly process, with the decision taken at each step in the process depending on the outcomes of all the previous steps. We shall not attempt to model the sequential nature of the bio-prospecting process. Instead, we take a very abridged view of the bio-prospecting process and assume that bio-prospecting activities last one period and that labor is the only input used in this process. Furthermore, we assume that the labor input needed in the search for drug $j, j \in J - J_0$, is B_j and that the probability of success is q_j . We shall also assume that bio-prospecting activities are carried out during period 0; that the outcomes of the various bio-prospecting programs are independent; and that the outcomes are only known at the end of period 0.

As for the production costs of existing or newly discovered drugs, we shall assume that drugs – existing or yet to be discovered – are produced with labor as the only input and that it requires ℓ_j units of labor to produce one unit of the drug

2.3. Preferences and Utility Maximization

We assume that the population of each country is a continuum of measure 1, and an individual is characterized by her type, which is represented by an ordered pair (h, θ) . Here h is a discrete variable that assumes one of the values $0, 1, \dots, n$, where $h=0$ indicates that the individual is healthy, and $h=j, j=1, \dots, n$, indicates that the individual has disease j . Also, $\theta, 0 \leq \theta \leq 1$, is a continuous parameter representing her ownership of the means of production and her claim to the profits of the firms.

The utility enjoyed by an individual depends on the amount of the consumption good she consumes, her state of health, and whether she consumes the drug that treats her illness, if she is not healthy. Let $\eta_j, j=0, \dots, n$, be the disutility suffered by an individual whose state of health is $h=j$. We shall assume that $\eta_0=0$ and $\eta_j > 0, j=1, \dots, n$. Obviously, a healthy individual does not need to consume any drug, and an individual suffering from disease j will not purchase drug $j', j' \neq j$.

A consumption bundle for an individual is a list $(y, x_1, \dots, x_n)$, where y is the amount of the consumption good and $x_j, j=1, \dots, n$, which takes on either the value 0 or the value 1, with the interpretation that $x_j=0$ indicates that she does not consume drug j and $x_j=1$ indicates that she consumes one unit of this drug. Furthermore, we shall assume that an individual who is afflicted with disease j obtains a benefit of ξ_j by consuming one unit of the drug that treats this disease. We shall assume that $\xi_j \leq \eta_j, j=1, \dots, n$. The preferences of an individual who is afflicted with disease j is assumed to be given by

$$(5) \quad u_j(y, x_1, \dots, x_j, \dots, x_n) = y + x_j \xi_j - \eta_j, \quad (j=1, \dots, n).$$

A healthy individual has no need for drugs, and his utility function is given by

$$(6) \quad u_0(y, x_1, \dots, x_j, \dots, x_n) = y.$$

Simple utility maximization yields the following individual indirect utility function of an individual who is afflicted with disease j :

$$(7) \quad v_j(m, (p_j)_{j=1}^n) = \begin{cases} m + \xi_j - \eta_j - p_j, & \text{if } p_j \leq \xi_j, \\ m - \eta_j, & \text{if } p_j > \xi_j, \end{cases} \quad (j = 1, \dots, n).$$

For a healthy individual, her indirect utility function is

$$(8) \quad v_0(m, (p_j)_{j=1}^n) = m.$$

Furthermore, for an individual who is afflicted with disease j , her demand for the drug that treats this disease is given by

$$(9) \quad x_j(p_j, m) = \begin{cases} 1, & \text{if } m \geq p_j \text{ and } p_j \leq \xi_j, \\ 0, & \text{otherwise.} \end{cases}$$

The world demand for drug j – as a function of p_j – is obtained by summing the individual demand curves (9) over all the individuals – in the North as well as in the South – whose incomes are at least equal to p_j .

The distribution of ownership types in country $i, i = N, S$, is captured by a distribution function, say $F_i(\theta)$. The distribution of h , the state of health of an individual, is assumed to be independent of θ , her ownership type, and the probability mass function of h is given by $\text{Prob}\{h = j\} = \varepsilon_j, j = 0, 1, \dots, n$, where $\varepsilon_j > 0$ and $\sum_{j=0}^n \varepsilon_j = 1$. Each individual – in the North or in the South – has one unit of labor that she supplies in-elastically in the labor market in each period. The income of an individual from the South comes from two sources: labor and land ownership.³⁰ For consumers in the North, there is another source of income: ownership of pharmaceutical firms. The pattern of land ownership in each country is assumed to be captured by a function that depends on the types of the individuals that constitute its population. More specifically, the amount of land owned by an individual of type θ in country $i, i = N, S$, is assumed to be given by $a_i(\theta)$. Thus in

³⁰ The profits made by the representative firm that produces the consumption good in the South is zero under perfect competition and constant returns to scale.

period 0, the stock of developed land in country $i, i = N, S$, satisfies the following stock constraint $A_{i,0} = \int_0^1 a_i(\theta) dF_i(\theta)$. Furthermore, it is assumed that in the North a consumer of type θ owns a fraction $b_j(\theta)$ of the pharmaceutical firm that produces drug $j, j = 1, \dots, n$. That is, for each pharmaceutical firm $j \in J_0$, we have $\int_0^1 b_j(\theta) dF_N(\theta) = 1$. In what follows, we shall assume that for $i = N, S$, both $a_i(\theta)$ and $b_i(\theta)$ are strictly increasing in θ ; that is, in each country type can be considered as a proxy for ownership of means of production other than labor.

2.4. General Equilibrium in the Second Period

The model we formulate is an inter-temporal general equilibrium model with imperfect competition. Contrary to the competitive general equilibrium model à la Arrow-Debreu, the general equilibrium models with imperfect competition are not well developed. For our own purpose, the equilibrium concept we use is the Cournot-Walras equilibrium developed by Gabszewicz and Vial (1972) and Gabszewicz (2002).

While the calculations of equilibrium prices and outputs in the South are simple, the calculations of the equilibrium prices and outputs in the North are quite complex because the activities of the pharmaceutical sector – in addition to the activities of the consumption good sector – must also be analyzed. Also, recall from (9) that the demand for a drug by an individual whose disease can be treated by the drug depends both on the income of the individual in question and the price of the drug. Although each pharmaceutical company is a monopoly for the drug it manufactures and can set the price it charges for its own drug, in general equilibrium the price it sets influences the distribution of income in each country, and thus indirectly has an impact on the demand curves of the other pharmaceutical companies. Thus the pricing strategy of each pharmaceutical company must be strategic. However, because modeling the pricing strategies of firms is extremely burdensome, Gabszewicz (2002), and Gabszewicz and Vial (1972), suggested that firms use instead quantity strategies – in the tradition of

Cournot – then let the prices adjust to clear the markets. We shall follow the approach propounded by these two researchers in modeling the general equilibrium of our two-country model in which pharmaceutical companies in the North behave strategically.

To find the inter-temporal equilibrium of our model, we first have to find the Cournot-Walras equilibrium for the economy in the last period. To this end, let J_1 be the set of drugs that are available at the beginning of period 1. Included in J_1 are the drugs available in period 0 and the newly discovered drugs, with $J_1 - J_0$ as the set of newly discovered drugs. The probability of the event J_1 is

$$(10) \quad q_{J_1} = \left(\prod_{j \in (J_1 - J_0)} q_j \right) \left(\prod_{j \in (J - J_1)} (1 - q_j) \right).$$

The second-period problem is a special case of a one-period problem with more general data, say $(\hat{J}, \hat{L}_N, \hat{A}_S)$, where $\hat{J}$ is the set of drugs already discovered; $\hat{L}_N$ is the fixed labor inputs in the North that are allowed for use in the production of the consumption good and the manufacturing of existing drugs; and $\hat{A}_S$ is the amount of developed land in the South. According to this embedding, the problem in the second period is obtained by setting $(\hat{J}, \hat{L}_N, \hat{A}_S) = (J_1, 1, \bar{A}_S)$.

To solve the general one-period problem with data $(\hat{J}, \hat{L}_N, \hat{A}_S)$, let $Z_j, j \in \hat{J}$, denote the output of drug j chosen by the pharmaceutical company that manufactures this drug. Of course, a list $(Z_j)_{j \in \hat{J}}$ of drug outputs is only feasible if the total labor input does not exceed the fixed labor supply allocated to the production of the consumption good and the manufacturing of existing drugs. That is, a list of drug outputs is feasible if

$$(11) \quad \sum_{j \in \hat{J}} \ell_j Z_j - \hat{L}_N \leq 0.$$

Furthermore, recall that for an individual – in the North or the South – there is a probability $\varepsilon_j, j = 1, \dots, n$, of catching disease j . Also, because of the assumption that the

number of individuals in each country is a continuum of measure 1, the total number of individuals in both countries that are afflicted with disease j is a continuum of measure $2\varepsilon_j$, according to the law of large numbers. Hence the manufacturer of drug j will never produce more than $2\varepsilon_j$, i.e.,

$$(12) \quad 0 \leq Z_j \leq 2\varepsilon_j, \quad (j \in J_1).$$

Given a feasible list of drug outputs $(Z_j)_{j \in J}$ that satisfies (11) and (12), and assuming that the labor market in the North clears, we obtain the following output of the consumption good in that country:

$$(13) \quad Y_N((Z_j)_{j \in J}) = H_N A_N^{\beta_N} \left[\hat{L} - \sum_{j \in J} \ell_j Z_j \right]^{1-\beta_N}.$$

The wage rate that clears the labor market is

$$(14) \quad \omega_N((Z_j)_{j \in J}) = (1 - \beta_N) H_N A_N^{\beta_N} \left[\hat{L} - \sum_{j \in J} \ell_j Z_j \right]^{-\beta_N}.$$

The rental rate of land that clears the land market in the North is given by

$$(15) \quad r_N((Z_j)_{j \in J}) = \beta_N H_N A_N^{\beta_N-1} \left[\hat{L} - \sum_{j \in J} \ell_j Z_j \right]^{1-\beta_N}.$$

The profit made by pharmaceutical company that produces drug j is given by

$$(16) \quad \pi_j(p_j | (Z_j)_{j \in J}) = [(1 - \tau_j) p_j - \omega_N((Z_j)_{j \in J}) \ell_j] Z_j, \quad (j \in J_1).$$

The income of a consumer of type θ in the North is then given by

$$(17) \quad m_N(\theta | (p_j)_{j \in J}, (Z_j)_{j \in J}) = \omega_N((Z_j)_{j \in J}) + r_N((Z_j)_{j \in J}) a_N(\theta) + \sum_{j \in J} b_j(\theta) \pi_j(p_j | (Z_j)_{j \in J}).$$

Using the assumption that ownership of means of production other than labor is strictly increasing in θ , we can assert that the income represented by (17) is strictly increasing in θ .

Now consider a consumer of type θ in the North who is afflicted with disease j and who has an income level represented by (17). Given this level of income, and given p_j , the price of drug j , her demand for this drug is given by

$$(18) \quad x_j(p_j, m_N(\theta|(p_{j'})_{j' \in J}, (Z_{j'})_{j' \in J})) = \begin{cases} 1, & \text{if } m_N(\theta|(p_{j'})_{j' \in J}, (Z_{j'})_{j' \in J}) \geq p_j \text{ and } p_j \leq \xi_j, \\ 0, & \text{otherwise.} \end{cases}$$

For each $j \in \hat{J}$, let

$$(19) \quad \theta_{j,N}^\#((p_{j'})_{j' \in J}, (Z_{j'})_{j' \in J}) = \text{Inf} \{ \theta | m_N(\theta|(p_{j'})_{j' \in J}, (Z_{j'})_{j' \in J}) \geq p_j \}$$

be the cut-off type at or above which a consumer in the North will buy one unit of drug j if she is afflicted with disease j . The demand for drug j in the North is then given by

$$(20) \quad X_{j,N}((p_{j'})_{j' \in J}, (Z_{j'})_{j' \in J}) = \varepsilon_j [1 - F_N(\theta_{j,N}^\#((p_{j'})_{j' \in J}, (Z_{j'})_{j' \in J}))] \quad (j \in J_1).$$

Now the output of the consumption good in the South is then given by

$$(21) \quad Y_S = H_S \hat{A}_S^{\beta_S}.$$

Furthermore, the equilibrium rental rate of land and the equilibrium wage rate in the South are given, respectively, by

$$(22) \quad r_S = \beta_S H_S \hat{A}_S^{\beta_S - 1},$$

and

$$(23) \quad \omega_S = (1 - \beta_S) H_S \hat{A}_S^{\beta_S}.$$

The income of a consumer of type θ in the South is

$$(24) \quad m_S(\theta|(p_j)_{j \in \hat{J}}, (Z_j)_{j \in \hat{J}}) = \omega_S + r_S a_S(\theta) + r_S [\hat{A}_S - A_{S,0}] + \sum_{j \in \hat{J}} \tau_j p_j Z_j.$$

Note that the third and fourth terms on the right side of (24) represents the transfers from the government of the South. Here we have assumed that the income generated by the land that used to house the biodiversity resources and the royalties on the new drugs are distributed equally to all the consumers in the South.

For a consumer of type θ in the South who is afflicted with disease j ; who has an income level represented by (24); and who faces p_j , the price of drug j , her demand for this drug is given by

$$(25) \quad \begin{aligned} & x_j(p_j, m_S(\theta|(p_{j'})_{j' \in \hat{J}}, (Z_{j'})_{j' \in \hat{J}})) \\ &= \begin{cases} 1, & \text{if } m_S(\theta|(p_{j'})_{j' \in \hat{J}}, (Z_{j'})_{j' \in \hat{J}}) \geq p_j \text{ and } p_j \leq \xi_j, \\ 0, & \text{otherwise.} \end{cases} \end{aligned}$$

For each $j \in \hat{J}$, let

$$(26) \quad \theta_{j,S}^\#((p_{j'})_{j' \in \hat{J}}, (Z_{j'})_{j' \in \hat{J}}) = \inf \{ \theta | \hat{m}_S(\theta|(p_{j'})_{j' \in \hat{J}}, (Z_{j'})_{j' \in \hat{J}}) \geq p_j \}$$

be the cut-off type at or above which a consumer in the South will buy one unit of drug j if she is afflicted with disease j . The demand for drug j in the South is then given by

$$(27) \quad X_{j,S}((p_{j'})_{j' \in \hat{J}}, (Z_{j'})_{j' \in \hat{J}}) = \varepsilon_j [1 - F_S(\theta_{j,S}^\#((p_{j'})_{j' \in \hat{J}}, (Z_{j'})_{j' \in \hat{J}}))] \quad (j \in \hat{J}).$$

Given the list of drug outputs $(Z_j)_{j \in \hat{J}}$, the world demand for drug j is then given by

$$(28) \quad \begin{aligned} X_j((p_{j'})_{j' \in \hat{J}}, (Z_{j'})_{j' \in \hat{J}}) &= \sum_{i=N,S} X_{j,i}((p_{j'})_{j' \in \hat{J}}, (Z_{j'})_{j' \in \hat{J}}) \\ &= \varepsilon_j \sum_{i=N,S} [1 - F_i(\theta_{j,i}^\#((p_{j'})_{j' \in \hat{J}}, (Z_{j'})_{j' \in \hat{J}}))] \quad (j \in \hat{J}). \end{aligned}$$

We shall assume that for any given list of drug outputs $(Z_j)_{j \in \hat{J}}$, there exists a unique list of drug prices $(p_j)_{j \in \hat{J}}$ such that demand is equal to supply for each drug, i.e.,

$$(29) \quad X_j((p_j)_{j \in \hat{J}}, (Z_{j'})_{j' \in \hat{J}}) = Z_j, \quad (j \in \hat{J}).$$

The unique list of drug prices that solves (29) will be denoted by $(p_j((Z_{j'})_{j' \in \hat{J}}))_{j \in \hat{J}}$. Given a list of drug outputs $(Z_{j'})_{j' \in \hat{J}}$ and the price function $(Z_{j'})_{j' \in \hat{J}} \rightarrow (p_j((Z_{j'})_{j' \in \hat{J}}))_{j \in \hat{J}}$, the profit made by pharmaceutical firm j is given by

$$(30) \quad \varphi_j(Z_j, Z_{-j}) = [p_j(Z_j, Z_{-j}) - \ell_j \omega_N(Z_j, Z_{-j})] Z_j, \quad (j \in \hat{J}).$$

DEFINITION: A list of drug outputs $(\hat{Z}_j)_{j \in \hat{J}}$ constitutes a Cournot-Walras equilibrium if for each $j \in \hat{J}$ the following inequality holds for any $0 \leq Z_j \leq 2\varepsilon_j$.

$$(31) \quad \varphi_j(Z_j, \hat{Z}_{-j}) \leq \varphi_j(\hat{Z}_j, \hat{Z}_{-j}).$$

We shall not attempt to show that there exists a Cournot-Walras equilibrium for our model. For the existence of the proof of a Cournot-Walras equilibrium in a more general setting, we refer the reader to Gabszewics and Vial, op cit. For our purpose, we shall present an example and compute the Cournot-Walras equilibrium directly in Section 3.

The list of drug outputs $(\hat{Z}_j)_{j \in J}$ that constitutes a Cournot-Walras equilibrium obviously depends on the data $(\hat{J}, \hat{L}_N, \hat{A}_S)$. We shall write $(\hat{Z}_j(\hat{J}, \hat{L}_N, \hat{A}_S))_{j \in J}$ to express the dependence of the equilibrium list of drug outputs on the data $(\hat{J}, \hat{L}_N, \hat{A}_S)$. From the equilibrium list of drug outputs, we can compute the equilibrium list of drug prices $(\hat{p}_j(\hat{J}, \hat{L}_N, \hat{A}_S))_{j \in J} = (p_j((\hat{Z}_{j'}(\hat{J}, \hat{L}_N, \hat{A}_S))_{j' \in J}))_{j \in J}$. Also, from the equilibrium list of drug outputs we can compute the equilibrium wage rate and the equilibrium rental rate of land in the North that we denote, respectively, by $\hat{\omega}_N(\hat{J}, \hat{L}_N, \hat{A}_S) = \omega_N((\hat{Z}_{j'}(\hat{J}, \hat{L}_N, \hat{A}_S))_{j' \in J})$ and $\hat{r}_N(\hat{J}, \hat{L}_N, \hat{A}_S) = r_N((\hat{Z}_{j'}(\hat{J}, \hat{L}_N, \hat{A}_S))_{j' \in J})$. Next, we can compute the income of an individual of type θ in the North that we denote by $\hat{m}_N(\theta | (\hat{J}, \hat{L}_N, \hat{A}_S))$ and the cut-off type $\hat{\theta}_{j,N}(\hat{J}, \hat{L}_N, \hat{A}_S)$, $j \in \hat{J}$, at or above which a consumer in the North will buy one unit of drug j . As for the South, the equilibrium rental rate of land $\hat{r}_S(\hat{J}, \hat{L}_N, \hat{A}_S)$ and the equilibrium wage rate $\hat{\omega}_S(\hat{J}, \hat{L}_N, \hat{A}_S)$ depend only on $\hat{A}_S$, and are given, respectively, by (22) and (23). Finally, as in the North, we can compute the income of an individual of type θ in the South – that we denote by $\hat{m}_S(\theta | (\hat{J}, \hat{L}_N, \hat{A}_S))$ – and the cut-off type $\hat{\theta}_{j,S}(\hat{J}, \hat{L}_N, \hat{A}_S)$, $j \in \hat{J}$, at or above which a consumer in the South will buy one unit of drug j .

The social welfare for the North, as a function of the data $(\hat{J}, \hat{L}_N, \hat{A}_S)$, is given by

$$(32) \quad V_N(\hat{J}, \hat{L}_N, \hat{A}_S) = \sum_{j=0}^n \varepsilon_j \int_0^1 v_j \left(\hat{m}_N(\theta | (\hat{J}, \hat{L}_N, \hat{A}_S)) \right) \left(\hat{p}_j(\hat{J}, \hat{L}_N, \hat{A}_S) \right)_{j \in J} d\theta.$$

The social welfare for the South, as a function of the data $(\hat{J}, \hat{L}_N, \hat{A}_S)$, is given by

$$(33) \quad V_S(\hat{J}, \hat{L}_N, \hat{A}_S) = \sum_{j=0}^n \varepsilon_j \int_0^1 v_j \left(\hat{m}_S(\theta | (\hat{J}, \hat{L}_N, \hat{A}_S)) \right) \left(\hat{p}_j(\hat{J}, \hat{L}_N, \hat{A}_S) \right)_{j \in J} d\theta.$$

2.5. The Problem of the South: To Conserve or not to Conserve Bio-diversity

If the South chooses not to conserve its bio-diversity resources in the first period, then it will immediately clear the wilderness land for agricultural production.³¹ The problem in the first period is the problem solved in Sub-section 2.4 for the data $(\hat{J}, \hat{L}_N, \hat{A}_S) = (J_0, 1, \bar{A}_S)$. Furthermore, under this action the problem in the second period is exactly the same as the problem in the first period. Applying (33), we obtain the following expression for the discounted social welfare enjoyed by the South over the two periods:

$$(34) \quad V_S(J_0, 1, \bar{A}_S) + \delta_S V_S(J_0, 1, \bar{A}_S),$$

where $0 < \delta_S < 1$ is the factor the South uses to discount social welfare. On the other hand, if the South chooses to conserve its bio-diversity resources and allows pharmaceutical companies in the North to carry out bio-prospecting activities among its flora, then the problem in period 0 is the problem solved in the preceding sub-section with the data $(\hat{J}, \hat{L}_N, \hat{A}_S) = (J_0, 1 - B_2, A_{S,0})$. The expected discounted social welfare obtained by the South under this action is given by

$$(35) \quad V_S(J_0, 1 - B_2, A_{S,0}) + \delta_S \sum_{J_0 \subset J_1 \subset J} q_{J_1} V_S(J_1, 1, \bar{A}_S).$$

The above condition – when satisfied – will induce the South into conserving its bio-diversity resources in the first period. This condition simply translates the idea that biodiversity should be conserved in the first period if the South's expected discounted

³¹ For this model, we are assuming no other use of undeveloped land.

payoffs over the two periods obtained under the conservation decision are at least equal to the payoffs obtained under the development action. The following proposition is now immediate.

PROPOSITION 1: The South will only conserve its bio-diversity resources if the discounted social welfare represented by (35) is at least equal to the social welfare represented by (34).

Proposition 1 states the idea that biodiversity should be conserved in the first period if the South's expected discounted payoffs over the two periods obtained under the conservation decision are at least equal to the payoffs obtained under the development action. Now the expected discounted payoff obtained by the South, when it chooses to conserve its bio-diversity resources, has its costs and benefits. In our model, the costs are simply the output of the consumption foregone in the first period because the wilderness land, which can be converted immediately into agricultural land, must be maintained in its natural state to make it possible for the pharmaceutical companies in the North to carry out bio-prospecting activities among the flora in the wilderness land. The benefits consist of the royalties – and these benefits are often considered to be foremost in the bio-diversity conservation decision – as well as the improvement in the state of health of its population that flows from the potential discovery of useful drugs. The expected discounted benefits also depend on the probabilities of discovering new drugs and the South's rate of discount.

3. A NUMERICAL EXAMPLE

In the North, the technology used in the production of the consumption good is given by

$$(36) \quad Y_N = A^{1/2} L^{1/2}, \text{ assuming } \beta_N = 0.5 \text{ and } H_N = 1.$$

In period 0, the amount of developed land, which is also the total land endowment, in the North is

$$(37) \quad A_{N,0} = \bar{A}_N = 1.$$

In the South, the technology used in the production of the consumption good is given by

$$(38) \quad Y_S = \frac{3}{4} A^{1/2} L^{1/2}.$$

The amount of developed land in period 0 in the South is

$$(39) \quad A_{S,0} = 1,$$

while the total land endowment in this region is

$$(40) \quad \bar{A}_S = 1.05.$$

The amount of wilderness land that houses the South's biodiversity is thus equal to 0.05.

There are two diseases in the model. An individual – in the North as well as in the South – has a probability $\varepsilon_1 = 0.1$ of catching disease 1 and a probability of $\varepsilon_2 = 0.1$ of catching disease 2. The pain suffered by an individual who has disease 1 is $\eta_1 = 1.25$, while that suffered by an individual who has disease 2 is $\eta_2 = 10$. We shall assume that a drug that treats a disease, if it is available, will completely cure the disease, i.e., $\xi_j = \eta_j, j = 1, 2$.

In period 0, the drug that treats disease 1 already exists, and the pharmaceutical company that owns the patent of this drug is called pharmaceutical company 1. We assume that it costs $\ell_1 = 1/8$ units of labor to manufacture one unit of drug 1. There is another pharmaceutical firm in the North that might carry out bio-prospecting activities among the flora in the South to find a drug that can be used to treat disease 2. The cost of the bio-prospecting program is $B_2 = 0.05$ units of labor, and if the drug is found, it costs $\ell_2 = 1/8$ units of labor to manufacture one unit of drug 2.

The size of the population in each country is assumed to be a continuum of measure 1, and among each population, consumers are differentiated by types. In each country, it is the type of an individual that characterizes her ownership of the means of production other than labor. In the North, the amount of land owned by a consumer of type $\theta, 0 \leq \theta \leq 1$, is

$$(41) \quad a_N(\theta) = 2\theta.$$

As for ownership of pharmaceutical companies, her shares in the two pharmaceutical companies are given by

$$(42) \quad b_1(\theta) = b_2(\theta) = 2\theta.$$

The distribution of types in the North is assumed to be uniform over the unit interval $[0,1]$.

In the South, the amount of land owned by a consumer of type $\theta, 0 \leq \theta \leq 1$, is assumed to be given by

$$(43) \quad a_s(\theta) = 2\theta.$$

As in the North, the distribution of types in the South is also uniform over the unit interval $[0,1]$.

3.1. The Autarkic Equilibrium

Suppose that the two countries live in isolation. Then in period 0 the South will convert the wilderness land into agricultural land, and the output of the consumption good that is produced in each period in the South will be given by

$$(44) \quad \bar{Y}_s = \frac{3}{4} \bar{A}_s^{1/2}.$$

In autarky, the equilibrium wage rate in the South is given by

$$(45) \quad \bar{w}_s = \frac{3}{8} \bar{A}_s^{1/2},$$

and the equilibrium rental rate of land is given by

$$(46) \quad \bar{r}_s = \frac{3}{8} \bar{A}_s^{-1/2}.$$

The income of an individual of type θ in the South is then given by

$$\begin{aligned} \bar{m}_s(\theta) &= \bar{w}_s + \bar{r}_s a_s(\theta) + \bar{r}_s (\bar{A}_s - A_{s,0}) \\ (47) \quad &= \frac{3}{8} \bar{A}_s^{1/2} + 2\theta \left(\frac{3}{8} \bar{A}_s^{-1/2} \right) + \frac{3}{8} \bar{A}_s^{-1/2} (\bar{A}_s - A_{s,0}) \\ &= \left[\frac{3}{8} \bar{A}_s^{1/2} + \frac{3}{8} \bar{A}_s^{-1/2} (\bar{A}_s - A_{s,0}) \right] + \left[\frac{3}{4} \bar{A}_s^{-1/2} \right] \theta. \end{aligned}$$

In the South, the autarkic social welfare in each period is then given by

$$(48) \quad \bar{V}_S = \bar{Y}_S - \varepsilon_1 \eta_1 - \varepsilon_2 \eta_2.$$

It is more demanding to find the autarkic equilibrium in the North because the pharmaceutical sector is a monopoly (pharmaceutical company 1 is the only active company in this sector) although the consumption good sector is perfectly competitive. As already explained, the equilibrium concept we use to describe such an economy is the Cournot-Walras equilibrium.

To find the autarkic Cournot-Walras equilibrium for the North, let $Z_1, 0 \leq Z_1 \leq \varepsilon_1$, be the output of drug 1. Given Z_1 , the equilibrium wage rate and the equilibrium rental rate of land in the North are given, respectively, by

$$(49) \quad \omega_N(Z_1) = \frac{1}{2} \bar{A}_N^{1/2} (1 - \ell_1 Z_1)^{-1/2},$$

and

$$(50) \quad r_N(Z_1) = \frac{1}{2} \bar{A}_N^{-1/2} (1 - \ell_1 Z_1)^{1/2}.$$

If $p_1, 0 \leq p_1 \leq \xi_1$, is the price of drug 1, then the profit made by pharmaceutical company that produces this drug is

$$(51) \quad \begin{aligned} \pi_1(p_1|Z_1) &= (p_1 - \ell_1 \omega_N(Z_1))Z_1 \\ &= \left(p_1 - \frac{1}{2} \ell_1 \bar{A}_N^{1/2} (1 - \ell_1 Z_1)^{-1/2} \right) Z_1. \end{aligned}$$

The income of an individual of type θ in the North is then given by

$$(52) \quad \begin{aligned} m_N(\theta|p_1, Z_1) &= \omega_N(Z_1) + r_N(Z_1)a_N(\theta) + b_1(\theta)\pi_1(p_1|Z_1) \\ &= \frac{1}{2} \bar{A}_N^{1/2} (1 - \ell_1 Z_1)^{-1/2} + 2\theta \frac{1}{2} \bar{A}_N^{-1/2} (1 - \ell_1 Z_1)^{1/2} \\ &\quad + 2\theta \left(p_1 - \frac{1}{2} \ell_1 \bar{A}_N^{1/2} (1 - \ell_1 Z_1)^{-1/2} \right) Z_1 \\ &= \frac{1}{2} \bar{A}_N^{1/2} (1 - \ell_1 Z_1)^{-1/2} + \theta \left(2p_1 + \bar{A}_N^{-1/2} (1 - \ell_1 Z_1)^{1/2} - \ell_1 \bar{A}_N^{1/2} (1 - \ell_1 Z_1)^{-1/2} \right) Z_1. \end{aligned}$$

The cut-off type – assuming that it is strictly between 0 and 1 – at or above which a consumer in the North who is afflicted with disease 1 and who is willing to buy one unit of drug 1 is the value of θ , say $\theta_{1,N}^\#(p_1, Z_1)$, that solves the following equation

$$\begin{aligned}
 m_N(\theta|p_1, Z_1) &= \\
 (53) \quad &= \frac{1}{2} \bar{A}_N^{1/2} (1 - \ell_1 Z_1)^{-1/2} + \theta \left(2p_1 + \bar{A}_N^{-1/2} (1 - \ell_1 Z_1)^{1/2} - \ell_1 \bar{A}_N^{1/2} (1 - \ell_1 Z_1)^{-1/2} \right) Z_1 \\
 &= p_1,
 \end{aligned}$$

i.e.,

$$(54) \quad \theta_{1,N}^\#(p_1, Z_1) = \frac{p_1 - \frac{1}{2} \bar{A}_N^{1/2} (1 - \ell_1 Z_1)^{-1/2}}{\left(2p_1 + \bar{A}_N^{-1/2} (1 - \ell_1 Z_1)^{1/2} - \ell_1 \bar{A}_N^{1/2} (1 - \ell_1 Z_1)^{-1/2} \right) Z_1}.$$

Using (54), we obtain the following expression for the demand of drug 1 in the North in autarky:

$$\begin{aligned}
 X_{1,N}(p_1, Z_1) &= \varepsilon_1 [1 - \theta_{1,N}^\#(p_1, Z_1)] \\
 (55) \quad &= \varepsilon_1 \left[1 - \frac{p_1 - \frac{1}{2} \bar{A}_N^{1/2} (1 - \ell_1 Z_1)^{-1/2}}{\left(2p_1 + \bar{A}_N^{-1/2} (1 - \ell_1 Z_1)^{1/2} - \ell_1 \bar{A}_N^{1/2} (1 - \ell_1 Z_1)^{-1/2} \right) Z_1} \right].
 \end{aligned}$$

Given Z_1 , the price of drug 1 that clears the market for this drug is the value of p_1 that solves the following market-clearing condition:

$$\begin{aligned}
 (56) \quad X_{1,N}(p_1, Z_1) &= \varepsilon_1 \left[1 - \frac{p_1 - \frac{1}{2} \bar{A}_N^{1/2} (1 - \ell_1 Z_1)^{-1/2}}{\left(2p_1 + \bar{A}_N^{-1/2} (1 - \ell_1 Z_1)^{1/2} - \ell_1 \bar{A}_N^{1/2} (1 - \ell_1 Z_1)^{-1/2} \right) Z_1} \right] \\
 &= Z_1.
 \end{aligned}$$

That is, the equilibrium price of drug 1, as a function of its output Z_1 , is given by

$$(57) \quad p_1(Z_1) = \frac{\left[\left(\bar{A}_N^{-1/2} (1 - \ell_1 Z_1)^{1/2} - \ell_1 \bar{A}_N^{1/2} (1 - \ell_1 Z_1)^{-1/2} \right) Z_1 \left(1 - \frac{Z_1}{\varepsilon_1} \right) \right]}{1 + 2Z_1 \left(\frac{Z_1}{\varepsilon_1} - 1 \right)}.$$

Equation (57) is the inverse market demand curve for drug 1. The profit made by the pharmaceutical company that manufactures drug 1, if Z_1 is the chosen output of this drug, is then given by

$$(58) \quad \varphi_1(Z_1) = Z_1(p_1(Z_1) - \ell_1 \omega_N(Z_1)).$$

When the North lives in autarky, the equilibrium output of drug 1, say Z_1^* , is the value of Z_1 that maximizes (58); that is,

$$(59) \quad Z_1^* = \arg \max_{Z_1} \varphi_1(Z_1).$$

It is simple to solve the profit maximization problem (59). Once Z_1^* has been found, the price of drug 1 is then given by $p_1(Z_1^*)$. The equilibrium wage rate, the equilibrium rental rate of land can also be computed from Z_1^* . Next, the income of each consumer can be computed, and finally the cut-off type can also be found. The autarkic Cournot-Walras equilibrium in the North can thus be computed explicitly.

TABLE I
THE ONE-PERIOD AUTARKIC EQUILIBRIUM

Variables	Results	
	North	South ³²
p_1	0.833921	NA
Z_1	0.0699388	NA
$\theta_{i,1}^{\#}$	0.300612	NA
V_i^0	0.843154	0.614817
$V_i^{1,0}$	-0.0174938	-0.0481479
$V_i^{1,1}$	0.0269881	NA
V_i^2	-0.894606	-0.923148
V_i	-0.0419573	-0.356479

³² As this is autarky, $V_i^{1,0}$ represents the utility of the people in the South who have disease '1', but can not consume drug 1 due to closed economy.

3.2. General Equilibrium under Free Trade: The Case Bio-diversity is not Conserved in the First Period

When the South chooses not to conserve its biodiversity in the first period, it will immediately convert the wilderness land into agricultural land. This action also precludes the discovery of new drugs. Now only drug 1 is available in both periods. The resulting model is then the model analyzed in Sub-section 3.1 opened for trade. The only new feature in the model of the present sub-section is that consumers from the South can now buy drug 1 in the international market. Furthermore, under the present scenario the equilibrium in the first period is replicated in the second period.

To find the Cournot-Walras equilibrium for the international economy, first note that given the output and price of drug 1, the Northern demand for this drug is still given by (55). Furthermore, in the South, the equilibrium wage rate and the equilibrium rental rate of land are still given by (45) and (46). Also, the income of an individual of type θ in the South is still given by (47). The cut-off type at or above which a Southern consumer will buy one unit of drug 1, say $\theta_{1,S}^*(p_1, Z_1)$, is then given by the following expression when it is in the interior of the unit interval $[0,1]$:

$$(60) \quad \theta_{1,S}^*(p_1, Z_1) = \frac{p_1 - \left(\frac{3}{8} \bar{A}_S^{1/2} + \frac{3}{8} \bar{A}_S^{-1/2} (\bar{A}_S - A_{S,0}) \right)}{\frac{3}{4} \bar{A}_S^{-1/2}}.$$

It follows directly from (60) that the Southern demand for drug 1 is given by

$$(61) \quad \begin{aligned} X_{1,S}(p_1, Z_1) &= \varepsilon_1 \left[1 - F(\theta_{1,S}^*(p_1, Z_1)) \right] \\ &= \varepsilon_1 \left[1 - \frac{p_1 - \left(\frac{3}{8} \bar{A}_S^{1/2} + \frac{3}{8} \bar{A}_S^{-1/2} (\bar{A}_S - A_{S,0}) \right)}{\frac{3}{4} \bar{A}_S^{-1/2}} \right] \end{aligned}$$

The global demand for drug 1 is then given by

$$\begin{aligned}
X_1(p_1, Z_1) &= X_{1,N}(p_1, Z_1) + X_{1,S}(p_1, Z_1) \\
(62) \quad &= \varepsilon_1 \left[1 - \frac{p_1 - \frac{1}{2} \bar{A}_N^{1/2} (1 - \ell_1 Z_1)^{-1/2}}{(2p_1 + \bar{A}_N^{-1/2} (1 - \ell_1 Z_1)^{1/2} - \ell_1 \bar{A}_N^{1/2} (1 - \ell_1 Z_1)^{-1/2}) Z_1} \right] \\
&\quad + \varepsilon_1 \left[1 - \frac{p_1 - \left(\frac{3}{8} \bar{A}_2^{1/2} + \frac{3}{8} \bar{A}_S^{-1/2} (\bar{A}_S - A_{S,0}) \right)}{\frac{3}{4} \bar{A}_S^{-1/2}} \right].
\end{aligned}$$

For each value of Z_1 , the value of p_1 , say $p_1(Z_1)$, that solves $X_1(p_1, Z_1) = Z_1$ yields the global inverse demand curve for drug 1. Because the equation $X_1(p_1, Z_1) = Z_1$ is linear in p_1 , it is simple to obtain an explicit expression for $p_1(Z_1)$. Once, the global inverse demand for drug 1 is found, the optimal output of drug 1 can also be found, as in the preceding sub-section.

TABLE II
THE ONE-PERIOD FREE TRADE EQUILIBRIUM WHEN BIO-DIVERSITY RESOURCES ARE
NOT CONSERVED IN THE FIRST PERIOD

Variables	Results	
	North	South ³³
p_1	0.702774	NA
Z_1	0.142078	NA
$\theta_{i,1}^\#$	0.169052	0.410173
V_i^0	0.872743	0.614817
$V_i^{1,0}$	-0.0109269	-0.0286027
$V_i^{1,1}$	0.0404914	0.0127317
V_i^2	-0.890907	-0.923148
V_i	0.0114004	-0.324202

³³ As this is autarky, $V_i^{1,0}$ represents the utility of the people in the South who have disease 1, but can not afford drug 1.

3.3. General Equilibrium in the First Period when Bio-diversity is Conserved

Suppose that the South chooses to conserve its bio-diversity resources in the first period. Then it will not convert the wilderness land into agricultural land in that period. The supply of developed land in period 0 in the South is then given by $A_{S,0} = 1$. In the North, after accounting for the labor input used by pharmaceutical company 2 in its bio-prospecting activities, the remaining labor supply allocated to the consumption good sector and the manufacturing of drug 1 is $1 - B_2 = 1 - 0.05 = 0.95$. The global demand for drug 1 can be obtained from (62) by replacing the original labor supply in the North by $1 - B_2$ and $\bar{A}_S$ by $A_{S,0}$. More precisely, the global demand for drug 1 in period 0 under the scenario that the South choose to conserve its bio-diversity resources in that period is given by:

$$\begin{aligned}
 X_1(p_1, Z_1) &= X_{1,N}(p_1, Z_1) + X_{1,S}(p_1, Z_1) \\
 (63) \quad &= \varepsilon_1 \left[1 - \frac{p_1 - \frac{1}{2} \bar{A}_N^{1/2} (1 - B_2 - \ell_1 Z_1)^{-1/2}}{(2p_1 + \bar{A}_N^{-1/2} (1 - B_2 - \ell_1 Z_1)^{1/2} - \ell_1 \bar{A}_N^{1/2} (1 - B_2 - \ell_1 Z_1)^{-1/2}) Z_1} \right] \\
 &\quad + \varepsilon_1 \left[1 - \frac{p_1 - \frac{3}{8} A_{S,0}^{1/2}}{\frac{3}{4} A_{S,0}^{1/2}} \right].
 \end{aligned}$$

As in the preceding, the global inverse demand curve for drug 1 can be immediately obtained from (63), and the monopoly profit maximization problem of the pharmaceutical company that manufactures this drug can be solved.

TABLE III
GENERAL EQUILIBRIUM IN THE FIRST PERIOD WHEN BIO-DIVERSITY RESOURCES ARE
CONSERVED

Variables	Results	
	North	South ³⁴
p_1	0.685523	NA
Z_1	0.142514	NA
$\theta_{i,1}^{\#}$	0.16083	0.41403
V_i^0	0.83127	0.6
$V_i^{1,0}$	-0.0104267	-0.0297994
$V_i^{1,1}$	0.0367047	0.012876
V_i^2	-0.896091	-0.925
V_i	-0.0385431	-0.341923

*3.4 General Equilibrium in the Second Period when the South Conserves its
Bio-diversity Resources in the first Period*

If no new drugs were discovered at the end of period 0, then the problem in the second period is the same as the problem solved in Sub-section 3.2.

If drug 2 was discovered at the end of period 0, then in period two there exist two drugs – drug 1 and drug 2. Because there is no more need to conserve the bio-diversity resources, the South will convert all the wilderness land into agricultural land. The supply of developed land in the South is now $\bar{A}_S$. Also, because no more bio-prospecting activities

³⁴ As this is autarky, $V_i^{1,0}$ represents the utility of the people in the South who have disease 1, but can not afford drug 1.

are carried out by Northern pharmaceutical firms, the supply of labor to the consumption good sector and the manufacturing of drugs in the North is equal to 1.

To find the Cournot-Walras equilibrium, let Z_1 be the output of drug 1 and Z_2 be the output of drug 2. Given the list of drug outputs (Z_1, Z_2) , the equilibrium wage rate and the equilibrium rental rate of land in the North are given, respectively, by

$$(64) \quad \omega_N(Z_1, Z_2) = \frac{1}{2} \bar{A}_N^{1/2} (1 - \ell_1 Z_1 - \ell_2 Z_2)^{-1/2},$$

and

$$(65) \quad r_N(Z_1) = \frac{1}{2} \bar{A}_N^{-1/2} (1 - \ell_1 Z_1 - \ell_2 Z_2)^{1/2}.$$

If $p_j, 0 \leq p_j \leq \xi_j$, is the price of drug j , then the profit made by pharmaceutical company that produces this drug is

$$(66) \quad \pi_j(p_j | Z_1, Z_2) = ((1 - \tau_j) p_j - \ell_j \omega_N(Z_1, Z_2)) Z_j, \\ (j = 1, 2).$$

The income of an individual of type θ in the North is then given by

$$(67) \quad m_N(\theta | (p_j, Z_j)_{j=1}^2) = \omega_N(Z_1, Z_2) + r_N(Z_1, Z_2) a_N(\theta) + \sum_{j=1}^2 b_j(\theta) \pi_j(p_j | Z_1, Z_2) \\ = \omega_N(Z_1, Z_2) + 2\theta [r_N(Z_1, Z_2) a_N(\theta) + \sum_{j=1}^2 \pi_j(p_j | Z_1, Z_2)].$$

The cut-off type – assuming that it is strictly between 0 and 1 – at or above which a consumer in the North who is afflicted with disease j and who is willing to buy one unit of drug j is the value of θ , say $\theta_{j,N}^\#((p_j, Z_j)_{j=1}^2)$, that solves the following equation

$$(68) \quad m_N(\theta | (p_j, Z_j)_{j=1}^2) = \omega_N(Z_1, Z_2) + 2\theta [r_N(Z_1, Z_2) a_N(\theta) + \sum_{j=1}^2 \pi_j(p_j | Z_1, Z_2)] \\ = p_j, \quad (j = 1, 2).$$

The Northern demand for drug j is then given by

$$(69) \quad X_{j,N}((p_j, Z_j)_{j=1}^2) = \varepsilon_j [1 - \theta_{j,N}^\#((p_j, Z_j)_{j=1}^2)], \quad (j = 1, 2).$$

In the South, the equilibrium wage rate and the equilibrium rental rate of land are given, respectively by (45) and (46). Also, the income of a Southern consumer of type θ is now given by (47) plus the transfer provided by the royalties collected from the manufacturing of drug 2, the new drug. More specifically, the income of an individual of type θ in the South is given by

$$(70) \quad m_S(\theta|(p_j, Z_j)_{j=1}^2) = \bar{w}_S + \bar{r}_S a_S(\theta) + \bar{r}_S(\bar{A}_S - A_{S,0}) + \tau_2 p_2 Z_2.$$

The cut-off type – assuming that it is strictly between 0 and 1 – at or above which a consumer in the South who is afflicted with disease j and who is willing to buy one unit of drug j is the value of θ , say $\theta_{j,S}^{\#}((p_j, Z_j)_{j=1}^2)$, that solves the following equation

$$(71) \quad \begin{aligned} m_S(\theta|(p_j, Z_j)_{j=1}^2) &= \bar{w}_S + 2\theta \bar{r}_S + \bar{r}_S(\bar{A}_S - A_{S,0}) + \tau_2 p_2 Z_2 \\ &= p_j, \end{aligned} \quad (j = 1, 2).$$

The Southern demand for drug j is then given by

$$(72) \quad X_{j,S}((p_j, Z_j)_{j=1}^2) = \varepsilon_j [1 - \theta_{j,S}^{\#}((p_j, Z_j)_{j=1}^2)], \quad (j = 1, 2).$$

Given the list of drug outputs (Z_1, Z_2) , the list of drug prices (p_1, p_2) that clears the markets for the two drugs must solve the following market-clearing conditions:

$$(73) \quad \begin{aligned} X_j((p_j, Z_j)_{j=1}^2) &= X_{j,N}((p_j, Z_j)_{j=1}^2) + X_{j,S}((p_j, Z_j)_{j=1}^2) \\ &= Z_j, \end{aligned} \quad (j = 1, 2).$$

Given the list of drug outputs (Z_1, Z_2) , (73) defines implicitly the list of drug prices that clears the markets for the two drugs. We shall let $(p_1(Z_1, Z_2), p_2(Z_1, Z_2))$ denote the equilibrium list of drug prices, given the list of drug outputs (Z_1, Z_2) .

The profit made by the pharmaceutical company that manufactures drug j , as a function of the joint drug outputs (Z_1, Z_2) is given by

$$(74) \quad \varphi_j(Z_1, Z_2) = Z_j(p_j(Z_1, Z_2) - \ell_j \omega_N(Z_1, Z_2)), \quad (j = 1, 2).$$

For each $j = 1, 2$, we have

$$(75) \quad Z_j^* = \arg \max_{Z_j} \varphi_j(Z_j, Z_{-j}^*).$$

Solving the maximization problems represented by (75), we obtain the Cournot-Walras equilibrium for the second period when drug 2 was discovered in period 0.

TABLE IV
GENERAL EQUILIBRIUM IN THE SECOND PERIOD WHEN BIO-DIVERSITY RESOURCES
ARE CONSERVED IN THE FIRST PERIOD

Variables	Results	
	North	South ³⁵
p_1	0.728994	NA
Z_1	0.141524	NA
p_2	0.736305	NA
Z_2	0.13997	NA
$\theta_{i,1}^{\#}$	0.166931	0.417834
$\theta_{i,2}^{\#}$	0.172479	0.427822
V_i^0	0.934294	0.631307
$V_i^{1,0}$	-0.0105331	-0.0281586
$V_i^{1,1}$	0.0457232	0.0124031
$V_i^{2,0}$	-0.161739	-0.40302
$V_i^{2,1}$	0.0451162	0.0119811
V_i	0.852861	0.224512

4. DISCUSSION OF NUMERICAL SIMULATION RESULTS

4.1. Conservation and Welfare of Different Groups

The numerical simulation results shed light on the welfare of various groups. In the numerical example, we consider two diseases and three subpopulations. The simulation results are shown in Table V. The second column presents the welfare in the second period under the scenario that wilderness land is conserved in the first period and drug 2 is discovered at the end of the first period. The third column presents the corresponding results – also for the second period – either when drug 2 was not discovered as wilderness land was not conserved in the first period. Note that the third column also shows the free

³⁵ As this is autarky, $V_i^{1,0}$ represents the utility of the people in the South who have disease 1, but can not afford drug 1.

trade scenario of the first period when land is not conserved. The fourth column shows the first period scenario when land is conserved.

TABLE V
DIFFERENCE IN WELFARE AMONG DIFFERENT GROUPS WITH AND WITHOUT
CONSERVATION

Group Types	Free trade with drug 2 discovered as land is conserved in period 0	Free trade with drug 2 not discovered as land is not conserved in period 0 ³⁶	Period 0 scenario when land is conserved
Welfare of healthy sub-population in the North	0.934294	0.872743	0.83127
Welfare of healthy sub-population in the South	0.631307	0.614817	0.6
Welfare of disease 1 affected sub-population in the North who can not afford the drug	-0.0105331	-0.0109269	-0.0104267
Welfare of disease 1 affected sub-population in the South who can not afford the drug	-0.0281586	-0.0286027	-0.0297994
Welfare of disease 1 affected sub-population in the North who can afford the drug	0.0457232	0.0404914	0.0367047
Welfare of disease 1 affected sub-population in the South who can afford the drug	0.0124031	0.0127317	0.012876
Welfare of disease 2 affected sub-population in the North who can not afford the drug	-0.161739	NA	NA
Welfare of disease 2 affected sub-population in the South who can not afford the drug	-0.40302	NA	NA
Welfare of disease 2 affected sub-population in the North who can afford the drug or the drug is not discovered (e.g. the other three case)	0.0451162	-0.890907	-0.896091
Welfare of disease 2 affected sub-population in the South who can afford the drug or the drug is not discovered (e.g. the other three case)	0.0119811	-0.923148	-0.925
Social welfare of the North	0.852861	0.0114004	-0.0385431
Social welfare of the South	0.224512	-0.324202	-0.341923

The above table clearly shows that all the population sub-groups – both in the South and the North – gains higher welfare when biodiversity is conserved. The only exception is the disease 1 affected sub-population in the South who can afford the drug. But at the aggregate level, the social welfare levels of both the South and the North are higher between the conservation and non-conservation scenarios. The reason behind this is that as the Southern population is generally poor, group that can afford to buy the drug for disease 1 are small and with equal weight for each group, their welfare loss does not influence the aggregate social welfare much. But notice that in period 0, social welfare

³⁶ This scenario is the same for both periods 0 and 1, and comparison can be made with period 0 scenario of land conservation.

of both the North and the South under non-conservation scenario is higher than the conservation scenario. So, at the inter-temporal level, the conservation decision will depend on the proposition, stated earlier in Sub-section 2.5 and discount rate will have a large impact on conservation decision.

4.2. Conservation and Social Welfare

Comparison of the discounted social welfare over two periods in the North and the South with and without conservation can show us whether bio-prospecting is viable to conserve biodiversity or not. The discount rate plays an important factor in the decision on conservation. The results of the numerical simulation are presented in table VI.

TABLE VI
DIFFERENCES IN DISCOUNTED SOCIAL WELFARE WITH AND WITHOUT CONSERVATION

Scenario	South			North		
	$\delta = 0.05$	$\delta = 0.07$	$\delta = 1$	$\delta = 0.05$	$\delta = 0.07$	$\delta = 1$
Conservation	-0.3306974	-0.326207	-0.117411	0.0040999	0.0211571	0.8143179
Non Conservation	-0.3404121	-0.346896	-0.648404	0.0119704	0.0121984	0.0228008

The above table clearly shows that unless the discount factor is very low, social welfare is higher both for the South and the North under conservation. But the social welfare gain from conservation is higher for the North than the South. Equation (35) also implies that the conservation decision depends on the probability of success and the number of new drugs that can be found. Unless the number of new drugs is large and their probabilities of discovery are high, it might not be profitable for the South to conserve its biodiversity in the first period.

4.3. Comparison of Other Variables

Analysis of the simulation results also provides other insights that can be helpful to take important policy decisions. Starting from the benchmark scenario of free trade when only drug 1 is available to the scenario – also under free trade – under which drug 2 is discovered, we make the following observations:

- i. The equilibrium quantity of drug 1 is lower and its price is higher.
- ii. Though the disutility of disease 2 is quite higher than that of disease 1, the price of drug 2 is not so high compared to the price of drug 1.
- iii. The profit of the firm that produces drug 1 rises under the conservation scenario.
- iv. The wage rate in the North is higher under the conservation scenario.
- v. The cut-off point of θ for drug 1 decreases in the North, but it increases in the South. So the group suffering from disease 1 becomes better off in the North and the same group in the South becomes worse off.

TABLE VII
DIFFERENCES IN OTHER VARIABLES

Variables	Free trade with drug 2 discovered as land is conserved in period 0	Free trade with drug 2 not discovered as land is not conserved in period 0 ³⁷
Equilibrium quantity of drug '1'	0.141524	0.142078
Price of drug 1 : p_1	0.728994	0.702774
Price of drug 2 : p_2	0.736305	NA
Profit of the producers of drug 1	0.0941648	0.0908887
Cut off level of θ in the North for drug '1'	0.166931	0.169052
Cut off level of θ in the South for drug '1'	0.417834	0.410173
Wage rate in the North	0.509036	0.5045

³⁷ This scenario is same for both period 0 and period 1, and comparison can be made with the period 0 scenario of land conservation.

The first three observations indicate that innovation of newer drugs does not necessarily imply decrease in market power of existing firms. Though the disutility from disease 2 is 700% higher, firm 2 can only charge a 1% higher price for drug 2. So, firms that market new drugs may not be able to charge a higher price or receive a greater profit than the existing firms. It implies that though the firms have monopoly over their own drug, still they have to behave strategically like oligopoly firm and have to take the behavior of the other firms into account. All these observations imply that too many new drugs may not be feasible in the market. These observations lead us to the following proposition.

PROPOSITION 2: Due to strategic nature of the market, if a large number of drugs are discovered, then the market power and profit of the new low-end drug firms may be low enough to drive them out of the market i.e. too many new drugs may not be feasible in the market.

Also as royalties are negotiated before bio-prospecting activities are carried out, they might be quite low if the labor input in bio-prospecting is high or if the probability of discovery is low. Thus if a drug with these characteristics is discovered, and if the manufacturing of the drug requires little labor, then the realized gross margin (price – production cost – royalty) of the drug will be high. If by chance a lot of drugs with high gross margins are discovered at the end of the first period, then according to observation four the demand for labor used in the manufacturing of these drugs will raise the wage rate substantially, which might make it unprofitable to manufacture the drugs with a low benefit. We summarize the results just discussed in the following proposition:

PROPOSITION 3: If a sufficient number of drugs with high benefits and low royalties are discovered, then their manufacturing will require a considerable amount of labor, and the ensuing rise in the wage rate will make the drugs with low benefits and high labor inputs unprofitable and drive these drugs out of the market.

Observation five shows that the innovation of a new drug may decrease the income of one group (group with disease 1) in the South and take some of the group members out of

the affordability range for their drug. But in the North, not all groups are better off with innovation of new drugs and conservation of biodiversity.

4.4. Sensitivity Analysis

We have also carried out a sensitivity analysis for the second period, under the scenario that drug 2 is invented, for different values of the parameters of the model. The exercise helps to understand how conservation decisions are affected by the different parameters. The results of the sensitivity analysis are presented in Appendix 2. The following observations are obtained from the sensitivity analysis exercise.

- i. Any increase in the probability of having a disease decreases social welfare. But the high disutility disease decreases social welfare more. It implies that drugs for high disutility diseases will provide greater incentive to conserve.
- ii. A higher level of disutility of disease 2 does not affect the demand, price, company profit, wage rate, or the cut-off points. Its only impact is to decrease social welfare. It implies that quality of the new drug to cure a high disutility disease is the most important factor that affects conservation decision.
- iii. Social welfare of the South is positively related with ξ_j . So, lower benefit from a new drug decreases the Southern social welfare.

Observations i, ii and iii implies if a *miracle drug*, i.e., a drug with a high value of ξ_j , might be discovered among the flora of the South that cures some high disutility disease of the South, then certainly the expected discounted payoff for the South will be much higher under the conservation action than under the development action. The following proposition is now immediate:

PROPOSITION 4: *If there is a drug $j \in J - J_0$ such that ξ_j , the benefit it yields, is sufficiently high, then the South will conserve its bio-diversity resources in the first period. That is, if the flora of the South contains the chemical structure of a miracle drug, then bio-diversity will be conserved in the first period.*

The following are some other observations from the sensitivity analysis.

iv. An equal increase in the per unit labor cost for drug production decreases the social welfare of both the North and South under conservation. But new drug with higher per unit cost (i.e. $\ell_2 > \ell_1$) decreases social welfare more. It implies that new drugs with very high per unit production cost may discourage conservation.

v. Higher values of the royalty, τ_j , increase the social welfare of the South, but decrease the social welfare of the North. Moreover higher royalty also decreases the profit of the drug company. So, very high royalty may make the production of a new drug infeasible.

vi. Social welfare of the South as well as conservation decision are positively related with $\bar{A}_S$. So, larger amount of land in the South works as incentive to conservation.

One of the important questions we would like the model to address is how the royalties are determined. To answer this question, note that if the bio-prospecting firms are assumed to be risk neutral, then competition among them will drive the expected profit of each of the bio-prospecting firms that obtains the right to search for bio-chemicals to zero. Now in computing the expected profit of a bio-prospecting firm, we have to take into consideration (i) the labor input (B_j) in the bio-prospecting process, (ii) the probability of discovery (q_j), (iii) the labor input (ℓ_j) required in manufacturing a unit of the drug, and (iv) the benefit (ξ_j) of the drug. A high labor input in the bio-prospecting process, a low probability of discovery, and a high labor input in the manufacturing process all lead to a low royalty. On the other hand, ceteris paribus, a drug

with a high benefit will command a high royalty. The following proposition is a formal statement of the results just discussed.

PROPOSITION 5: Competition among bio-prospecting firms will drive the expected profit of the ones that obtain the rights to search for bio-chemicals among the flora of the South to zero. Furthermore, ceteris paribus, a high value of B_j , a low value of q_j , or a high value of ℓ_j will mean a low value of τ_j , the royalty on drug j , $j \in J_1 - J_0$. On the other hand, a high value of ξ_j , $j \in J_1 - J_0$, means a high value of τ_j , $j \in J_1 - J_0$.

6. CONCLUSION

Bio-prospecting is often suggested as a market-based policy tool for conserving biodiversity. Through a two-period two-country general equilibrium model, this paper shows how bio-prospecting might help in the conservation of biodiversity and under what conditions it might fail. The paper hints that a systematic search process increases the success of bio-prospecting. Also, a lower cost of the bio-prospecting process or manufacturing of drugs, a high probability of drug discovery, and a drug with a high benefit provide incentives for conservation. Through prior research, the firms may choose only those drugs which will have high values of ε_j or ξ_j and enough royalty payment to ensure conservation.

However, there are some caveats concerning the conservation biodiversity through the bio-prospecting process. First, if the South demands very high royalty payments, then bio-prospecting might become unprofitable. Second, due to strategic nature of the market a larger set of bio-prospected drug induces a rise in wages rate and decrease in profitability and might drive the low-benefit drug inventors out of the market. Third, the drug companies may ignore some diseases in the South if these diseases do not generate sufficient demand to cover the bio-prospecting costs and the costs of manufacturing the drugs that treat these diseases. Fourth, the search process may take a very long time and derive the cost high.

As the South faces a dual pressure for conservation and land development at the same time, if bio-prospecting contracts take a long time and fail to deliver some marketable products, the bio-prospecting process may break down in longer terms. Thus, bio-prospecting might be one of the feasible options for biodiversity conservation, but might not be a strong or only option.

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APPENDIX A

TABLE 1: PARAMETER VALUES FOR SIMULATION

Parameters	Numerical Simulation	
	North	South
H_i	1	3/4
$\bar{A}_i$	1	1.05
β_i	1/2	1/2
ℓ_j	1/8	NA
B_2	0.05	NA
$\varepsilon_1 = \varepsilon_2$	1/10	NA
ξ_1	1.25	NA
ξ_2	10	NA
η_1	1.25	NA
η_2	10	NA
τ_2	1/5	NA

APPENDIX B

TABLE 2: PARAMETER VALUES FOR SENSITIVITY ANALYSIS

Parameters	Numerical Simulation
$\bar{A}_i$	1.15
$\ell_1 = \ell_2$	0.1251
$\varepsilon_1 = \varepsilon_2$	0.105
ξ_2	3
τ_j	0.20015

APPENDIX C
SENSITIVITY ANALYSIS TABLES

TABLE 3: CASE 1, INCREASE IN BOTH ℓ_1 and ℓ_2 ,

Variables	Free trade with drug 2 discovered as land is conserved in period 0	Free trade with drug 2 discovered as land is conserved in period 0
Demand for drug 1: Z_1	0.141519	0.141524
Demand for drug 2: Z_2	0.139964	0.13997
Price of drug 1 : p_1	0.729016	0.728994
Price of drug 1 : p_2	0.736333	0.736305
Cut off level of θ in the North for drug 1	0.166947	0.166931
Cut off level of θ in the South for drug 1	0.417864	0.417834
Cut off level of θ in the North for drug 2	0.1725	0.172479
Cut off level of θ in the South for drug 2	0.427861	0.427822
Profit of drug '1' producer	0.0941574	0.0941648
Profit of drug '2' producer	0.0735349	0.0735422
Wage rate in the North	0.509043	0.509036
Social welfare of the North	0.852822	0.852861
Social welfare of the South	0.2224472	0.224512

TABLE 4: CASE 2, $\ell_1 \neq \ell_2$,

Variables	Free trade with drug 2 discovered as land is conserved in period 0 ($\ell_1 = 0.1251$ $\ell_2 = 0.125$)	Free trade with drug 2 discovered as land is conserved in period 0 ($\ell_1 = 0.125$ $\ell_2 = 0.1251$)	Free trade with drug 2 discovered as land is conserved in period 0 ($\ell_1 = \ell_2 = 0.125$)
Demand for drug 1: Z_1	0.141518	0.141524	0.141524
Demand for drug 2: Z_2	0.13997	0.139964	0.13997
Price of drug 1 p_1	0.729018	0.728992	0.728994
Price of drug 1 : p_2	0.736303	0.736335	0.736305
Cut off level of θ in the North for drug 1	0.166949	0.166929	0.166931
Cut off level of θ in the South for drug 1	0.417866	0.417832	0.417834
Cut off level of θ in the North for drug 2	0.172478	0.172502	0.172479
Cut off level of θ in the South for drug 2	0.42782	0.427863	0.427822
Profit of drug 1 producer	0.0941575	0.0941647	0.0941648
Profit of drug 2 producer	0.0735421	0.073535	0.0735422
Wage rate in the North	0.509039	0.509039	0.509036
Social welfare of the North	0.852852	0.852831	0.852861
Social welfare of the South	0.224512	0.224473	0.224512

TABLE 5: CASE 3, INCREASE IN BOTH ε_1 and ε_2

Variables	Free trade with drug 2 discovered as land is conserved in period 0	Free trade with drug 2 discovered as land is conserved in period 0
Demand for drug 1: Z_1	0.148467	0.141524
Demand for drug 2: Z_2	0.14685	0.13997
Price of drug 1: p_1	0.731448	0.728994
Price of drug 1: p_2	0.73873	0.736305
Cut off level of θ in the North for drug 1	0.166319	0.166931
Cut off level of θ in the South for drug 1	0.419706	0.417834
Cut off level of θ in the North for drug 2	0.171776	0.172479
Cut off level of θ in the South for drug 2	0.429654	0.427822
Profit of drug 1 producer	0.0991408	0.0941648
Profit of drug 2 producer	0.0774336	0.0735422
Wage rate in the North	0.509492	0.509036
Social welfare of the North	0.846286	0.852861
Social welfare of the South	0.195187	0.224512

TABLE 6: CASE 4, $\varepsilon_1 \neq \varepsilon_2$

Variables	Free trade with drug 2 discovered as land is conserved in period 0 ($\varepsilon_1 = 0.105$, $\varepsilon_2 = 0.1$)	Free trade with drug 2 discovered as land is conserved in period 0 ($\varepsilon_1 = 0.1$, $\varepsilon_2 = 0.105$)	Free trade with drug 2 discovered as land is conserved in period 0 ($\varepsilon_1 = \varepsilon_2 = 0.1$)
Demand for drug 1: Z_1	0.148485	0.141506	0.141524
Demand for drug 2: Z_2	0.139861	0.146963	0.13997
Price of drug 1: p_1	0.730153	0.730294	0.728994
Price of drug 1: p_2	0.737479	0.73756	0.736305
Cut off level of θ in the North for drug 1	0.166463	0.16679	0.166931
Cut off level of θ in the South for drug 1	0.419394	0.418153	0.417834
Cut off level of θ in the North for drug 2	0.171984	0.172273	0.172479
Cut off level of θ in the South for drug 2	0.429404	0.42808	0.427822
Profit of drug 1 producer	0.0989645	0.0943328	0.0941648
Profit of drug 2 producer	0.0736125	0.0773598	0.0735422
Wage rate in the North	0.509262	0.509266	0.509036
Social welfare of the North	0.853945	0.845175	0.852861
Social welfare of the South	0.218108	0.201663	0.224512

TABLE 7: CASE 5, LOWER LEVEL OF ξ_2

Variables	Free trade with drug 2 discovered as land is conserved in period 0 (Smaller value of ξ_2)	Free trade with drug 2 discovered as land is conserved in period 0 (status Quo)
Demand for drug 1: Z_1	0.141524	0.141524
Demand for drug 2: Z_2	0.13997	0.13997
Price of drug 1 : p_1	0.728994	0.728994
Price of drug 1 : p_2	0.736305	0.736305
Cut off level of θ in the North for drug 1	0.166931	0.166931
Cut off level of θ in the South for drug 1	0.417834	0.417834
Cut off level of θ in the North for drug 2	0.172479	0.172479
Cut off level of θ in the South for drug 2	0.427822	0.427822
Profit of drug 1 producer	0.0941648	0.0941648
Profit of drug 2 producer	0.0735422	0.0735422
Wage rate in the North	0.509036	0.509036
Social welfare of the North	0.973596	0.852861
Social welfare of the South	0.523988	0.224512

TABLE 8: CASE 6, HIGHER LEVEL OF τ_2

Variables	Free trade with drug 2 discovered as land is conserved in period 0 (Higher value of τ_2)	Free trade with drug 2 discovered as land is conserved in period 0 (status Quo)
Demand for drug 1: Z_1	0.141525	0.141524
Demand for drug 2: Z_2	0.13997	0.13997
Price of drug 1 : p_1	0.728996	0.728994
Price of drug 1 : p_2	0.736314	0.736305
Cut off level of θ in the North for drug 1	0.166935	0.166931
Cut off level of θ in the South for drug 1	0.417815	0.417834
Cut off level of θ in the North for drug 2	0.172489	0.172479
Cut off level of θ in the South for drug 2	0.427813	0.427822
Profit of drug 1 producer	0.094166	0.0941648
Profit of drug 2 producer	0.0735277	0.0735422
Wage rate in the North	0.509036	0.509036
Social welfare of the North	0.852837	0.852861
Social welfare of the South	0.224537	0.224512

CHAPTER 5

CONCLUSION TO THE THESIS

The thesis started with the motivation to look into the problem of biodiversity depletion and suggest some policy tools that may help in its conservation. The three essays have looked into three different tools of biodiversity conservation – green consumerism, valuation of ecosystem services and bio-prospecting and each of the essays have provided some policy suggestions for biodiversity conservation.

Chapter two has lent support to some of the concerns of environmental activists that when there is absence of market for the biodiversity resources itself, free trade may deplete the world's biodiversity. Biodiversity resources provide different goods and services that often do not have any market. In fact the market for many of the non-use values of biodiversity is global in nature and scope. It implies that the South alone could not correct the missing market problem. Due to absence of markets for these services and products derived from biodiversity rich land, the opportunity cost of their alternative use in agriculture becomes significant and causes land clearing. Further, when developing countries can not monetize the value of the conserved biodiversity they have no other alternatives but to deplete their rich biodiversity resource stock in order to meet pressing subsistence needs to the current population, even though this may be welfare decreasing for the future generations in these countries as well as in the world at large.

On the other hand, the chapter has also provided support to the concerns of environmental and resource economists that even without trade, unsustainable population growth alone can deplete biodiversity resources. Demand-side mechanisms like discounting of biodiversity depleting products and supply side mechanisms such as eco-friendly agricultural technologies can have a positive impact to decrease biodiversity loss. But, merely discounting southern agricultural products and not being concerned about the biodiversity resources directly, may not provide sufficient incentives for biodiversity conservation in the long run. If Northern 'green' consumers really care about biodiversity loss in the South, then biodiversity should be an argument in their utility function. In such a case, their valuation of Southern biodiversity can be measured and they should be willing to pay for the conservation of biodiversity in the South equal to that value. Not valuing biodiversity directly and only discounting differentiated products as shown in this essay can only slow down the depletion of biodiversity stock, but cannot provide a more sustainable long term solution.

The above discussion leads to the conclusion that policy planners should try to create markets for the different goods and services provided by biodiversity rich lands. For example, they may further explore alternative markets such as bio-prospecting or eco-tourism in order to appropriate economic values for the conservation of the biodiversity stock. Also the biodiversity rich developing countries have to diversify with respect to domestic production and trade. They need to decrease their dependence on export of natural resources and agricultural products and diversify their export towards manufacturing products. Above all, if consumers in all regions of the world really care

about the existence of biodiversity, they should be prepared to pay a premium for the conservation and provision of this global public good. Hence, institutions such as the Global Environmental Fund should become one of the principle mechanisms for the conservation of biodiversity.

Chapter three looks into how the inclusion of ecosystem services and land market being the only real asset market in the South affect biodiversity. The results of the model in this chapter also have important policy implications. To the Southern workers, land clearing is a form of investment as ecosystem services provided by biodiversity rich land are not valued in the market system. Competitive market solution leads to over exploitation of biodiversity rich land and does not create any incentive for creating a market for undeveloped land and its ecosystem services. Hence the government has to use fiscal tools or create markets through institutional mechanisms. But politically, these mechanisms may be hard to implement as they might lower the welfare of the Southern consumers.

The model also shows that the absence of markets for real assets – other than developed land – in the South encourages land clearing. So, the creation of alternative real asset markets, such as the bond market, the stock market (for ownership of physical capital), or an income-generating system for the older generation are important policy measures to reduce biodiversity loss in the South. Alternative earning and employment opportunities other than land clearing can also slow down destruction of biodiversity.

The results of the paper also imply that naturally, geographically, and biologically remote areas of the biodiversity-rich land would probably be safe for the near short run due to very high cost of land development. Development of access facilities, such as roads and other forms of communication should be avoided for highly biodiversity-rich areas, known as the “hot-spots.”

Chapter 4 explains the condition that can make a bio-prospecting process successful. It suggests that a systematic search process, that relies on prior scientific and ethnobotanical information on the plant species and takes into account the health characteristics of the population, could increase the success of bio-prospecting and biodiversity conservation. Through prior research, the firms may choose the diseases with higher disutility and search for their cure. But there are some caveats of this search process. The drug companies will ignore the low value (i.e. low disutility) diseases. Cost, discount rate and probability of success to get a new drug play key role in the decision to conserve biodiversity under a bio-prospecting scheme. This explains why some of the famous bio-prospecting schemes currently existing around the world are not that successful. Long time window and low success rate are the two key reasons. So with low success rate and high cost of bio-prospecting against higher opportunity cost of land development may lead to the break down of the bio-prospecting contracts in the long run.

Future research extension of the thesis will consider combining several tools suggested in the thesis to find how it can help biodiversity conservation. More extensive modeling of the resource dynamics by including the evolution of the biodiversity resources, ecosystem

services and combining it with the economic models is another future extension that will be looked into.

The three essays of this thesis suggest that green consumerism, payment for ecosystem services or bio-prospecting scheme can be viable tools for biodiversity conservation. But the strong message in all the three essays is also that there is no one miracle tool that can save biodiversity. Any of these tools slows down the process of biodiversity destruction in the short run, but may not save it in the long run. As long there is no market just for the existence value of biodiversity rich areas, initiatives to capture the other values can only slow down the destruction process, but can not stop it fully. If we as world citizens do not consider biodiversity resources as global public goods and pay for their global value, the trend in decline of biodiversity resources will continue.