

ABSTRACT

Title of Document: RENEWABLE RESOURCES AS A FACTOR OF PRODUCTION IN INTERNATIONAL TRADE

Gustavo Adolfo Anríquez Nilson, Doctor of Philosophy, 2005

Directed By: Professor Ramón López
Agricultural and Resource Economics
Department

This work provides an extensive review of the literature on trade and environmental issues that has been growing since the early 1990s. The gaps in this literature are identified and generalizations are provided from results that are scattered.

Next, we contribute to this literature by studying a Ricardian model of trade, in which one of the sectors uses a renewable resource as a factor of production. The contribution lies in the study of trade and welfare through the full horizon of the welfare maximization problem, not relying in equilibrium analysis.

This study is divided into small country case and a 2 country – 2 factor model. In the first case, we show how trade prevents extinction, and if the assumption of full open access environmental externality is relaxed the welfare expected results change substantially. In the 2 x 2 model we show that equilibrium is actually not possible invalidating many such analyses existing in the literature. This lack of equilibrium may lead the country that is free from environmental externalities to actually lose with trade *vis-à-vis* autarky.

RENEWABLE RESOURCES AS A FACTOR OF PRODUCTION IN INTERNATIONAL TRADE

By

Gustavo Adolfo Anríquez Nilson

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Advisory Committee:
Professor Ramón López, Chair
Professor John Horowitz
Professor Roberto Patricio Korzeniewicz
Professor Tigran Melkonyan
Professor Lars Olson

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Dedication

To my dearly loved grandfather, Gustavo Anríquez, who left us this year, for teaching me the value of solidarity and how to face with optimism the obstacles in life. *Gracias todayo...*

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Thanks to the Department of Agricultural and Resource Economics of the University of Maryland, for not only financially supporting me, and thus making my studies possible, but for providing a rich academic environment to grow in.

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Chapter 1:

Trade and the Environment:

An Economic Literature Survey

The trade and environment literature started in the early 1970's as a response to the first environmental protection policy enacted in OECD countries. The concern was that this policy together with trade would force regulated industries to migrate to unregulated regions. During the 1980's environmental issues in general became less important amidst the world recession at the beginning of the decade. However, with the beginning of the next decade environment and trade issues took the headlines for the first time. Two passionate intellectual camps took positions: the anti-globalization group fiercely started to oppose further trade integration worried that globalization in general will translate in progressive lowering of environmental and labor standards. In the opposite side free-traders argued that integration (including trade) is the only policy that guarantees growth, which is unavoidably accompanied by improvements in income, labor and environmental standards. In the middle, or perhaps, isolated from the hot headed debate a rich economic literature bloomed, providing arguments for both camps,

understanding the linkages, and providing the settings under which trade can be beneficial for the environment, as well as welfare.

This survey aims to collect in a comprehensive and orderly fashion the economic thought developed the last decade. This study is founded on early surveys done at the beginning of the nineties that helped this trade and environment literature boom (Dean (1992), Beghin et al. (1994), Xing and Kolstad (1996)), and hopes to help and guide a new and better generation of economic research on this subject of great consequence.

This exploration over the trade and environment literature will first take us over the theoretical literature. We will see how many second best results have been formalized, the effects of removing trade (price) distortions in the presence of a second distortion (the environmental externality). These results have been explored for different types of environmental externalities: when the environment is factor of production, when production damages the environment, when consumption depletes the environment, and when there are spillover transboundary environmental externalities. Additionally, we will see why when these two externalities are present environmental and trade policy are linked. Finally, we see how competition for policies can actually revert many policy effects that are thought to be unambiguous.

In the second section we revise the empirical literature. In this section we review how economists have measured the trade and environment links. We see different roads to measure environmental externalities and the effects of trade when these are present. Direct and indirect channels through which trade can affect the environment are identified and estimated. Some important questions regarding trade policy, political economy forces and environmental effects are estimated in this literature. Do differences

in environmental policy determine patterns of trade, industry location, and DFI flows?
Does corruption matter?

Finally, we take a brief break to learn about the main criticism that this literature has received. Some argue that not all the environmentally degrading effects of trade are being considered by mainstream economics. The intention in reviewing this critique is to investigate areas that may be improved in future research.

I.- The Theory¹

1. Environmental Regulations, Distortions and the Patterns of Trade

As OECD countries began to impose environmental regulations in the early 1970's, one of the first concerns of economists, when thinking about environment and trade, was that these controls could impose burdens too heavy that would alter patterns of trade, and ultimately make industries migrate to unregulated regions. Pethig (1976) using a two-sector Ricardian model with emissions and labor as inputs shows that a country will specialize in the production of the environmental-intensive good if their environmental regulations are less restrictive than the other country. Siebert (1977) expanded the analysis in a single factor model, but with non-linear technology. He shows that environmental policy improves the environment, but at the cost of reducing the output of the environmental intensive good, and further, reducing the standard gains from trade. If the environmental regulation becomes too restrictive, eventually it could revert the comparative advantage of a country in the pollution intensive good. These results are confirmed in a Heckscher-Ohlin framework by McGuire (1982). The author adds to the

¹ Many of the seminal papers discussed in this section have been recently compiled by Dean (2002).

standard trade model one factor of production in one sector, the environment, which is subject to a quantitative restriction. As modeled, the restriction acts as negative technical change in the good that uses the environment, redistributing income between the standard factors of production, to the factor used intensively in the non-environmental good. If the restriction is large enough, it can revert a comparative advantage the country may enjoy in the good that uses the environment. Furthermore, if capital and labor are freely mobile across countries, the country that imposes the restriction on the environment has its factors emigrate until it only produces the non-environment good, at the limit of the cone of diversification.

Lack of regulations, can also determine the patterns of trade. If a country has a property rights problem in the access to the environment, there will be an over-exploitation of the environment that would give the country an apparent comparative advantage in the environment-intensive good (we describe this literature in detail in the next section).

Thus, environmental regulations can change the patterns of trade, altering the direction of Ricardian (technological) comparative advantage, and even standard comparative advantages based on relative factor abundance: at the margin it can drive industries out of international markets.

Copeland and Taylor (1994), show that environmental considerations can drive industries out of countries even when environmental policies are the same². The authors construct a model with a continuum of goods indexed by their emissions intensity, with

² In their model both countries use the same policy as they tax emissions at their marginal damage level. However, since the richer country imposes a different (higher) tax, the authors call this different environment policies.

pollution affecting welfare as a bad, and an efficient government taxing emissions at their marginal damage level. Since the marginal damage, increases with income, i.e. environmental quality is a normal good, when countries trade the richer country specializes in cleaner goods (reducing pollution *vis-à-vis* autarky), while the poorer country specializes in the dirtier goods (augmenting pollution). Overall pollution increases for the same reasons there are standard gains from trade, the specialization expands output³. In Copeland and Taylor (1995a) the authors expand the analysis to the case of consumer generated pollution, showing that with the advent of trade, pollution decreases in the rich country and increases in the poor country, confirming in a broader sense that the dirty industry migrates from the richer to the poorer country.

Furthermore, differences in the environment's ability to replenish itself or to absorb pollution can also determine patterns of trade. Countries with "larger" environment, or with resources with a faster capacity to replenish themselves, enjoy a competitive advantage in the production of pollution intensive goods. Siebert (1977), for example, formalizes this result by showing that the country with an environment with higher assimilative capacity imposes a lower emissions tax which gives it a comparative advantage in the pollution intensive good. Leger (1995) extends this idea in a model with regional distribution of industries. He presents a Heckscher-Ohlin model with regional differences in the environmental assimilative capacity, showing that countries will export the good produced in the region with the higher environmental assimilative capacity (although which industry locates in that region is determined by history/chance).

³ More specifically, the authors show pollution increase because pollution increasing composition effects dominate the scale (pollution increasing) and technique (pollution decreasing) effects. These effects are explained in the next section.

2. Renewable Resources and Property Rights Failure

When the environment is viewed as a factor of production, there is a potential for over-exploiting it due to property rights problem. For example, assume the relevant environment was a lake with fish in it. When property rights (private or common) are correctly enforced, in the economic decision of harvesting fish agents must consider the costs of extraction plus the cost imposed on the stock of fish by altering its ability to regenerate. In a property rights regime of open access, only the current costs of harvesting are considered which translates into an over-harvesting of the resource. In this case there is a dynamic externality as only current costs are internalized in the economic decision of fishing, while the cost over the future availability of the resource is ignored. In a static scenario, a similar analysis is valid. Imagine every agent makes the decision to extract from the environment, taking other agents extraction decisions as given. In (Nash) equilibrium the amount harvested depends on the amount of agents, and with a sufficiently large amount of agents, each extracts until revenues equal average costs, instead of marginal costs which would be optimal; i.e. there is over extraction of the resource. Note that the property rights failure is not a problem of lacking a private property rights regime. It is possible for a community to manage a common resource optimally and fail to do so when a private property regime is imposed⁴.

There is a rather fertile literature that examines trade in a general equilibrium framework, when the environment is a factor of production subject to property rights failure. In this literature it has become customary to call the South the country/region with the externality in its access to the environmental resource, while the North is the

⁴ López (1998) provides an example of this.

region that optimally manages its resources. Obviously, these categories want to stress the fact that less developed nations, usually located in the South suffer from property rights failure.

2.1. North-South Trade Models

One of the earlier North-South trade models is presented by Chichilnisky (1994), which is an extension of the Heckscher-Ohlin model. Two final goods are produced with one factor, capital, in fixed supply, while the other factor is an intermediate good, an environmental good that is extracted from the environment⁵. The country without a complete property rights regime “South”, extracts more from the environment than is optimal, for any given price of the environmental good in comparison to the North. In autarky the final good that uses the environmental intermediate good more intensively, is cheaper in the South. Therefore the South has the standard endowment Heckscher-Ohlin type comparative advantage in that good and exports it. But the comparative advantage is not a real comparative advantage, it is only apparent, given by the externality in the access to the environment. Due to this environmental distortion the South loses with trade, and exacerbates the environmental problem by over-harvesting the environment even more, while the North, externality free gets the standard gains from trade. She also shows that if the environmental good is produced by subsistence farmers-harvesters, reducing the price of the environmental intermediate good (for example with an export tax) may lead to more over-extraction as farmers try to maintain subsistence levels of income.

⁵ In Chichilnisky (1993) the environment is modeled as a renewable, but all the main results hold.

Brander and Taylor (1997b) expand the North-South model by allowing the environment to be a renewable resource⁶. They assume linear technologies; two goods, one using labor exclusively, and the other labor and the environment as production inputs. As before, the South over-extracts the environmental input, but does not always expand output with additional efforts committed to harvesting the environment. Renewable resources have a regeneration capacity that is a function the stock. The most common growth function for this type of resources is an inverted-U shaped function like, for example, logistic growth. This means that the resource grows slowly when the stock is too large due to congestion, or when the stock is too low and the growth is hindered by a reduced population; and grows at the highest rate when the stock is around half of its maximum or carrying capacity. This means in the context of the trade model, that when the stock is high (equivalently, the price of the resource good is low) additional efforts would increase output of the good that uses the renewable resource. However, after a certain threshold, steady state output of the resource good falls in the South as it employs more labor in this sector (which happens when the price of resource good is high and the stock in the South is low). Thus, the authors show, that Chichilnisky's result (South loses with trade while the North gains) is changed, when the price of the resource is high and the resource in the South is depleted. In this latter case, the North is more productive in the good that uses the environment, exports it, and both countries gain with trade.

Note that in these North-South trade models the North that is externality free always gains with trade. The South does not have a real comparative advantage in the good that uses the environment (more intensively), and if it exploits it loses with trade.

⁶ Brander and Taylor (1997a) presents the same model under the assumption of small open economy taking international prices as given.

When the North exports the environment good, trade is efficient, in the sense that it follows real comparative advantages, and is thus beneficial for both countries.

2.2 South-South Trade Models

When both trading partners have an environmental externality, the possibilities expand: trade can be beneficial for both partners, to only one, or even reduce welfare vis-à-vis autarky for both countries.

Brander and Taylor (1997) present a model where both countries have an open access externality, but have different endowments of production factors: labor and natural resources. This endowment differences will motivate trade. Here the country with more natural resources (higher natural growth rate of the resources) relative to labor, exports the resource good as expected. The country that exports the resource good loses with trade, while the other country gains. Thus if in an after-trade equilibrium the resource exporting country imposes an export tax, it will gain from it, and make the importing country lose. Furthermore, if the resource importing country imposes an import tariff, it will always benefit the resource exporting country, and may cause the importer to lose or gain from trade (i.e. the tariff may be Pareto improving).

Karp, Sacheeti, and Zhao (2001) present a South-South model where trade is motivated not by differences in endowment of productive factors, but by varying levels of the environmental externality, and environmental stock level. The authors build on the work of Chichilnisky (1994). They assume fixed proportions technology for the final goods, and they assume that one good is a subsistence good, consumed only to a maximum level. Additionally a Cobb-Douglas technology is assumed for the production of the intermediate environmental good, and they model the property rights externality in

a way that it can vary from extreme open access to more moderate property rights problem. First, they show that, in autarky, when the stock of the resource is more abundant the level of the environmental externality (property rights problem) does not affect the steady state level of the resource, but it does when the resource is very depleted. On the other hand, when the countries trade, the level of the externality will always have an effect on extraction levels, regardless of the initial abundance or scarcity of the resource.

The authors do not limit their analysis to steady states; so many possible trade outcomes are possible. We can delimit them into two groups efficient trade patterns (when trade is originated by real comparative advantage, and not generated by the property rights externality), and inefficient ones. Under inefficient patterns the country with a higher degree of environmental externality always loses from trade, but also can “pull down” the other and also make it a loser from trade. If the patterns of trade are efficient, then both countries can win or at the least one is indifferent and the other gains from trade. The results of the model can be conveniently organized according to the regeneration capacity of the renewable resource. When the environment has low growth (i.e. it is fragile) long run free trade and autarky levels are identical. For levels a bit higher of growth rate, both countries lose from trade. For still higher environmental growth levels, there exist initial conditions (initial stock levels) that can make both countries gain from trade. For even higher environmental growth rates (resilient environment) the country with the greater environmental externality always loses under free trade, while the other always gains (as in North-South trade models).

2.3. Treating the Environmental Externality as Endogenous

The next step in North-South trade models is to treat the environmental externality, the lack of environmental policy or property rights as endogenous. The first determinant of the existence or lack of environmental policy is of course income: the wealthy North has property rights, while the less wealthy South does not. Copeland and Taylor (2004) attempt to answer the question: What are the other determinants for the absence of property rights in renewable resource extraction?

The authors assume that there is always a property rights regime (government assigns extraction permits), but agents can cheat, so there exists a different *de facto* property rights regime determined by the amount of cheating. They show when trade occurs, and the price of the good that uses the renewable resource intensively is raised, countries may or may not improve the *de facto* property rights regime. In the losing spectrum there are countries that regardless of how high the price of the resource is raised will never improve their *de facto* open access regime. These countries are characterized by a large number of agents that can extract the resource, agents with a short life span, a government with limited ability to punish cheaters, and a renewable resource with a low intrinsic growth rate. At the opposite side, countries with strong governments, a very reproductive environment, and few but long lived agents, can change from open access to perfect property rights regime for high enough international price. There are some countries in the middle, that can improve their property regime, but never achieve perfect property rights regime. Thus when the South opens to trade and enjoys higher price of the resource using good, the latter two types of countries earn unambiguously with trade,

both from the standards gains from trade as well as from the dynamics gains accrued from the improved property rights regime (i.e. extraction rents).

2.4. Multiple Equilibria

One of the reasons so many different welfare outcomes occur in the Karp, Sacheti, and Zhao (2001) model, is that their assumption of fixed proportions technology, and a subsistence good with maximum consumption level, translates into multiple possible equilibria in the renewable resource, both under autarky, and under trade. The possibility for multiple equilibria is more than a theoretical curiosity; it presents the possibility for trade to cause severe environmental depletion or even collapse.

Copeland and Taylor (1997) present a case where trade induces multiple equilibria, while under autarky this possibility does not exist. In their model a small open economy produces two goods, one of them a polluting good. A benevolent government taxes emissions optimally, in a static sense. However, pollution also affects natural capital which is used as a factor of production in the non-polluting sector. The government internalizes the effect of pollution in welfare, but not the long-run effect of pollution on natural capital (a renewable resource): as in standard renewable resources model there is a property rights externality. In autarky the economy will have its natural capital move towards a unique steady state. When it opens to trade two different outcomes are possible. First, if the externality is weak, (which in this model corresponds to low productivity of natural capital, the one affected by the long-run externality), then opening to trade would produce the standard North-South models results. If it exports the polluting good, the economy has short terms gains, and over time the reduction of natural capital may completely offset these gains. If the country exports the non-polluting good it

will have short and long-run gains. However, if the externality is strong, as defined by a high productivity of the non-polluting industry, for the same autarky price, the same steady state becomes unstable. Outside that unstable equilibrium there are two different stable equilibria: the country either finishes in a low equilibrium with very low natural capital; or the opposite, it specializes in the non-polluting good. The welfare effects are exactly opposing, big long-run losses in the former case, and important long-run gains in the latter.

In Karp, Sacheti, and Zhao (2001), multiple equilibria is a result of the assumed technology together with low reproductive ability of the natural resource. In Copeland and Taylor (1997) multiple equilibria is a result of a large dynamic externality and trade, which for a small open economy de-links allocation of factors of production, output and relative prices. This type of results provides arguments for those who oppose trade, viewing it as an agent of environmental destruction, or can even provide economic explanations for known environmental breakdowns, like the one believed to have occurred in Easter Island, for example.

3. Trade and Transboundary Pollution

Transboundary pollution is understood by economists as a public bad. Public goods get undersupplied because economic agents can not preclude their use by other agents. Thus, to avoid free riders public goods get supplied in a smaller quantity than what is socially optimal. Equivalently, the public bad pollution gets over supplied when its transnational effects are not internalized. Put in a different way, the public good: transnational environmental quality gets undersupplied (less than optimal abatement effort) because

not all of the benefits can be excluded by the ones who carry the burden of the cleaning effort.

In the presence of transboundary pollution, free trade is not optimal. If country A grants free trade (zero tariffs) to country B, then, since country B does not suffer from the transboundary effects, it will have the incentives to pollute more than what is optimal, both from a global perspective, as well as from the point of view of country A. This result was formalized early by Markusen (1975a), who presents the optimal tariff structure for the country suffering from transboundary eyesore pollution (that pollution that affects welfare, but does not affect the country's production possibility set). Two caveats are highlighted by the author: the outcome is not Pareto optimum, which would involve cooperative solutions; and the author assumes that the other country does not retaliate with tariffs of its own. In Markusen (1975b) the author explores other second best instruments to deal with transboundary pollution, like consumption and production taxes.

If countries internalize through policy the domestic effects of pollution, but not the transboundary effects, then trade is likely to benefit the country that specializes in the dirty industries, while it reduces the welfare of the country that specializes in the clean goods. If countries are equivalent in every respect but initial endowment of income, this means surprisingly, that the rich country loses with trade, while the poor country gains. This result is formalized in Copeland and Taylor (1995), with a model that is an extension of Copeland and Taylor (1994). There is a continuum of goods produced with Cobb-Douglas technology using emissions and labor, and indexed between 0 and 1 according to their emission intensity. Consumers are affected by local pollution but also by a share of world pollution. Firms must pay for their emissions purchasing pollution

permits priced at the local marginal damage, so that they internalize the damage caused by pollution within their boundaries (governments choose a permit price that maximizes welfare taken other countries' emissions as given), but the problem of global transboundary pollution lingers as a global public bad. Countries differ only in their endowment of labor which is understood as effective labor (raw labor times human capital), so that the rich nation is better endowed with labor. In autarky all countries generate the same amount of pollution regardless the amount of human capital: countries with higher human capital increase the demand for pollution permits, but the ensuing higher income reduces the pollution consumers are willing to accept raising taxes and moving the production towards cleaner goods (all are perfect substitutes). When countries open to trade the poor pollutes more, the North pollutes less, and world emissions remain unchanged (unless there is no factor price equalization in which case global pollution increases, note that this would occur if the world distribution of income was highly skewed). The South improves welfare from increased revenues from pollution permits, while the North is made worse off with trade: less permit revenues and more transboundary pollution (this is consistent with the fact there is no local environmental externality). A final important result is that it takes just two player in this set of n global polluters for an agreement of emissions reduction to be welfare improving (i.e. only a unilateral emission reduction is welfare reducing). Of course the rest of the $n-2$ players (free riders) would always benefit from such an agreement.

Cross country differences in pollution damages generates comparative advantages. If one industry pollutes and affects the productivity of another clean industry, then the country that suffers less damage from pollution has a comparative advantage in

the clean industry. This concept is formalized by both Benarroch and Thille (2001) and Unterberdoerster (2001). Benarroch and Thille (2001) present a simple Ricardian model of trade, with pollution that differentiates both local effects as well as transboundary effect. There are two sectors, a dirty one (i.e. manufactures) that pollutes and affects the productivity of the clean sector (i.e. agriculture). Due to the pollution externality, the production possibility set is convex. Due to transboundary pollution, the relative price of goods does not always reflect the real comparative advantage. Thus there is a possibility for trade to cause the wrong or inefficient allocation of resources and direction of trade. In this case there is a possibility for both countries to lose with trade. When there is an efficient allocation of resources that reflect real comparative advantages, the country that remains specialized in the externality free, polluting good, wins with trade, while the other country may win if it specializes in the good that is non-polluting but affected by the externality. In other words the country that exports the clean good can win if it can earn large standard gains from trade, which in a Ricardian model requires specialization, to overcome the losses from the transboundary pollution. Thus there is a possibility for trade to be welfare improving for both countries, even though there is an externality.

Unterberdoerster (2001) develops a very similar Ricardian model, with a dirty industry affecting a clean industry, and differentiating local from foreign pollution. The main results are the same than that of Benarroch and Thille (2001), but he explores further the determinants for trade being welfare improving for both countries or welfare reducing for both trading partners. He shows that when demand for the polluting good is high, the country that exports the clean good can not specialize and thus loses with trade⁷.

⁷ Comparable results are presented in Chapter 3.

Also, if the pollution damage is strong both countries lose with trade. On the other hand, when the demand for the cleaner good is large, both countries may win with trade.

Intuition would suggest that in the presence of transboundary pollution, if one country reduces emissions, that would provide incentives to the other country to expand output and emissions. Gürtzgen and Rauscher (2000) show that this is not always the case. The authors adapt a Dixit and Stiglitz (1977) model of intra-industry trade with monopolistic competition and endogenous number firms to include transboundary pollution. They show that when country tightens environmental policy, the number of firms in the trading partner can actually reduce if fixed costs are large and/or the monopolists' mark-up factor is low, i.e. demand is elastic.

Obviously one of the important challenges for the future is to design policy, ideally in a cooperative framework to deal with transboundary pollution. As green-house gases emissions increase, eventually countries will have to deal with the global "tragedy of the commons". Cooperative solutions have not proven to be very successful, as the Kyoto protocol commitments are not being upheld by some countries like the US. In Europe, there is a new transnational authority, the Community's government that can tackle the international externality. Some European economists have thus studied incentive proof policy that could deal with transboundary pollution. Harmonization of environmental policy does not produce efficient outcomes; because it is more efficient to make more emission reductions where it is cheaper (see for example Eyckmans (1999)). On the other hand, equalizing environmental standards has the merit of being easier to impose and supervise. Also, under asymmetrical information between polluters and

policy makers the best policy could be harmonization of environmental policy (Bigano (1999)).

We can sum up the main findings in this literature by noting that trade in the presence of transboundary pollution is similar to South-South trade. Since both countries suffer from an externality trade can be welfare reducing for both countries. At the same time there is the possibility that trade improves the well-being of both countries, but in general that result requires either small transboundary effects or big standard gains from trade or both.

4. The Trade and Environment Policy Linkages

Given that bad environmental policy (i.e. existence of environmental externality) and barriers to trade represent two different distortions, initially economist suggested to deal with both problems separately (see for example Beghin et al. (1994)). Although first best treatment of these problems require that they be tackled with separate instruments it is necessary to deal with them jointly. As Copeland (1994) notes, it is well known since the 1970's that in the presence of many distortions an arbitrary reduction in any given distortion may reduce or increase welfare, because of second best problems.

4.1. Linkages at the National Level

Both Copeland (1994) and Beghin et al. (1997) study trade policy for small economies (that take prices as given) in the presence of environmental externalities (sub-optimal pollution regulation) using dual function: restricted revenue functions and expenditure function. Beghin et al. (1997) additionally explore other policy instruments like consumption taxes. Both find that one can not generalize results about trade policy in the

presence of both distortions. For example assume a country eliminates tariffs. That policy changes the composition of output, thus depending on whether the dirtier industries (more polluting) expand or contract the environment will improve or deteriorate. Although there will be standard gains from trade, the losses caused by a more polluted environment could over-compensate these gains for a net welfare loss. Thus additional assumptions are necessary to make welfare generalizations. For example, if all industries that are subject to trade protection (positive tariffs) are pollution intensive then a small equiproportionate reduction in tariffs will improve welfare. Also, if all industries that are subject to trade protection are pollution intensive then a small reduction in emission taxes in this sector is welfare improving. The intuition for the latter generalization is that the emissions taxes reduce the production of pollution-intensive sector which is indirectly subsidized by tariffs. The emission taxes reduction decreases the deadweight loss of the implicit production subsidy. The reader may refer to Copeland (1994) and Beghin et al. (1997) for additional generalizations.

Two conclusions can be highlighted from the previous two examples. First, environmental policy and trade policy are (imperfect) substitutes. Given that dealing with both distortions with one instrument is second best, only small changes in the policy instruments are welfare improving. Both papers highlight that small *coordinated* movements in both instruments toward first best are always welfare improving. The first best policy is to get rid of the trade distortion with zero tariffs (small country case) and to use emission taxes equal to marginal damage.

Zhao (2000) generates the same conclusions but modeling the environmental distortion as an open access externality and using iso-welfare curves which is a nice

graphical tool that captures the necessity of coordinating policy in one easy to understand image. What the iso-welfare curve shows is that coordinated reform toward first-best is always welfare improving. Also, it shows that large reductions in any one distortion, while keeping the other constant, is welfare decreasing. The message is that if a country suffers from large environmental distortions (for example no pollution regulation) and completely eliminates tariffs and opens to trade, most likely it will reduce well being rather than improving it.

Thus, at the national level the benevolent policy maker must link both environmental and trade policy.

4.2. Linkages at the International Level (Strategic Trade Policy)

Let us begin by noting that in practice there are international linkages between trade and the environment. There are several trade agreements that contain environmental provisions, like NAFTA, European Union. There are also some environmental agreements that contain trade sanctions like the Montreal Protocol on Substances that Deplete the Ozone Layer, or the Convention on International Trade in Endangered Species (CITES) that bans trade of certain endangered species and by-products like ivory and furs. Some authors in the policy world consider that these linkages are necessary to create credible threats necessary to make international law that deals with global environmental problems, and possibly as a tool of a future World Environment Organization (WEO), (see for example, Runge (1994)). On the other hand, the WTO has been consistent in not accepting differences in environmental damage of a product's

production process as a ground for trade exceptions⁸. For the international organism, a product x is product x if it was produced with very clean or very dirty technology.

Many incompatibilities and challenges linger in the plane of international law. However, theory suggests that trade agreements should be linked to environmental agreements because environmental regulations may be used as an instrument to hide subsidies and gain international market shares. The GATT and later the WTO in their effort to facilitate trade have banned the use of non-tariff trade barriers and export subsidies. As we have indicated before, environmental policy can be used as an imperfect substitute of subsidies, and thus can be used to hide export subsidies.

The concept of strategic environmental policy has been formalized by Ulph (1992), Barrett (1994), Rauscher (1994), and Copeland (2000). Strategic environmental policy refers to the use of environmental policy to help domestic oligopolistic competitors gain market shares. These models are based in Spencer and Brander (1983) and Brander and Spencer (1985) that show how by subsidizing these firms directly or supplying R&D subsidies to their sector, the firms can be turned from Cournot-Nash competitors to Stackelberg leaders. Rents are shifted from foreign firms to domestic firms increasing welfare. With strategic environmental policy instead of offering a direct subsidy (not allowed by a trade treaty like GATT), firms are granted emissions taxes which are below the environmental damage as a hidden subsidy (this has been called “environmental dumping”). Since there is a negative welfare effect from excess pollution

⁸ See for example the high profile Tuna-Dolphin case between the US and Mexico (Rugman (1994) and Sampson (2000)). Following the Marine Mammals Protection Act (MMPA- 1972) the US embargoed imports of tuna from Mexico because they had as by-catch more than 1.25 times the dolphins’ by-catch of US fisheries. Mexico disputed this ban in the WTO (1991). The WTO found that the US measure was not valid because the ban was based on the process not the product, which violates the equal treatment of products provision of the GATT. The US did not abide by the ruling.

firms are not granted enough emission allowance for them to become Stackelberg leaders, but they are still allowed to expand output to levels above the Cournot player capturing additional rents at the expense of other competitors, and most importantly, the local environment.

However, if one considers the general equilibrium effects it is not clear that always the policy to apply to expand the output of the oligopolist sector is to weaken their environmental standards. Rauscher (1994) shows that by weakening the environmental policy of a sector, it makes the good produced by in it cheaper, and that reduces the marginal returns of the factor employed there, forcing them to migrate to the other sector. This latter effect could overcome the direct effect of expanding output because of cheaper production. Similarly, Duval and Hamilton (2002) show that with asymmetric partners, the best strategic behavior may be to reduce environmental taxes to shift the tax burden to the trading partner.

Copeland (2000) expands the discussion by showing in a two country scenario, that if the other country also subsidizes their oligopolist with strategic environmental policy, then they may end up in a new lose-lose Nash equilibrium. Countries lose, because as both expand output their monopoly rents are shrunk, and they further lose because of environmental deterioration: a classic prisoner's dilemma case. In the presence of strategic environmental policy free trade may be welfare reducing. Tanguay (2001) shows that in the absence of the trade tariff instrument, countries will play the strategic game with only one instrument, the environmental tax. In their efforts to grab monopoly rents, governments will end up choosing lower environmental taxes, and

consequently pollution increases and welfare declines as compared to a restricted trade scenario: the prisoners' dilemma again.

Although, they have not been formalized in the literature, one can think of more scenarios where environmental policy can be used as strategic trade policy. For example, if an industry has economies of scale, it might be beneficial to subsidize it to drive competitors out of the market.

The policy implications of strategic environmental policy are straightforward. If countries commit to trade policy establishing tariffs and subsidies levels, they must also commit to environmental policy. This trade and environmental policy linkage is necessary to avoid countries gaining unfair market power, or even worse, end in a case of trade wars, where not only trade gains are lost, but furthermore, the environment is depleted.

This issue of "environmental dumping" is extremely tricky. What constitutes environmental dumping is not that countries have different environmental policy, but that they impose an environmental policy that is more lax than what is optimal for that country. Differences in environmental policy are expected to be observed, for the same reasons that there are comparative advantages: countries have different endowments of resources including the environment. For example it is natural to expect for a poorer country to have weaker environmental policy, because at its income level it is efficient for the country to trade off more pollution for additional income. Also, the ability of countries to absorb the environmental damage of output varies. For example the marginal damage of additional pollution is much higher in cities that are enclosed like Los Angeles, Santiago, and Mexico City, than in cities with good ventilation like New York.

Furthermore, measuring if the environmental policy is too low is at best, very difficult. It must be shown that for given preferences, income level and the environment's ability to regenerate, the policy is too lax, i.e. taxes emissions below their marginal damage. At the current state of the art, we do not know how to value the environment accurately (although non-market techniques can provide lower bounds); nor do we know the real extent of the damage of pollutants to the environment, beyond their effect to human health.

There is some empirical support for linking trade and environmental agreements. Abrego et al. (1997) construct a Computed General Equilibrium (here forth CGE) model and allow for a repeated game to occur to determine trade and environmental policy. They study the effects of this policy on welfare, under different bargaining strategies: non-cooperative, bargaining over trade (Nash equilibrium), bargaining over trade and the environment (Nash equilibrium). In the model the South owns all of the environmental resources and it uses it to produce both the traded and non-traded good. The North does not use the environment as an input, but has a valuation for it. Results indicate both regions gain from expanding the trade bargaining set to include environment. However, compared to bargaining with cash side payments, linking trade and environmental policy through negotiation provides significantly inferior developing country (South) outcomes. Thus, in presence of non-use valuation of the environment by the North, a trade and environment policy-linked negotiation may be better than an environment-only negotiation, but negotiating compensation to developing countries for environmental restraint would be better.

5. Political Economy and Policy

Usually, the gains from trade are not equally distributed among factors of production, as the Stolper-Samuelson theorem highlights in the Heckscher-Ohlin model. This redistribution of income brought about by trade also changes the political economy equilibrium, which may under certain circumstances improve environmental regulations and ultimately the environment. Furthermore, if the effects of environmental damage affect different groups of society with varying intensity (or some groups do not care about the damage), then there are incentives for these groups to compete and lobby for the policies that are more beneficial to them. These political economy linkages between trade and the environment are receiving an increasing amount of attention from economists.

Consider the case that pollution is originated by consumption, and only a group, “the greens” care about pollution (or are affected by it). Further, assume that home production is protected by a tariff. Hillman and Urpsprung (1992) show that in this case “the greens” would lobby for higher tariffs, because that would reduce consumption if as assumed foreign and local goods are less than perfect substitutes. The authors argue, that the more probable end result is that “the greens” displace the producers of the good in the lobby effort for higher tariffs, i.e. they free-ride the “green’s” lobbying. These results change dramatically if pollution is assumed to be caused by production. In this case, the greens want free trade to displace contaminating production as much as possible to the other country. However, the trading partner’s greens behave similarly, and the result is a prisoners’ dilemma Nash equilibrium for the greens with both countries choosing free trade and maximizing pollution. However, if there are spillovers (transboundary

pollution), the greens in both countries would lobby for protection, or if they can lobby for environmental policy, the greens would lobby for less stringent environmental policy (i.e. lower pollution tax), see Conconi (2003).

Although, the efficient policy to control pollution is an environmental tax equivalent to the social marginal damage, Hoekman and Leidy (1994) argue that for political economy reasons this is not the more likely instrument used. The authors argue that quantitative restrictions are many times preferred because they are easier to enforce, and may appear as the more secure way of achieving emission reductions. The large deadweight losses that accompany inefficient policy may be reduced by the government by providing increased trade protection to the polluting and import competing sector. Thus the authors argue that inefficient environmental policies may be chosen for political reasons at the expense of free trade.

Fredriksson (1997) and Fredriksson (1999) explore the political economy competition for emission taxes when pollution is a by-product of production, and groups of society are affected differently by pollution. In this setup, greens of course want tight environmental policy to reduce pollution that decreases its welfare, while industrialists want lenient environmental policy that would allow them to increase output and increase rents. Additionally there is a government that maximizes a combination of social welfare and rents from lobby contributions (in a similar setup to Grossman and Helpman (1996)). In Fredriksson (1997) the author shows, that if all of society were a member of either lobby group then the pollution tax would not deviate from the social optimum. However, if this is not the case, than the higher the weight the Government gives to contributions relative to social welfare, then the further apart from its optimal level the pollution tax

will be. That is as far as unambiguous relationships go. The political economy considerations bring counteracting forces into the comparative static of trade. For example assume that the environmental lobby group grows. It would be expected for the pollution tax to increase because (i) the disutility from pollution grows among the greens, and (ii) social welfare is more heavily affected by pollution. However there is a counteracting political economy effect (iii) a greater share of the tax revenues are rebated to the greens, which would want this group to prefer a higher tax. In Fredriksson (1999) the author explores the change in the pollution tax given a change in the trade policy. Note that, the pollution tax competition happens *given the trade policy*. Again, the effect of trade reform (reducing tariffs) has ambiguous effects over the pollution tax. Assume the production of the protected and polluting sector decreases after tariffs are reduced (as expected); then one side, the environmentalists lobby effort for a higher pollution tax is reduced because production falls *ceteris paribus*. On the other hand, the industrialists also reduce their lobby effort for a lower pollution tax as the tax affects less produced units. There is a final effect on rebated tax revenues; if the tax elasticity of revenues increases there is political economy effect pulling for a higher pollution tax.

Bommer and Schulze (1999), provide an example of how trade opening may cause tighter environmental policy to re-establish a political economy equilibrium after one sector receives all the gains from trade. The author develops a model with two sectors each with a fixed factor, and competing for labor. One sector, the export sector, additionally uses the environment for production, which is subject to a quota restriction as an environmental policy. There are four sectors lobbying for an environmental policy (quota) *given the trade policy*, the export sector and labor, that want lower environmental

standards, and the import competing sector and the environmentalist that want tighter environmental policy. The government chooses the environmental policy, given the trade policy, maximizing a welfare function that weighs the welfare level of all four lobby groups. As a consequence of opening to trade there are windfall gains for the export sector and labor, and losses for the other groups. In order to re-establish a political maximizing equilibrium, the government trades off some of these gains to the harmed sector by tightening environmental controls. Note however, that these results would be completely reverted if the sector that used the environment was the import competing sector, in that case as a result of opening to trade environmental policy would be relaxed to re-establish the political maximizing equilibrium.

Aidt (1998), with a very similar framework to that used by Fredriksson (1997) explore the more general case where lobby groups bid for both a pollution tax and a production subsidy (which can be understood as a protective tariff in an open economy). This exercise highlights the importance of targeting externalities with the right instrument. When there is political competition for both instruments simultaneously, only the pollution tax addresses the environmental externality, while the production tax/subsidy plays exclusively the role of distributing income. Of course, for the same political economy reasons the chosen pollution tax is different from the optimal Pigouvian rate. Schleich (1999) studies a very similar model, with a government choosing simultaneously trade and pollution policy, but instead of pollution affecting only the environmentalists, like in Aidt (1998) and Fredriksson (1997), all agents suffer disutility from pollution. In this case, the optimal pollution tax is also a deviation of the Pigouvian tax, but now the optimal trade policy is no price distortions with zero

tariff/subsidy, even though lobby groups are competing for protection. All the income redistribution in this case is provided by the sector specific pollution tax. On the other hand, if pollution was caused by consumption, rather than production, then both the trade tariff/subsidy and the pollution tax are different from zero.

Damania (2001) expands the Fredriksson (1997) setup and allows the possibility for polluters to invest in more efficient abatement technologies. He shows that under plausible assumptions of abatement technology, when the costs of more efficient technologies are high, polluters invest less in abatement and redirect resources to more contributions to obtain lower pollution taxes. The intuition of this result lies in the fact that when the least efficient (abatement wise) have greater marginal benefits from a lower pollution tax. Additionally, lower investment in abatement technology acts as a credible threat for the government that profits are going to come down and so will political contributions. A government that values these hand-outs will lower the environmental tax.

Another linkage that could be beneficial for the environment is provided by the median voter, which is rational to believe in most countries is not a manufacturer or capital owner, but rather a consumer. As such, he receives only the externality of pollution, but not the direct rents from manufacturing goods. In a closed economy the median voter is willing to trade some weaker environmental policy for cheaper goods, but under free trade he would prefer zero pollution, because it would not affect price at he can buy the same imported goods (small country assumption). This idea is formalized by Yu (2000), in his model environmental regulations are tighter under free trade, but pollution is not brought to zero, because the government does not maximize its chances

of being re-elected (follow the median voter's policy), but has an objective function that maximizes chances of being re-elected and contributions from lobbies (including the manufacturing/polluting sector).

6. Trade, the Environment and Growth

This literature is mostly concerned with the feasibility of growth when one of the assets is limited by nature, i.e. has a maximum carrying capacity. Thus if the economy produces two goods, one that uses the environment, and another one that does not, is growth still possible? Trade is not the main concern; however, trade makes growth feasible. López, Anríquez and Gulati (2001), show with an endogenous growth model that growth requires structural change, that is, as productivity grows labor must migrate to the non resource using sector in order for growth to be feasible. The authors make the small open country assumption, thus trade allows the growing country to free ride on the rest of the world, by allowing the growing consumption demand for the resource good to be filled by the rest of the world. This main result is confirmed by McAusland (2005) who assumes exogenous productivity growth in both the resource and non-resource sector. She shows that growth is not possible in the closed economy, however it is possible in the trading economy, as long as the country does not specialize in the resource good. She highlights that in the growing economy, labor employed in the resource sector must be shrinking over time.

Eliasson and Turnovsky (2005) present a more *ad-hoc* model, because they assume that productivity only grows in the non resource sector, and that the resource good is basically exchange coin for foreign consumption good. Under these assumptions the more labor in the non-resource good (without productivity growth) the lower the

growth rate of the economy. The authors show that under these assumptions, there is a fixed optimal allocation of labor, so as the non-resource sector grows there is a relative contraction of the resource sector.

7. Other Trade and Environmental Linkages

We now review other mechanisms presented in the economic literature by which trade can affect the environment.

7.1. The Terms of Trade Argument

Some authors have shown that very restrictive environmental policy may be pursued to restrict the output of an exported good that uses the environment and gain terms of trade benefits, assuming the country is big and can exert market power.

Alpay (2000) presents a simple Ricardian model with three goods produced, in a two country setting. Two are normal goods that can be traded, and another is environmental quality. Welfare depends on the goods that can be traded and the environmental quality, both: the one produced at home as well as the one produced abroad. Thus, the environmental good is a public good, that as is standard without cooperative behavior gets under-supplied. When countries trade, they may end supplying more of the environmental good than under autarky. This happens because there is a terms of trade incentive. By producing more environmental good one country reduces the supply of the good in which it is specialized, improving its terms of trade; also this effect is augmented by strategic behavior as the other country behaves just like the other. Thus free trade through this term of trade effect can improve environmental quality, and under

certain parameter restrictions, it can supply more environmental quality than in a cooperative game.

The balance in Alpay (2000) model is skewed towards environmental improvement, because the Ricardian model forces specialization in the traded goods, and all the terms of trade effect is channeled through the reallocation of resources from the traded sector to environmental investment. Rauscher (1994), shows the same result in a standard Heckscher-Ohlin framework where the factors of production are capital and emissions. In a Heckscher-Ohlin setting, if a country wants to improve its terms of trade it has to increase the relative price of the good that uses intensively the factor with which it is relatively well endowed (i.e. the good it exports). Thus a country well endowed with environmental resources should use a restrictive policy in the use of the environment, the opposite of environmental dumping. Note however, that the country relatively well endowed with capital should apply environmental dumping.

The terms of trade argument may apply in certain types of trade. What is important for it to be a relevant issue is that one country or a small group of countries own a big share of the world supply, in order to affect the world price. For example, OPEC country behave accordingly in their supply of oil (a non renewable natural resource), and one may conjecture it was the policy pursued by South American countries in early 20th century when they enjoyed the monopoly of natural rubber.

7.2. Debt, Resource Management, and Trade.

Rauscher (1989) points to another trade and environment link that is especially important for small open countries that are exporters of renewable resource intensive goods. He shows that the level of public debt that a country manages determines the speed at which

renewable resources are depleted. The target steady state level of natural resources that the country would like to preserve is independent of the level of debt, as it depends on terms of trade, preferences and technology. However, during the transition phase when the stock of natural resources is being harvested; the level of debt determines the speed and effort spent in extracting renewable resources. The author shows that during transition if debt increases, so does the rate of extraction of renewable resources. That is, if public debt increases it is worthwhile for the country to reduce the debt faster, shifting extraction of the exportable resource from the future to the present. Obviously debt relief would have positive environmental effects, as extraction can be shifted from the present to the future.

II.- Empirical Analysis

1. Patterns of Trade and Industry Location

From the literature described above, the researcher expects to observe with the greater factor mobility and growth of trade among nations a constant migration of pollution/environment-intensive industries from the developed world to developing countries. Developing countries are poorer; because of income and political economy considerations have weaker environmental regulations; and in general, as a consequence of being in earlier stages of development have more abundance of environmental resources. For all these reasons, a growing share of the dirtier goods should be produced in the developing world. This phenomenon has been called: the “dirty industry migration” or “industry flight”; “displacement” of industry, when it is the tightening of

the controls in developed countries that causes it; or “pollution haven” when it is the lack of regulations in the developing world that attracts the industries. Although there is broad theoretical support for this industry migration, the empirical evidence is rather mixed.

During the 1970’s and 1980’s some research was conducted among these lines, we briefly mention the most important results of this work, while focusing in the work published in the last decade⁹. Early studies found that the environmental abatement costs relatively to total cost were rather low. Walter (1973) estimates that environmental control costs relative to total costs of export goods were 1.75% (using 1968-1970 data). Robinson (1988) supplies some support for the industry migration hypothesis showing that in the US, between 1973 and 1982, pollution content of imported goods rose faster than the pollution content of the exported goods. In other words, during the period there was a shift in US trade towards importing relatively more pollution intensive goods. Tobey (1990) uses a Heckscher-Ohlin-Vanek model and a cross section of the most polluting industries (those whose abatement costs are higher than 1.85% of total production costs) from a pool of 64 standard industrial and agricultural sectors, covering 23 countries. Different regression analysis tests suggest that environmental control is not a valid variable in explaining the patterns of trade.

Lucas et al. (1992) present evidence of polluting industry relocation, but they do not link the phenomenon to trade. The authors first calculate emissions per industry by linking Environmental Protection Agency’s (EPA here forth) Toxic Release Inventory (1987) data to industrial census (1987) data, to calculate total toxic emission per dollar of

⁹ The 1970’s and 1980’s research is more completely covered in earlier literature surveys, Dean (1992) and Xing and Kolstad (1996). Less comprehensive in this area, but also a good previous literature survey is Beghin et al. (1994).

output for different industries in the US. Then they assume that these pollution intensities remain constant through time (1960-88) and across countries (56 countries) to prepare a panel data set of toxic pollution per country and through time. Next, the authors review the effect of trade liberalization on toxic emissions. They conclude that although developing nations as a whole had greater toxic intensity growth during the 70's and 80's this trend was more pronounced in fast growing closed economies (i.e. trade would not have caused the toxic industry flight). Birdsall and Wheeler (1992) use Lucas et al. (1992) data for an empirical study of pollution intensive industries in Latin America. The authors regress the growth of toxic intensity of output on income growth, measures of openness to trade, and other control variables. They reach similar conclusions to that of Lucas et al. (1992): slow and closed economies exhibit faster toxic intensity pollution growth, while open and fast growing economies show lower toxic emission growth.

Low and Yeats (1992) explore the hypothesis of dirty industry migration by examining world trade data from 1967-68 and comparing it to 1987-88. They create a revealed comparative advantage index per industry: ratio of the country's share of export in one industry (i.e. country's export in that industry over the world total exports of that industry) to the country's share of total exports (i.e. country's total exports over world's overall exports). If the index is greater than 1, it is assumed that the country has a revealed comparative advantage in that industry. The authors study the evolution of the index for the five dirtiest industries according to the EPA's Toxic Release Inventory: iron and steel, nonferrous metals, refined petroleum, metal manufactures, paper and articles. The main conclusions are that: (i) the amount of countries with revealed comparative advantages in dirty industries has been growing; (ii) dirty industries account for a

growing share of exports in some developing countries; while at the same time *(iii)* the share of dirty industries in total exports has been declining over time. Thus, the authors provide support for the hypothesis that dirty industries have been migrating, but they do not link it either to tougher environmental standards in developed countries (displacement) or opening to trade.

Grossman and Krueger (1993) repeat a similar exercise to that performed by Tobey (1990): check the effect of environmental regulation on trade flows, in their case import penetration by industry. Grossman and Krueger use data on US imports from Mexico, and confirm Tobey (1990) results, that environmental policy has no effect over the trade flows.

Mani and Wheeler (1999) present evidence for the displacement theory, that is, tougher environmental standards in richer countries have forced polluting industries to relocate in developing nations with weaker regulations. The evidence comes from showing that in OECD countries the polluting to non-polluting output ratio has been falling, at the same time that the import to export ratio of polluting industries has been growing in the 1960-1995 span. The industries identified as most polluting are the top 5 of the EPA's Toxic Release Inventory. The support for the displacement theory is closed with evidence that the polluting to non-polluting output ratio has been growing in general in Latin America and in Asia (excluding Japan), and the import to export ratio of polluting industries has been falling in these same regions. However, the authors do not do a good job in convincing the reader that it is environmental regulations that cause this regional relocation of industries, since as they recognize different factors could explain the phenomenon: *(i)* income growth and the low income elasticity of demand of pollution

intensive industries; *(ii)* the rise in the prices of energy and land (polluting industries are intensive in these inputs); *(iii)* tougher environmental standards (mostly since 1970s).

Wheeler (2001) supplies evidence that apparently contradicts the dirty industry migration hypothesis. The author shows that the countries that receive the greatest share of the world's overall foreign direct investment (FDI): Brazil, Mexico and China, have actually shown a reduction in the levels of urban air pollution (particulate matter).

The fact that different regression analysis shows that abatement costs, or environmental controls do not explain trade flows (Tobey (1990), Grossmann and Krueger (1993)) has puzzled researchers. A possible explanation is that higher abatement costs are not necessarily associated with reductions in output due to general equilibrium forces could be off-setting the intuitive result. Eskeland and Harrison (2002) show that when abatement costs rise, there is a substitution in production towards other factors, i.e. capital, if these factors are less polluting, they could reduce marginal costs, more than the rise in marginal costs produced by the hike in abatement costs; an unlikely but possible scenario. The authors, study foreign investment from US to Mexico and Venezuela, and French Investment to Morocco and Côte d'Ivoire discovering that these flows are not explained by the abatement costs these industries face in their homelands. The authors are not surprised by the result, because as they argue previously larger abatement costs ought not to be unambiguously related to higher marginal costs.

Another possibility, for the ambiguous result of environmental policy explaining trade flows is provided by Levinson and Taylor (2001) and Ederington and Minier (2001), who argue that the economic theory we have reviewed above suggests that environmental policy is really endogenous. The strategic trade argument suggests that

environmental policy can be used as a trade instrument to protect industries. Additionally, the political economy literature suggests that environmental policy may be used to redistribute income among groups in society. For these reasons, previous work that treated environmental policy as exogenous was getting biased results, and could explain the apparent ambiguity. Levinson and Taylor (2001) examine US imports (1974-1986) from Canada and Mexico and show that when environmental policy is treated as exogenous it does not explain imports. However, when they treat abatement costs as endogenous the ambiguity disappears; industries with the biggest increase in abatement costs import more. Ederington and Minier (2001) carry out a similar exercise using imports from a cross section of all US manufacturing industries (1978-1992). The authors find that environmental regulations have a significant but very minor effect on trade flows. They find more specifically that environmental regulations (measured as share of abatement costs of total costs) increases imports, but the elasticity is very low 0.53. However, when they treat the environmental regulation as an endogenous variable, and estimate a system of two equations with an efficient method (imports and environmental regulations) they find that the effect of environmental regulations on trade flows is much larger; they estimate an elasticity of 35. Additionally, the authors find evidence that environmental policy is being used as an indirect instrument for protecting industries, as import penetration has a significant (negative) effect over environmental policy.

A different method to test the effect of environmental policy on industry location is to estimate the marginal effect of environmental policy in the observed location choice for industrial plants. Levinson (1996) applies a conditional logit model to explain observed plant location of US firms in the 48 contiguous states controlling for the other

factors that affect plant location like market size, infrastructure, wages, energy cost, etc. He uses different environmental stringency variables, with mixed result. However, both the FREE (Fund for Renewable Energy and the Environment) index of environmental law stringency and the industry's abatement costs, jointly and separately are significant (and negative) in explaining industry location choices. List and Co (2000) use the same method to explain plant location of foreign firms, that is, US inbound FDI. Their results are unambiguous as all the measures of environmental regulation used explain negatively foreign plant location decisions. That is, states with lower abatement costs, and states which spend less effort in regulating polluters have a higher probability of receiving new foreign plants.

We can summarize the evidence supplied by this empirical literature by recognizing that originally the evidence seemed mixed, but the later research seems to converge to accepting the hypothesis of industry migration. On one hand, there seems to be a well documented relative growth of pollution-intensive industries in developing countries. On the other, newer studies point to growth in the pollution content of imports of developed countries from developing nations (see Kahn 2003 and Muradian, et. al (2002)). Furthermore, as others have argued (see Cole et. al (2001)), the apparent lack of relationship between industry location and environmental regulations may be due to countervailing forces, factor endowment versus pollution haven. For example the chemical industry is very polluting, but requires ample supply of human capital; a developing nation may provide economies by allowing dirtier technologies, but be less endowed of the skilled labor production factor.

At the beginning of the decade the mixed evidence for the industry migration hypothesis was justified by low abatement costs relative to other factors affecting industry location such as tax breaks, price of inputs, proximity to markets, political stability, etc. It was also argued that the growth of pollution in developing countries (Lucas et al. (1992)) could be justified by the development path rather than differences in environmental policy. However, the latest empirical research that more comprehensively collects the results from the theoretical literature and treats environmental policy as endogenous is showing that environmental policy does affect industry location and the patterns of trade.

2. Evaluating the Development, Trade, and Environment Linkages

A very useful tool in understanding the mechanisms by which trade affects the environment is decomposing the economic consequences of trade in scale, composition, and technique effects. This decomposition first suggested by Grossman and Krueger (1993), has been widely adopted by economists¹⁰.

The scale effects refer to the changes in pollution emissions caused by output expansion assuming the nature of economic activity remains unchanged. That is, a change in pollution is purely caused by the scale effect when all sectors of the economy expand in equal proportions and the technique to produce output remains unchanged. However this is an unlikely outcome after an economy opens to trade. Trade will cause sectors that enjoy comparative advantages to expand, while others contract, as factors are reallocated with the change in relative prices that the opening to trade encompasses. This

¹⁰ Grossman and Krueger credit Task Force on the Environment and the Internal Market (1990) for proposing a similar decomposition.

change in pollution caused by this modification of the structure of output is called the composition effect. Finally, the opening to trade and foreign investment is likely to change the technique used to produce output, changing the environmental damage by unit of output.

Many channels can explain this change in production techniques. For example, trade could bring the adoption of cleaner foreign technology. However, the main channel is through the growth in income. Although the empirical literature that examines it is not free of controversy, there is an overwhelming consensus that trade causes growth. Given that it is assumed that environmental quality is a normal good, as income grows after opening to trade, better environmental quality is demanded. Consequently, stricter environmental standards are imposed, which translate into the use of cleaner techniques or the investment in abatement efforts.

The scale effect is unambiguously environmentally degrading, the composition effect could either harm or improve the environment depending on the country's comparative advantages, and the technique effect has a positive effect on the environment. Thus, *a priori* one can not provide a definite answer for the question: Is trade good for the environment? For example, if the composition effects make a country leave the production of dirty industries and specialize in cleaner sectors, trade is then likely to be good¹¹. In any case, globally the composition effect brought abroad by trade should be neutral as what one country does not produce should be produced in another place. Furthermore, if the technique effect becomes stronger with development (as income grows) eventually countries would observe environmental improvement.

¹¹ Bandara and Coxhead (1999) provide an example (with a Computed General Equilibrium model for Sri Lanka) where trade is good to the environment because positive composition effects dominate.

Grossman and Krueger (1993) supply evidence with a cross country study that emissions of both sulfur dioxide (SO₂) and dark matter (smoke) grow with income until a certain threshold, above which emissions begin to diminish. Thus, emissions plotted with respect to income follow an inverted-U shape further labeled in the literature as an Environmental Kuznets Curve (here forth EKC)¹².

Certain technological conditions and preference structures must be assumed to observe EKCs. López (1994) shows that the environmental Kuznets curve result relies both on a high degree of technical substitution elasticity between dirty and clean inputs, and on the preferences side, a high relative risk aversion (curvature of welfare with respect to income). Also, welfare must be non-homothetic with respect to the environment and consumption goods. Alternatively, if the environmental improvement is thought of as the result of investment in abatement technologies, then that technology must show increasing returns to scale in order to observe a EKC, as Andreoni and Levinson (1998) show. Chavas (2004) using endogenous discounting shows that the EKC hypothesis is implicitly assuming the existence of alternative capital goods (engines of growth) that are less harmful to the environment. It is important to refer to these technical requirements, because they may not describe all industries or economies.

Grossman and Krueger's finding of an EKC has inspired a vast literature trying to confirm or reject the findings for different samples (countries and periods), pollutants, and measures of environmental quality. It is not within the scope of this survey to cover

¹² The original Kuznets Curve describes the relationship of income inequality with respect to income.

comprehensively this literature, but we can refer to the main findings¹³. Most studies find that the EKC seems to exist for sulfur dioxide (SO₂), as Grossman and Krueger (1993) show. This finding, however, has been lately rejected as the product of time trend rather than income (Stern and Common (2001)). The evidence is mixed with respect to particulate matter. Grossman and Krueger (1993) reject the EKC for particulate matter, but Wheeler (2001) provides evidence of EKC for particulate matter in developing countries. The evidence for CO₂ is also mixed, see for example Galeotti and Lanza (1999). EKC do not seem to exist for industrial water pollution (Hettige et. al (1999)) or for deforestation (Koop and Tole (1999)). Furthermore, anecdotal evidence suggests that EKCs do not exist (or we have not observed the turning point) for pollutants like trash per person, ozone, and other.

In summary, there does not seem to be a predetermined road to environmental improvement where trade or development could lead to. Trade brings about changes in the economy that could be either harmful or beneficial to the environment. If comparative advantages are mostly determined by differences in environmental regulations, trade is likely to be harmful for the environment. EKC may exist for some pollutants, especially those that have important harmful effects at the local level, like NO₂ related to acid rain, but its existence is not so clear for emissions with global effects, like CO₂, a green house gas.

¹³ See Nordstrom and Vaughan (1999), Levinson (2002), and Stern (2001) for a more complete coverage and summary of the empirical literature that has studied EKCs for different pollutants and environmental quality measurements.

3. Empirical Evaluation of the Effects of Trade on the Environment and Welfare

3.1. CGE Estimations

Many of the empirical assessment of trade effects on the environment and welfare have been carried out with the use of CGE models. These models vary in their degree of generality, their realism, and how well calibrated they are. Their results should be taken with caution, as they are only an approximation, and especially when they try to measure the effects of large changes in the variables of the models like prices. General equilibrium holds relations at the margin, so large changes of variables may cause substitutions that are not necessarily captured either by the model or the assumed functional forms. In general, CGE simulations confirm theory discussed above (as they should); for example, trade does not necessarily improve welfare or the environment when the environmental externality is not addressed; also, trade may provide welfare gains in the presence of the externality if large positive composition effects dominate. We now review this research starting from the most general estimations to the country case studies.

Cole et al. (1998) and Cole et al. (2000) provide the most general results of the effects of trade on the environment, calculating the effects of the GATT Uruguay Round on five air pollutants (nitrogen dioxide, sulphur dioxide, carbon monoxide, suspended particulate matter and carbon dioxide), and the monetary costs associated with this emissions changes. Of course such global results are very rough estimates and require brave assumptions. They first combine estimations on composition changes associated to the trade agreement (borrowed from the literature) with separate estimations on pollution intensity by industrial sector (Lucas et al. 1992), to calculate the composition effects of emissions. Then they use the estimated income effects (borrowed from the literature) and

econometrically estimate environmental Kuznets curves (assumed to exist for all pollutants) to compute what they call the combined technique and scale effect. Then they use estimates in the literature of the cost of pollution in health, labor, etc., to calculate the monetary costs of the pollution changes. They observe that all regions (9) are predicted to increase their nitrogen dioxide emissions, while sulphur dioxide, carbon monoxide and suspended particulate matter are predicted to increase in the developing world and fall in the developed world. There are overall costs associated to the trade agreement, especially in the case of nations that grow faster, that is when there are strong scale effects.

Perroni and Wigle (1994) also provide some general estimations of the effects of trade on the environment. The authors prepare a CGE model that incorporates environmental effects. There are three regions that trade goods. Production is affected by emissions, both produced at the local level, and also at the global level, i.e. transboundary pollution. The authors assume that governments charge an effluent tax for emissions, and that firms can pay to abate emissions. The authors also assume that the emission revenues are transferred not to the affected parties, but to the consumers where the emissions are generated (an efficient but unrealistic possibility). The model is calibrated with very low abatement costs, as estimated in the literature (Walter (1973)). The results are standard in this CGE models. Without payment for emissions (without solving the environmental externality) trade worsens the environment quality. The authors are very happy to show that the damage is very low. However this damage depends on the environmental damage function that is assumed; no such function has been estimated in the literature. Also without emission payments welfare improves with trade as environmental quality is not valued in the welfare function. When the environmental externality is internalized

through emission payments, there can be both environmental quality improvements and welfare gains with free trade.

There are many different CGEs that study the environmental and trade effects of policy in specific countries. We begin with one of the earlier such studies, Beghin et al. (1995), who apply a CGE model developed at the OECD and later also applied to Chile in Beghin et al. (2002). In this first paper the author use a dynamic and recursive CGE model for the Mexican economy including 9 sectors with different pollution intensities for 13 types of pollutants. The authors show that a unilateral trade opening would cause in the Mexican economy a composition change toward cleaner sectors, but the scale effect would dominate toward an overall more polluting end-result. Emissions taxes increase abatement, but cause overall income losses that vary by the type of emission targeted, but always with a negative income (output) effect. Linking emissions taxes with trade opening can result in both income gains and pollution reduction, the amount of the gains and the reduction of pollution varies with the type of emissions targeted. Very similar results are shown for Chile in Beghin et al. (2002), which actually has better welfare analysis because emissions are valued by their health impacts. Unilateral trade reform in Chile induces considerable worsening of the environment mainly caused by the cheaper access to imported energy sources. On the other hand trade agreements with NAFTA or the MERCOSUR have more benign environmental effects. Again, unilateral reform together with taxes on emissions (especially small particulate matter) can bring overall welfare gains.

There are different studies for Indonesia in the literature. Lee and Roland-Holst (1997), develop a CGE model that studies the trade pattern of Indonesia with special

attention to the bilateral trade with Japan. The authors first examine the patterns of trade between Japan and Indonesia, noting that Indonesia exports to Japan the more pollution intensive goods. Then they develop a three region (Japan, Indonesia and World) trade CGE model that includes emissions. The results indicate that unilateral trade liberalization by Indonesia would increase the ratio of emission levels to real output for almost all major pollution categories, which results actually in welfare losses. However, when tariff removal is combined with a cost-effective tax policy (that internalizes the environmental effects), the twin objectives of welfare enhancement and environmental quality improvement appears to be feasible. A more optimistic scenario is presented by Strutt and Anderson (2000) using a dynamic CGE. These authors, using a different model show that unilateral trade reform would actually improve air and water pollution over the horizon of 2 decades, and would slightly increase the degradation of renewable resources, even in the absence of policy directed to correct the environmental externality.

Dessus and Bussolo (1998) study the case of Costa Rica, also using a CGE. The authors find that environmental taxes alone, produce a small reduction in growth but sharply reduce emissions. On the other hand, unilateral trade reform, with across the board tariff reductions, promotes growth but also promotes specialization in dirty industries which translates into strong environmental damage. Like in the studies mentioned above, unilateral trade reform with the proper effluent taxes allows for growth and emission abatement.

Bandara and Coxhead (1999) develop a CGE model to study the effects of trade reform in the Sri-Lankan economy. The authors discover that unilateral opening to trade produces a win-win scenario for the country. That is, trade reform produces income gains

as well as environmental improvements. This rather unconventional result is explained by the dominance of positive composition effects. Unilateral trade reform in Sri-Lanka would increase the demand for land for tea production. Being tea a much less erosive crop, causes trade to be environmentally improving.

3.2. Regression Analysis

A completely different approach to measure the effects of trade on the environment is offered by Antweiler et al. (2001). Instead of using CGE measurements, the authors use world trade data to separately estimate composition, scale, and technique effects of trade on the environment, using regression analysis. The authors first develop the micro-foundations for pollution emissions decomposing the scale, composition and technique effects. They use this theoretical equation to estimate the determinants of Sulfur Dioxide (SO₂) emissions. The data comes from the Global Environment Monitoring System (GEMS) spanning from 1971-1996 and covering 44 countries, mostly developed. They conclude that trade has a positive impact on the environment as they show that a 1% growth in the scale of output causes 0.3% increase in pollution concentrations, while at the same time income drives concentrations down by 1.4% via the technique effect. To the surprise of the authors they show that trade in itself is overall pollution reducing, when theory suggests that the overall effect should be zero, that is the aggregate composition effect should be zero. However, the results of these authors should be moderated, they do not show that trade is good for the environment as they pretend, but only show that trade reduces SO₂ emissions. From EKC studies we already knew that SO₂ emissions always seem to follow the EKC pattern. Also, the fact that trade reduces

the emissions of one pollutant does not mean that it improves the environment, that result would require at least the same reduction pattern for a larger set of pollutants.

Frankel and Rose (2002) extend the analysis by treating environmental quality as endogenous together with income. They estimate a system of two equations treating per capita income and environmental damage as endogenous, using data from a cross-section of countries, unfortunately limited by the availability of data for the environmental damage indicators used: SO₂, NO₂ and particulate matter. In spite of the concern of selection bias, the authors provide results consistent with Antweiler et al. (2001), opening to trade appears to improve the environment as measured by SO₂, the result on NO₂ pollution is inconclusive, and there is no statistical relation between opening to trade and air particulate matter pollution.

Dean (2000) follows a similar methodology to show that trade reform (opening) has been beneficial to the environment (water pollution) in China. The author develops a 2 by 2 trade model where pollution, a factor of production, is endogenized with an implicit demand for environmental quality (tolerance of pollution), which as theory indicates depends on income, price of goods and environmental policy. Based on the model the author estimates a system of two equations where water pollution growth and income growth are treated as endogenous, using province level data from China (1987-1995). The specification allows the identification of both composition and technique effects. The estimations suggests that trade liberalization has a direct negative effect over the environment via the composition effect. However, trade reform causes growth in income, which then causes a reduction in water pollution (technique effect) greater than the increase originally caused by the composition effect. Thus, trade appears to be good

for the environment (reduces water pollution). One should be careful on generalizing these appealing results from China, because in China water pollution is taxed (which is why there is data on pollution), which reduces and potentially eliminates the environmental distortion.

3.3. Renewable Resources and Property Rights Failure

North-South trade models stress the over usage of natural resources, and the possibility of trade being welfare reducing under these circumstances. Unfortunately very few studies have attempted to measure the existence of this type of environmental externality, and the effects of trade under this externality. López (1998), and López (2000) provide empirical estimations of this environmental externality by joining observed economic behavior from household surveys and environmental (biomass) depletion from satellite data in poor tropical countries. López (1997), estimates a production function for farms in Ghana (1988-1989), with biomass as a factor of production. He uses the estimated function to test the hypothesis that land is being cleared (after fallow periods) at socially optimal levels, and rejects it for assumed discount rates lower than 50%. He shows both, that biomass is an important factor of production (estimated factor share of 15-19%) and that biomass is overexploited, which reduces productivity of land and consequently farm income. Using, the parameters estimated, and others borrowed from the literature the author estimates the effect over national income of both reducing export taxes on agricultural goods, and across the board trade liberalization. Not surprisingly, reducing export taxes would diminish national income, as increasing the local price of agricultural goods would augment the pressure over biomass, reducing even further the productivity of farms. More surprising is the result that across the board trade reform would also

reduce national income, that is, standard gains from removing price distortions, are less than the losses associated to the magnification of the environmental externality.

In López (1998), and López (2000), a similar exercise is carried out for Côte d'Ivoire (1985-1987). The author first estimates a revenue function for farms, where again biomass is a factor of production. The author shows that biomass is an important factor in production, with an implicit factor share estimated of 17%. Additionally, for reasonable social discount rates lower than 60%, the revenue estimation suggests that land is being over used, by clearing more forests and reducing fallow periods. Obviously this behavior results in sub-optimal productivity of land and lower rural revenues. In López (1998), the author argues that trade reform that improves the relative price of non-tree crops over tree crops, would increase land usage, magnifying the environmental externality, and potentially reducing national income. This issue is studied further in a general equilibrium framework in López (2000), where the author shows that complete removal of trade distortions increases real income up to 9% in the long run when land usage is in a new equilibrium.

4. The Political Economy of Environmental Policy

As Dean (2000), Levinson and Taylor (2000), Ederington and Minier (2001) argued, environmental policy can not be treated as exogenous. Furthermore, Fredriksson (1997) shows that environmental policy will deviate from the optimal depending on how the Government values social welfare *vis-à-vis* lobby groups' contributions. Damania, Fredriksson and List (2000) argue that this relative valuation of lobby contributions may be understood as corruption. Using a similar framework to Fredriksson (1999) the authors show that trade opening reduces the pollution tax if corruption is low, and the opposite

happens when corruption is high. The authors test this hypothesis estimating an equation for environmental policy (lead content on gas) for a time series pooled cross section of countries using different trade openness measures, a government honesty index, and other country characteristics as controls. The authors find evidence that their hypothesis is correct. First, government honesty tightens environmental policy, with a significant coefficient in all specifications. Furthermore, the cross product of the government honesty index and openness is always significant, and indicates that the effect of trade openness on the pollution tax depends on the degree of corruption of the government. Increased corruption amplifies the more stringent environmental policy effect brought by opening trade.

III.- The Ecological Economists' Critique

From the fringe of mainstream economics, ecological economists have constructed a body of strong criticism to the way most economists have studied trade and environment issues. Some arguments are better founded than other, but is a productive exercise to review them, because it highlights the strengths and weaknesses of traditional economic analysis of the trade and environment debate.

One of the most important criticisms coming from the ecological economics camp has been called the *race to the bottom* hypothesis¹⁴. They argue that mainstream economists focus just on trade, ignoring the fact that there is factor movement in the globalized world we live in. If factors are allowed to move freely across borders, then

¹⁴ A good summary of the ecological economics view of trade and the environment is given by Muradian and Martínez-Alier (2001).

traditional comparative advantages based on relative abundance of factors of production does not motivate trade, but instead absolute advantages do. Countries in an effort to gain absolute advantage will be forced to lower environmental standards, and labor standards as well, in a race to the bottom towards the lowest common denominator (see Daly (1993), Daly (1997)). Poor countries desperate for investments and jobs will lower their standards, while developed countries will be forced to lower theirs too in an effort to stop the exodus of capital, as the world falls in a vicious cycle of lowered wages and destroyed environment.

A well thought response to this hypothesis is given by Wheeler (2001). The author rejects the “race to the bottom” hypothesis, and its policy implication: equalizing international environmental standards and the possible use of trade as a coercive instrument. He first shows that in developing countries that captured most of the world’s foreign direct investment (FDI) in recent years (Brazil, Mexico, and China), pollution (particulate matter) has been decreasing over time; the opposite result to what the “race to the bottom” hypothesis predicts. The “race to the bottom” hypothesis is flawed, according to Wheeler, because: (i) pollution control is not a critical cost factor for most firm; (ii) even low income communities penalize toxic polluters, and even in the absence of regulation; (iii) rising income strengthens environmental regulation; (iv) local businesses sometime control pollution because abatement reduces costs; and (v) large multinational firms generally adhere to OECD environmental standards in their developing-country operations. We can add that although there is a more integrated worldwide economy, we are far from observing perfect factor mobility.

Nonetheless, there is certain theoretical support for the race to the bottom argument. Rauscher (1995) shows that when countries compete for industry location by offering tax rates for the environmental damage, the tax rate chosen varies from the cooperative tax rate. When the environmental damage is low, countries offer a lower rate than what would be optimal if countries chose the tax rate cooperatively and shared the benefits and costs of industry location. Furthermore, if there are large transboundary effects of pollution then countries may end up offering zero tax (or even a subsidy if possible) to attract industry location. These results follow Markusen et al. (1995) study for environmental policy competition within regions of a country: when disutility from pollution is low, regions compete undercutting each other's tax level; and when pollution disutility is high the polluting industry is driven off the market with high taxes.

Ecological economists also argue that economists assume very easily the dogma of two causal relationships: first, trade causes growth, and second, growth causes better environmental protection (and eventually improvement). There is widespread consensus that trade causes growth, however this is not undisputable. Standard gains from trade are static, but there is theoretical support for trade causing growth: economies of scale, monopolistic competition, diffusion of technology and learning by doing, etc. In the end if trade causes growth is an empirical issue, and the literature that has examined this question has not been exempt of controversy. There is overwhelming support for a positive empirical correlation between openness to trade and growth, but the causality arrow can not be shown to be unambiguously there. The second correlation is suggested by theory: if we value the environment positively, as we grow richer we are willing to make higher trade offs between income and the environment. However, the point at

which environmental improvements become observable is very important on itself and seems to be ignored.

This latter argument appears to be the best founded criticism against traditional economic analysis. In economic analysis ecological considerations are ignored. Ecosystems are characterized by a complex web of inter-relationships some linear, some non-linear, some discontinuous, some not apparent, etc. Limiting the analysis of the effects of trade on the environment to EKC's can be extremely misleading. For example, a complete ecosystem may be destroyed by acid rain (and in turn destroying the sustainability of growth) in a certain region, before the economic threshold of reducing SO₂ emissions is achieved. This is possible because the point of irreversible damage for a particular ecosystem may be reached before the economic turning point for environmental improvement. Abatement is not always the solution. The abatement cost to recover extinguished species is infinite. How do we even value the genetic information contained in disappeared species? Thus, the fact that eventually, through income growth, there is demand for environmental improvement nothing guarantees that the supply will be there. Furthermore, it is efficient to trade off some environmental damage for income; however, agents and governments may be dealing with this trade off with severe undervaluing of the environmental damage due to ignorance.

IV.- Conclusion

Although the literature that studies trade and environment has grown productively during the last decade, there are still many gaps to cover. A better multi-disciplinary approach is needed to determine more clearly the effects of output and emissions on the environment.

For starters, it is necessary to deal with the toxicity of the emissions mix as very few studies have done. Furthermore, for the benefit of the policy makers it is necessary to delimit more clearly the conditions under which trade reform can be welfare improving in the presence of both local environmental externalities and transboundary pollution. Finally, in the ground of empirical evaluation more estimations are necessary beyond CGE analysis to creatively determine the effects of trade on the environment, differentiating among the competing effects brought about by trade.

Chapter 2:
Trade of Renewable Resources in the
Ricardo-Schaefer Model.
The Small Country Case

I. Introduction

Natural resources approach to the trade-environment discussion has started recently and its contributions have been growing in the literature. We are aware of a few works that consider renewable resources in the trade and environment analysis. Copeland and Taylor (1997) develop a model of two goods, where the environment, a renewable resource is used as a factor of production by one sector, and deteriorated by the other sector. Assuming that the country is an international price taker the authors discover a threshold for the production externality, that when exceeded, trade can actually be income reducing for the country in equilibrium. This work does not include any intertemporal considerations, and limits itself to steady state analysis. On the other hand, Brander and Taylor (1997a, 1997b, 1998) have developed a model where a renewable resource is used as a factor of production by one sector, while a second sector only uses a fixed supply factor. They show how the “South” with an open access externality overexploits the natural resource, and in equilibrium trade could reduce welfare vis-à-vis

the autarky equilibrium. However, like Copeland and Taylor (1997), only equilibrium response is studied ignoring the dynamics of the model. Recently, both Emami and Johnston (2000) and Hannesson (2000) have expanded the Brander and Taylor analysis by studying the effects of moving from an open access to optimal resource management regime in a trade scenario. Emami and Johnston use the Brander and Taylor framework, Hannesson varies it slightly by assuming decreasing returns in the non-resource sector, but both show that under certain conditions “immiserizing resource management” can occur. This result states that *after* moving from open access to optimal management real income can be lower than *before* the change.

The latter result is interesting but reflects the drawbacks and limitations of steady state analysis. For example, in this paper we show that technological progress in the resource sector causes the steady state resource stock to decrease. Then, depending on the original stock, *after* the technological change real income may be lower. Furthermore, it is possible for the advanced country to have a lower steady state welfare than the backwards country. However, this does not mean that technological progress can be welfare reducing. What happens is that optimal management means maximizing welfare over a time horizon, not maximizing the welfare achieved at steady state. That is why optimal management can not really be immiserizing, and why it is necessary to study the behavior during the whole time horizon, not only steady state.

The work we present as the Ricardo-Schaefer model is an extension of the traditional analysis of renewable resource in trade in several directions. First, we let the North, the country that manages its resource optimally, to have a positive but finite discount rate, which let us study the behavior of the resource managing country under

more realistic assumptions, as well as make more accurate welfare comparisons for the whole planning horizon. Next, we focus in the dynamics of the transition periods. These are important to study, because as we show, the direction of trade may be completely determined by the transition period. Also, during the transition period, we can observe the extreme behavior of allocating all resources in the depletion of the resource, as apparently some countries do. Paradoxically, this latter behavior we show can be optimal. We also expand the model by allowing the South, the country which extracts resources with an open access externality, to have varying degrees of the open access externality. Under these circumstances the behavior of the South can be very different to what is expected. Furthermore, we study the conditions under which extinction of the resource can occur, and we argue that complete elimination of the resource can not occur under free trade.

II. Discounting and Valuation of the Resource

When one wants to determine the optimal consumption and saving across time of an accruing stock, one can not ignore time discounting. The following example from Clark (1990) will hopefully make this very clear.

It is estimated that the Antarctic waters can hold a maximum of 150,000 Antarctic blue whales. Additionally, a population of whales can grow at a maximum of 2,000 whales per year, when the stock of whales in the ocean reaches about half of the maximum population, around 75,000 creatures. Assuming that the market revenues of selling a whale amounts to \$10,000 then the maximum revenue that may obtained from the whales, keeping its population constant is \$20 million per annum. Alternatively, the industry may decide to liquidate the whole whale stock in one year obtaining from it \$750 million, that invested in any other sector that yields a rather conservative 5% per

annum would give returns of \$37.5 million per year. This example not only shows why whales were saved from extinction by an international ban, but also demonstrates that discounting is necessary to reflect alternative uses of resources. And that is what economics is all about, efficient allocation of limited resources over less limited possibilities. Also, even if, like in our model, there are no other alternative investment opportunities for a stock that can be accumulated, time discounting is still necessary to reflect preferences over the usage through time of this growing stock.

The author loves whales, like probably the reader, and is willing to pay money and time some day to enjoy their gigantic beauty. Thus, this example of the whales serves us to dissipate another source of confusion. Sometimes renewable resources, like whales, have an economic value beyond their productive usage simply by their existence. For example, a forest has an economic value as timber, which has a competitive price and a market, but also the same forest has an existence value, as people value the existence of the species contained in the forest. This latter value could be reflected by time and money people are willing to pay to visit the forest, or willing to give to conservation groups. Thus, in the whale example there is an externality problem as the whaling industry only considers the productive value of the whales, but not their existence value.

In the model we present the renewable resource only has a productive value, it does not have an existence value. However, it can be overexploited given an open access externality, which is one of the central points we explore in the model we present. Ignoring this existence valuation could be a more reasonable assumption for some types of resources than other. Nonetheless, we can *a priori* determine that this type of externality (ignored value) results in an overexploitation of the renewable resource.

III. The Ricardo-Schaefer Model.

The model we present could be safely labeled the Ricardo-Schaefer model as it blends a standard Ricardian model of trade, with Schaefer's pioneering work in the economics of the exploitation of renewable resources. The Ricardian part of the name recognizes that we are using linear technologies in the production of both sectors. This assumption has benefits and drawbacks. The main drawback is that it predicts specialization during transition which is a rather unrealistic prediction that may discomfort the reader. The linear technology assumption has, on the other hand, some considerable advantages. First, it allows us to solve explicitly for equilibrium, which can be very helpful in equilibrium analysis as we hope to show below. Also, this simple technology allows us to fully describe the transition paths with relative ease. Additionally, the linear technology, as in the original Ricardian model, allows us to clearly isolate the differences in technology as driving force in trade. Finally, as Gordon (1954) and later Schaefer (1957) suggested, the law of diminishing returns does not apply to an industry like fisheries (the quintessential renewable resource). The benefits overwhelm the drawbacks, and that is why it has been very popular in the literature of trade and renewable resources; see for example, Brander and Taylor (1997a, 1997b), Benarroch and Thille (2001), Unterorberdoerster (2001), McAusland (2005), and many others.

In this section we describe the production decisions of the North, the country that fully accounts their natural resources, and take prices as given. Special attention is given to the adjustment of the economy towards steady state equilibrium. The amount of resources conserved by the North are described and analyzed. In the next section we

describe the differing behavior of the South, a small country that also takes prices as given but their natural resources display an open access problem. The problem of extinction, or termination of the natural resource is discussed in the following section. Finally, we study how the model behaves given changes in its different parameters, i.e. comparative dynamics.

1. The Model.

Two different products are produced by one country using two factors of production: one mobile, and another specific. One sector depends only on the mobile factor of production, labor, and for exposition purposes we will call it the Manufactures sector. The second sector uses the stock of renewable resources, the specific factor, and labor to produce its output, and therefore call it the Resource sector.

$$R = \theta SL^R \tag{1}$$

$$M = L^M \tag{2}$$

$$L = L^R + L^M \tag{3}$$

Equation (1) gives the production function for the resource sector. Note that S , the stock of the resource acts as a productivity shifter in the production of the resource good, as more available stock makes the labor employed in the sector more productive. Additionally, the production of the resource good depends on an exogenous technical parameter, θ . The second equation, (2), gives the production function for the manufactures sector. Note that for a particular choice of units, M will depend one-to-one on the amount of labor employed. Finally, equation (3) gives the labor endowment

constraint. If one takes the stock S as a constant, equations (1) - (3) constitute the standard Ricardian trade model.

At any particular moment in time this economy behaves like the standard Ricardian economy. Using the labor requirements per unit produced, i.e. $a(R) = L^R / R$, $a(M) = L^M / M$, we can define the instantaneous linear production possibilities frontier for this economy:

$$L = a(R) \cdot R + a(M) \cdot M = \frac{1}{\theta S} R + M . \quad (4)$$

However, the model differs substantially from the standard Ricardian one because the stock has a dynamic that depends on the natural growth of the resource and the production of the resource good:

$$\dot{S} = G(S) - R(S) \quad (5)$$

where the dot over the variable indicates the time derivative.

The growth of the stock $G(S)$ in this model follows a logistic function given by:

$$G(S) = \gamma S(1 - S/C) \quad (6)$$

The logistic function, that can be traced to 1838, is the most commonly assumed for the growth of renewable resources, because it captures in the simplest fashion what we believe describes the growth of these kind of resources¹⁵. Equations (5) and (6) make up biologist M.B. Schaefer's (1957) model of fisheries. In the Cartesian space the function begins at the origin increasing with the stock until it reaches a maximum at $C/2$ (known in the biological literature as the Maximum Sustainable Yield), then it starts falling as the stock increases until it gets back to zero again when the stock reaches C .

¹⁵ P.F. Verhulst used the logistic equation to describe the dynamics of human population in, "Notice sur la loi que la population suit dans son accroissement", in *Correspondance Mathématique et Physique*, N. 10, 1838

This hill shape is what we believe (state of our ignorance) best describes the growth of renewable resources. When the stock is relatively low, increases in the stock can support higher growth rates; however, when it is too large (greater than $C/2$) the growth rate will diminish with stock increases as the overcrowding or congestion effect affects the growth. In (6), γ is the intrinsic growth rate, and C is the maximum carrying capacity.

In steady state, when $\dot{S} = 0$ the production of the resource good is equal to the growth of the stock. The dynamics of the stock are graphed in Figure 1. For example, if originally the production of the resource good was $R(S^0)$, the extraction of the stock would be higher than the natural growth rate of the stock and, therefore, the stock would be reduced until it reaches a steady state level at S_s , where the production of the resource good would be $R(S_s)$. Alternatively, if the stock was originally at a level below its steady state level, the opposite would occur, while the stock grows to reach its steady state level. Two important features of the model may be extracted from Figure 1. First, if the production of the resource good through time was too high, the stock would be completely depleted to zero. In the graph this would happen if the line $R(S) = \theta SL^R$, was steeper than the slope of the logistic growth function at $S=0$, that is γ the uncongested growth rate. Therefore, if $R'(S) = \theta L^R > \gamma = G'(0)$, the stock would be entirely depleted and the economy would have to specialize in the production of manufactures. Second, there is one maximum level of production of the resource good. Then, if the stock extraction is augmented from a steady state to the right of this maximum, the production level of the resource good would augment, alternatively, the opposite happens to the left of the Maximum Sustainable Yield ($C/2$).

2. The Production Pattern in the North

For exposition purposes, we will call South the country that does not internalize the effects of their production of the resource good on the dynamics of the stock (that is on its later availability or scarcity). By doing so, we think we are capturing the stylized fact that in many developing countries (South) the lack of enforcement of property rights causes harvesters of natural resources to consider only their private costs of extracting the resource, and not the costs that their extraction causes to the pool of the resource. Obviously, the end result of this behavior is an over exploitation of the resource. It is important to stress that this lack of internalization of all relevant costs may occur in a *poorly enforced* private or communal property regime. Neither regime guarantees that the externalities problem is solved. For example, in poor sub-Saharan African nations, the introduction of private property rights deteriorated communal controls over the use of land causing over usage of their available (and fragile) biomass¹⁶. Alternatively, the very known “tragedy of the commons” exemplifies how in a private property regime any communal resource gets over used. Therefore, one should be careful not to call this problem the “common property externality” as erroneously some have, but more accurately call it the open access externality.

We will first solve the economic problem for the North that has a well-enforced property rights regime, and later study how the allocations differ in the South that has an open access externality.

The economy would like to maximize a given representative agent’s utility function $U(R,M)$, given the technological constraints (1) - (3) and the biological

¹⁶ Cf. Lopez (1998)

constraints (5) - (6). Usually in the trade literature homotheticity is assumed to ensure that income redistributions do not affect optimal consumption patterns. However, in this case no assumptions over U beyond quasiconcavity and monotonicity are needed, because the small country takes prices as given. Therefore, since the country is the sole owner of its revenues we can reduce the algebra of the problem to maximization of revenue given the aforementioned constraints. Given this optimal revenue and international prices, consumers can then choose optimal consumption bundles offered with infinite elasticity at the international prices. What is important for our welfare analysis is that there exists a direct relationship between welfare and real revenue, given monotonicity.

The problem of the economy is to $\text{Max} \int_0^{\infty} [pR + M] e^{-rt} \cdot dt$, given the technological and biological constraints and a given initial stock level $S(0) = S_0$. The problem can be expressed as the current value Hamiltonian:

$$H(L^R, S; \lambda) = p\theta SL^R + (L - L^R) + \lambda [\gamma S(1 - S/C) - \theta SL^R] \quad (7)$$

The Hamiltonian shown is simplified by including the labor endowment restriction (3) into the production of manufactures (2). The first order conditions of this problem are:

$$p\theta S - 1 - \lambda\theta S = 0 \quad (8)$$

$$\dot{\lambda} = -[p\theta L^R + \lambda(\gamma - 2\gamma S/C - \theta L^R)] + r\lambda \quad (9)$$

$$\dot{S} = \gamma S(1 - S/C) - \theta SL^R \quad (10)$$

$$\lim_{t \rightarrow \infty} e^{-rt} \lambda(t) = 0 \quad (11)$$

$$S(0) = S_0 \tag{12}$$

Condition (8), can be interpreted in several ways. Expressing it as $(p - \lambda)\theta S = 1$, it says that the social marginal revenue of labor in the resource sector $(p - \lambda)\theta S$ must be equal to the marginal revenue of labor in the manufactures sector. Here λ can be viewed as consumption tax. Alternatively, rewritten as $p = 1/\theta S + \lambda$, it says that the unit revenue of the resource good pays the labor unit cost of producing the resource good $a(R)=1/\theta S$, plus the marginal cost of use of the stock (marginal user cost), λ , which could be viewed as resource stock property rents. If there was complete open access to the resource and no property rent could be extracted, then λ would be zero, agents would extract the resource until $p = 1/\theta S$ or equivalently $S = 1/\theta p$ holds, like in Brander and Taylor (1997a). This extreme case occurs when there is complete open access or agents are solving problem (7) with a discount rate r equal to infinity. The latter is an unsatisfactory explanation, and that is another reason why we later solve the more general problem, and model the externality in a different fashion.

Note that the Hamiltonian (7) is linear in the control, and will thus have a bang-bang solution¹⁷. Also, note that condition (8) does not depend on the control variable L^R , and will only hold in steady state, provided that a diversified steady state equilibrium is achieved. If the country is unable to achieve equilibrium, for example due to insufficient labor supply, condition (8) will be an inequality. Away from the steady state, the

¹⁷ Formally, in a single control, single state problem, labeling $O(s,c,t)$ the objective function of the state s the control c and time t , and labeling $f(s,c,t)$ the function of flow of the state with the same arguments; if $\frac{\partial \left[\frac{\partial O(s,c,t)/\partial c}{\partial f(s,c,t)/\partial c} \right]}{\partial c} = 0$, then the control displays a most rapid approach path (MRAP) or bang-bang behavior. It is easy to see that in our problem this condition is met as the control enters linearly in both the objective function and the state motion equation.

economy chooses L^R so as to arrive to equilibrium, and make condition (8) hold as fast as possible. We define the switching function:

$$\sigma(t) = \theta S(p - \lambda) - 1 \quad (13)$$

The control variable, labor in the resource sector, will be determined by the switching function as follows:

$$L^R = \begin{cases} 0 & \text{if } \sigma(t) < 0 \\ L & \text{if } \sigma(t) > 0 ; \\ L_s^R & \text{if } \sigma(t) = 0 \end{cases}$$

where L_s^R is the steady state level of labor in the resource sector.

We can readily make economic sense of the switching function. First note that this extreme, all or nothing behavior is consistent with the Ricardian nature of the problem. If $\sigma(t) > 0$, then $p > 1/\theta S + \lambda$, that is, revenues from producing the resource good are higher than the costs, and therefore, like in the standard Ricardian model, all labor resources are used to produce the resource good. Following the same reasoning, when $\sigma(t) < 0$, then $p < 1/\theta S + \lambda$ and the country specializes in the production of manufactures. The big difference though, lies in that after specializing S , λ will change through time and a diversified production equilibrium may be reestablished if equality of marginal cost and marginal revenue is recovered.

The mathematical explanation for this extreme or Most Rapid Approach Path (MRAP), is also quite intuitive. Given that the control variable appears linearly both in the objective function and the state flow equation, allows us to express the value function (i.e. the objective function accounting for the dynamic restriction (5), $V(S, \dot{S})$) after

appropriate transformations as a function of only the state variable, $V(S)$ ¹⁸. This means that the value function has (given linearity of the control in the objective function and state equation, see footnote 17) only one S that maximizes it, and the integral of the value function is thus maximized by attaining this maximum as quickly as possible.

Also, it is important to note, that the MRAP is a result of trade, this economy in autarky approaches its steady state with a continuous change in its harvesting effort. When the stock is lower than the long-run, optimal labor in the resource sector is increasing until steady state and vice-versa (see more details in chapter 3). The economic explanation for this behavior is that specialization is not feasible in autarky because as the production of one sector decreases its demand determined relative price rises hindering specialization. Mathematically, under autarky we have that the Hamiltonian (7) does not take the price as a parameter but is instead determined by demand according to the consumers' welfare maximization condition: $p = \frac{U_R(R(L^R), M(L^R))}{U_M(R(L^R), M(L^R))}$. In this latter case

the objective function is no longer linear on the control.

In the next section we study the motion of S and λ to see if the value function maximizing stock level is achievable and under what conditions.

3. The Model Dynamics

The first step in our study of the Ricardo-Schaefer model is to study how the problem is solved for any given amount of initial stock, S_0 . To determine if a steady state is reached we look at the movement of S and λ , as determined by the first order

¹⁸ See Spence and Starrett (1975) for the mathematical details.

conditions (8) - (10). It is helpful to look first at the schedules that make their time derivatives equal to zero:

$$\lambda|_{\dot{\lambda}=0} = \frac{p\theta L^R C}{2\gamma S + (r - \gamma)C + \theta L^R C} \quad (14)$$

$$S|_{\dot{S}=0} = 0, S|_{\dot{S}=0} = \frac{C(\gamma - \theta L^R)}{\gamma} \quad (15)$$

If condition (8) is initially not met with equality, there are profits to be extracted in either sector. That is, for example, if $p > 1/\theta S + \lambda$, the resource sector is more profitable than the manufactures, and given the (Ricardian) linear technology all the labor is directed to the resources sector. In that case the relevant schedules are:

$$\lambda|_{\dot{\lambda}=0} = \frac{p\theta LC}{2\gamma S + (r - \gamma)C + \theta LC} \quad (16); \text{and}$$

$$S|_{\dot{S}=0} = 0, S|_{\dot{S}=0} = \frac{C(\gamma - \theta L)}{\gamma} \quad (17)$$

However, on the other hand if the inequality is reversed and $p < 1/\theta S + \lambda$, the profitable sector is the manufactures one, in which case the resource sector employs no labor, and the relevant zero time change schedules are:

$$S|_{\dot{\lambda}=0} = \frac{C(\gamma - r)}{2\gamma} \quad (18);$$

$$S|_{\dot{S}=0} = 0, S|_{\dot{S}=0} = C \quad (19)$$

Solving for the first order conditions of the Hamiltonian, we can find a steady state stock level, we label S_s as a function of the parameters of the model. In the next section we describe this stock level, but for now let us assume that it exists. The convergence to the steady state will depend on the initial stock level S_0 , on whether it is

greater or smaller than the steady state stock level. Note that given that the logistic growth function is quadratic over the stock, the $\dot{S}|_{\dot{S}=0}$ schedule has two solutions; one of them is always zero reflecting the fact that once the resource is completely depleted it can not recover, it becomes extinct.

Let us study first, with the aide of Figure 2 the case when the initial stock S_0 is greater than the steady stock S_S , that is the resource is initially underexploited. For descriptive purposes, we call this, the pristine environment scenario. To understand the dynamics of the system we need to include first order condition (8) which determines the extreme bang-bang behavior of labor. In Figure 2, condition (8) is graphed in the λ, S space as line z (z for zero profits), only combinations of λ and S that lie in the z line can support a diversified equilibrium, where no profits can be extracted from either sector. Points above the z line, where $\sigma(t) < 0$, represent combinations of stock and marginal cost of use of the stock that make the manufactures sector more profitable than the resource sector, and therefore, consistent with no resource extraction, and thus, resource stock growth. The opposite happens, below the z line where $\sigma(t) > 0$ and the resource sector is more profitable which is consistent with all labor resources being employed in harvesting the resource and in that way reducing its stock.

When the initial stock S_0 is greater than the steady state level, the fastest and optimal way to approach a lower stock level is to direct all labor resources to the production of the resource good. Therefore, the relevant schedules, when the initial stock is above the optimal are given by (16) and (17). Although in Figure 2 the $\dot{S} = 0$ schedule (the vertical dotted line) is shown over the positive stock region, it may be positioned at a

negative stock value if there is a relative abundance of effective labor with respect to the resource, i.e. $L > \gamma/\theta$.

Given the initial stock level S_0 , the social planner, or the agents that internalize all social costs, will choose a $\lambda(0)$ that will send the economy in a revenue maximizing transition path (MRAP) to the steady state stock level. The instant when the resource stock, after being harvested at maximum capacity, reaches its steady state level, a diversified equilibrium is established. Production diversification is achieved because no further profits are there to be extracted from the resource sector. At this moment in time, L^R is chosen to keep both S and λ with no time change, and the remaining labor is employed in the manufactures sector. Note that the steady state is unique, it represents the only point over the z line where an L^R can be chosen to maintain both S and λ in steady state. Figure 3 describes the steady state in the λ, S space. The diversified steady state is achieved even though, during transition, the stock may be harvested at an unsustainable rate (i.e. $L > \gamma/\theta$) that if maintained would drive the resource to extinction. Also, if the desired optimal stock level required a higher steady state labor employment, than the labor endowment (a country with vast natural resources but little labor to exploit it), then the optimal stock could not be achieved. In this case the country would end specialized in the production of the resource good, in a sub-optimal steady state with positive profits in the resource sector. This latter case can be represented in a phase diagram like Figure 2, with an optimal S_s to the left of the $\dot{S} = 0$ schedule, and the intersection of both the $\dot{\lambda} = 0$ and the $\dot{S} = 0$ schedules below the z line. Also note that in this case condition (8) is not met with equality.

During the transition the economy specializes in the production of R . Both the continuous decrease in the resource stock as well as the continuous increase in the marginal use cost guarantee that the profit gap in the resource sector closes. Current value national income during the transition is: $NI = p\theta S(t)L + \lambda(t)[\gamma S(t)(1 - S(t)/C) - \theta S(t)L]$, and is falling from time zero until steady state is reached for two reasons: first, as the stock falls the productivity of labor is falling; and second, the rising marginal use cost subtracts the negatively changing stock. After steady state has been achieved, national income permanently becomes: $p\theta S_s L_s^R + (L - L_s^R)$. Wages, $p\theta S(t)$ are also falling, from time zero, but are higher than their steady state value 1. Labor income wL is greater than national income, as national income subtracts the cost of over-harvesting the resource during transition; λ thus, plays the role of a price that values the depreciation of the stock. Labor, during transition is all devoted to resource good production, and at steady state has a discrete jump to a lower level that sustains a diversified production equilibrium. Finally, if both goods are essential, a natural assumption, throughout the transition the economy exports the resource good and imports manufactures; while at steady state the direction of trade will be determined by preferences, and steady state production levels.

When the initial stock is less than the optimal, the dynamics of the model are different. As no labor is employed in the extraction of the resource, the stock grows following its logistic growth function to its maximum level C , which is what schedule (18) is reflecting. On the other hand the marginal user cost is constant only when the stock is equal to $C/2 \cdot [(\gamma - r)/\gamma]$, schedule (19). Since, $C/2$ is the stock level of maximum sustainable yield, we will call the stock level that maintains a constant λ , the

discounted maximum sustainable yield. It can be shown, that the MSY is the stock level that solves for $G'(S)=0$, while the discounted MSY is the stock level that solves for $G'(S)=r$. One expects the discount rate to be relatively low, in comparison to the uncongested growth rate of the resource, γ . If this were the case the discounted MSY would be slightly to the left of the maximum sustainable yield. Nonetheless, it is possible for a country to be so impatient that $r > \gamma$, in this case the discounted MSY would be negative. To the left of the discounted MSY, the marginal user cost is falling, as is shown in Figure 4, which is consistent with increasing profitability in the resource sector.

Also note that, unless the country is extremely impatient, i.e. $r > \gamma$, to the left of the discounted MSY the resource growth is increasing in the stock ($G'(S) > 0$). Thus, it is rather intuitive, that as increased steady state resource good output may be achieved, the higher relative profitability of the manufactures sectors is falling. To the right of the discounted MSY, the marginal user cost is increasing, causing the manufactures sector to be increasingly more profitable than the resource sector. This fall in the profitability of the resource sector may be understood by decreasing steady state resource good output (negative $G'(S)$), which happens to the left of the MSY; or the productive gains are positive, but less than the discounting ($G'(S) < r$), which happens between the discounted MSY and the true MSY.

From simple inspection of the phase diagram presented in Figure 4, it can be seen that if the steady state stock level was to the left of the discounted MSY, there would exist a revenue maximizing path (MRAP) that would send the economy to steady state. However, as we show in the next section the steady state stock level is always to the left of the discounted MSY. In the case we call the depleted environment scenario, no labor is

employed in harvesting the resource to let it grow to the optimal level, which is higher. During this transition, the stock follows its logistic growth process, converging to its carrying capacity: $\dot{S} = G(S)$. Additionally, when no labor is employed in the resource sector, the equation of motion λ becomes, $\dot{\lambda} = \lambda[r - G'(S)]$, from where the time path of λ may be readily obtained: $\lambda(t) = \lambda(0)e^{[r - G'(S)]t}$. Given that the steady state stock level is greater than the discounted MSY, over a region where the marginal user cost is increasing, we should check that the path that takes the economy to the optimal stock level is feasible. By feasible path we mean that: the optimal path does not cross the z line before reaching the steady state stock level, which would avoid the convergence of the stock to its optimal level; and, the optimal path does not overshoot the optimal stock level sending the economy in a permanent path of specialization in manufactures and ever decreasing profitability of the resource sector, i.e. exploding marginal user cost.

We can prove that the path is feasible. First note the slope of the optimal path is given by:

$$\frac{d\lambda}{dS} = \frac{\dot{\lambda}}{\dot{S}} = \frac{\lambda(r - G'(S))}{G(S)} \quad (20)$$

On the other hand, the slope of the zero profit line z is given by:

$$\left. \frac{d\lambda}{dS} \right|_{\sigma(t)=0} = \frac{1}{\theta S^2} \quad (21)$$

Solving for the stock level that makes both slopes equal we discover that the z line and the optimal path have the same slope exactly at the steady state optimal stock level which we describe in the next section. This result proves that the optimal path is feasible, because the planner or agents can always choose a $\lambda(0)$ that will make the optimal path

tangent to the zero profit line exactly at the optimal stock level without ever crossing the zero profit line. Thus, the optimal path has the characteristics shown in Figure 4. When steady state is achieved, the discrete jump in labor employed in the resource sector from 0 to its steady state level, will shift both $\dot{\lambda} = 0$ and $\dot{S} = 0$ schedules to their steady state levels as shown in Figure 3.

The economics of the converging optimal path may be readily summarized. First, an initial marginal user cost is chosen to maximize the discounted flow of revenues until the unharvested resource grows to its steady state level. Throughout the transition, the economy remains specialized in the production of manufactures until the stock grows to its optimal level, when equality of profits in both sectors guarantees that a diversified production equilibrium is established. During the transition L^R is zero, but jumps to $L_s^R = \gamma / \theta(1 - S_s / C)$ when the stock reaches its steady state level. The stock grows according to its logistic function until it reaches its optimal level. The marginal user cost initially falls, as productivity of the resource good grows; then starts increasing after the stock gets larger than the discounted MSY level, as the gains in resource output $G'(S)$ are less than the discount rate r . Wages are constant during the transition at 1, the marginal productivity of labor in manufactures sector, and remains at that level after steady state. Current value national income is during the transition greater than labor income, wL , as national income accounts for the appreciation in the natural stock: $NI = L + \lambda(t)(\gamma S(t)[1 - S(t)/C])$. Also, throughout the transition path current value national income is growing. The change in national income while there is specialization in manufactures can be shown to be given by:

$$\frac{\partial NI}{\partial t} = \dot{\lambda}(t)\dot{S}(t) + \lambda(t)\ddot{S}(t) = r\lambda(t)\dot{S}(t) \quad (22)$$

which, although at varying levels, is always positive. Finally, if both goods are essential, throughout the transition the economy exports manufactures and imports the resource good; while at steady state the direction of trade will be determined by preferences, and steady state production levels.

4. The Steady State Stock Level.

Solving for the steady state stock level, using equations (8) - (10), we find:

$$S_s = \frac{C}{4} \left[\frac{1}{p\theta C} - \frac{r-\gamma}{\gamma} + \sqrt{\left(\frac{r-\gamma}{\gamma} - \frac{1}{p\theta C} \right)^2 + \frac{8r}{p\theta C\gamma}} \right] \quad (23)$$

This, solution is very similar to the steady state stock level of the generalized Schaefer model as studied by Clark (1979) and (1990). That model is a single sector revenue maximization of a fishery. The difference, thus, lies that instead of having a fixed marginal cost c , here the fixed marginal cost is 1, the cost of opportunity of not producing a unit of manufactures when a unit of labor is employed harvesting the resource.

Following Clark (1990), we simplify the steady state stock by dividing by the carrying capacity, C , to normalize the maximum biomass to 1, and we call the normalized stock level Σ . Furthermore, as previously stated the open access stock level, when $\lambda=0$, is $S_\infty = 1/\theta p$, and therefore, $\Sigma_\infty = 1/\theta pC$. Also, we can label the ratio of discount rate, to uncongested growth rate of the resource as $\delta = r/\gamma$, which allows us to write the normalized stock level as a function of two variables:

$$\Sigma_s = 1/4 \left[(1-\delta + \Sigma_\infty) + \sqrt{(1-\delta + \Sigma_\infty)^2 + 8\delta\Sigma_\infty} \right] \quad (24)$$

Using this simplified notation, the normalized discounted maximum sustainable yield is $(1-\delta)/2$. By inspection, the reader should observe that the optimal normalized stock level is always bigger than the discounted MSY, unless $\Sigma_{\infty} = 0$ which is impossible for any finite price. This is one of the results presented in Table 1, where the discounted MSY is labeled DMSY. Given the quadratic nature of the solution, the optimal stock is not very sensitive to δ when the open access stock level is very high, but as the resource becomes scarce, the optimal level becomes very sensitive to the discount rate. Also, the optimal stock level is more sensitive to the open access stock level, the higher the relative discount rate is.

IV. Production Decisions in the South

Assuming a complete open access externality, as is usually done in the literature, is a good benchmark to start understanding the economic behavior of agents when property rights are not clearly defined, but it is also many times an unrealistic assumption. For example, it is not uncommon to observe commercial fishermen in an open access regime to return the small catch or pregnant samples, and even observe voluntary moratoriums when a particular specie is breeding. Also, it is not uncommon to observe loggers under an open access regime to cut only full-grown samples while protecting those not fully developed. This kind of behavior is not consistent with the full open access assumption, because under that regime future rents that may be extracted from the resource stock have zero value. Therefore, we try to advance from the benchmark case, and describe the production decisions in the South under more general open access assumption.

We assume that agents in the South consider only a fraction ϕ of the marginal user cost, where $\phi \in (0,1)$, when they make their production decisions. Under such conditions, we may restate the problem of the Southern economy as:

$$\text{Max } H(L^R, S; \lambda) = p\theta SL^R + (L - L^R) + \lambda [\phi\gamma S(1 - S/C) - \phi\theta SL^R] \quad (25)$$

As expected, in the South the steady state stock is lower than in the north, $\tilde{S} = 1/[\theta(p - \phi\lambda)]$, but the interesting questions are how smaller, and how the externality affects the resource level that is preserved. We can answer those inquiries by solving for the steady state in the South. Using the simplified notation explained in section III.4, the normalized steady state stock level in the south is given by:

$$\tilde{\Sigma} = 1/4 \left[(1 - \delta/\phi + \Sigma_\infty) + \sqrt{(1 - \delta/\phi + \Sigma_\infty)^2 + 8\delta\Sigma_\infty/\phi} \right] \quad (26)$$

The limit of $\tilde{\Sigma}$ as ϕ goes to zero is naturally, Σ_∞ . From the formula, it should become clear that if the discount rate is small relative to the intrinsic growth rate of the resource, i.e. δ is small, the externality does not have an important effect over the steady state stock level in the South. In Table 2 the South's normalized stock level is presented for different discount to growth rate ratios and externality levels, assuming that the complete open access normalized resource level is 1/4. What is very striking is that if the δ is small, that is if the discount rate is low, or the uncongested growth rate of the resource is large, or both, the steady state stock level would be very different from the benchmark full externality scenario. Even if the externality was very large and agents only considered one hundredth of the shadow value of the resource, still the amount of biomass conserved in the South would be almost double of what the full open access assumption predicts!

Obviously, the South's choice of steady state stock is sub-optimal, as the optimal choice would be to mimic the North at Σ_s , but what is important is that it is over-exploiting the resource. Although in the strict context of this model, it is equally as bad (in welfare terms) to over or under exploit the resource from its optimal steady state level, it is important to note this overexploitation as the resource could have non-use values either in the country or in the rests of the world. Much of the current concern with free trade is that it causes overexploitation of the natural resource. In the context of this model trade will always cause an increased exploitation of the resource for the resource rich country (as determined by having an autarky price lower than the international price). This overexploitation will be intense, as all the factor of production are directed to exploit the resource during the transition to steady state; however, there will be a *real* over exploitation in the South where there exists an open access externality to some degree.

The dynamics in the South are identical to the North, only the amount of the resource preserved is different. Also, as a sub-optimal steady stock level is chosen in the South, welfare in the south is lower than in the north over the whole planning horizon. This remains true even if the instantaneous utility was higher in the South than in the North over any particular period of this horizon.

V. Economics of Extinction

As we saw in section II, if the labor employed in extracting the resource was permanently established at a very high level, i.e. $L^R > \gamma/\theta$, the resource would be harvested until extinction. Brander and Taylor (1997a) show that if the labor force L surpasses a certain threshold, the closed open access economy would extinguish the

resource. We will first show that this result holds only under certain assumptions about preferences, and later argue that the open economy under any resource management regime will never extinguish the resource.

To study the equilibrium of the closed economy, by Walras' law it is only necessary to check equilibrium in one of the markets, naturally we check the resource good market. Brander and Taylor assume Cobb-Douglas preferences, therefore the amount of resource good demanded is $R^D = \alpha L / p$, where α is the share of consumption of the resource good, and L is national income. Remember that in steady state national income is wL and as long as manufactures are produced, which is always the case in the closed economy, $w = 1$. Also, we know that producers in an open access property regime equate price to: $p = 1/\theta S$. Equating the producers' condition, with the consumers' inverse demand, we can solve for the equilibrium resource good: $R = \theta S \alpha L$. Thus, if $\alpha \theta L > \gamma$, the resource would be harvested until extinction, as shown in Figure 5 by line and demand X. The figure explains why the resource is harvested to extinction. Demand is always larger than any quantity supplied, therefore, producers try to meet demand by extracting more and more of the resource, as prices go up, until there is no more resource to harvest, and the price has exploded to infinity. Also, note that this result is a product of the extreme assumption of $\lambda = 0$, if producers have any sense of the value of scarcity, as we did in the previous section, then extinction is not possible.

However, this result is driven by the assumption of Cobb-Douglas preferences, which imply constant elasticity of demand equal to 1. If we assume that demand elasticity is greater than one, the closed open access economy would always have an equilibrium with a positive stock, as shown by line and demand Y in Figure 5. Let us assume that

demand has in general price elasticity β like in: $R^D = \alpha L / p^\beta$. If demand is price elastic, $\beta > 1$, then demand would look like Y in Figure 5b; however if demand was inelastic, $\beta < 1$, if it would look like demand Z. Using the producers price condition, we can establish that the equilibrium amount of resource good traded is $R = (\theta S)^\beta \alpha L$, which is plotted as line Y for $\beta > 1$ in Figure 5a, and as line Z for the price inelastic case, $\beta < 1$. When demand is inelastic there can be two equilibria, or none, when labor is too large relative to the resource. We have drawn the former case. Note that equilibrium 1 in the figure is unstable, and if perturbed could send the economy in an extinction cycle in which as price rises to infinity, demand always exceeds supply.

When we are dealing with two sectors, we expect demand to be inelastic, as manufactures is not expected to be a good substitute of the resource good. Therefore, we expect extinction to be a definite possibility for the closed economy with an open access regime. If the small open economy opens to trade, extinction would be avoided because under free trade prices are exogenous, which would stop the spiral of increasing prices and stock reduction that leads to extinction. The small open economy harvests the resource until $S = 1/\theta p$ under open access, or $S = 1/[\theta(p - \lambda)]$ under optimal management, both of which are always positive. Even if the country has a large labor force relative to the growth of the natural resource, even if the stock during transition is harvested at an unsustainable rate, and even if there is a complete open-access externality in the resource market, opening the small economy to trade prevents extinction.

VI. Comparative Statics and Comparative Dynamics

1. Price Changes, and its Effects on the Optimal Stock, Goods Supply and Welfare.

We begin our study of the steady state by determining its stability. It will be useful to do so, in terms of the stock and the labor variables, which determine the real sector of the economy, that is both sectors' output. We know that at steady state condition (8) is met with equality, there are zero profits in both sectors. Using this condition into (9) we can express the equation of motion of the user cost as at steady state:

$$\dot{\lambda} = -L^R / S + (p - 1 / (\theta S))(r - G'(S)) = 0 \quad (27)$$

Also at steady state, the stock is not changing, therefore:

$$\dot{S} = \gamma S(1 - S / C) - \theta S L^R = 0 \quad (28)$$

The reader should be aware, that we are not using equations (27) and (28) to describe the dynamics of the model, which we did on the previous section, but to describe the steady state. Anyway, the stability of the steady state guarantees that given any marginal change in the parameters of the model, the steady state would be reestablished. To understand how the model behaves given changes in its parameters it is useful to see a phase diagram in the control and state space. The schedules according to (27) and (28) are given by:

$$L^R \Big|_{\dot{\lambda}=0} = S(p - 1 / \theta S)(r - G'(S)), \text{ and}$$

$$L^R \Big|_{\dot{S}=0} = G(S) / (\theta S).$$

These schedules are graphed in the L^R, S space in Figure 6. To understand the shape of the $\dot{\lambda} = 0$ schedule note that it is convex in S . This schedule intercepts the stock

axis at S_∞ , the open access stock level, when $p = 1/\theta S$, and at S_r , the discounted MSY when $r = G'(S)$. The particular shape drawn in the figure in which the schedule, from above the origin, moves into negative L^R is the effect of having a discount rate lower than the uncongested growth rate of the stock, $r < \gamma$. We believe this should be the empirical regularity. In the unlikely case the country is very impatient and $r > G'(C)$, then the $\dot{\lambda} = 0$ schedule would always be positive for all $S > 0$.

To describe the dynamics of the model let us assume that the country is in autarkic equilibrium with labor and resource stock at steady state values given by L_s^R and S_s respectively. If the country opens to trade and the international price was higher than in autarky, that would cause the $\dot{\lambda}$ schedule to shift, to a new position like $\dot{\lambda}' = 0$. When the price increases, the resource sector becomes more profitable than the manufactures sector, $p > 1/\theta S + \lambda$, and so all of the labor resources are directed to produce the resource good, $L^R = L$. As more stock is extracted, than its previous steady state growth rate, the stock starts declining. Also, as the stock becomes scarcer, and the price increases, the marginal user cost starts growing. This process will continue until the equilibrium is reestablished with $p = 1/\theta S + \lambda$, at which moment the labor drops to the new steady state value, which was higher than the first. Also, at their new steady state values the shadow value of the stock also increases, and the stock decreases. Figure 7 summarizes these results graphically.

The stock level at which the $\dot{\lambda} = 0$ schedule crosses the positive horizontal axis is $S_r = C/2 \cdot (\gamma - r)/\gamma$, once again the discounted MSY. This level does not depend in the price, thus as the price increases, the steady state stock level asymptotically reaches S_r (remember that the schedule is convex in S). However, this result changes dramatically if

the country is too impatient, $r > \gamma$. In this latter case, the stock level at which the $\dot{\lambda} = 0$ crosses the horizontal axis with a positive slope is $S = 1/\theta p$, which is abysmally different from the case of the patient country (or country with fast growing resource). In this latter case, the steady state stock level will be much more sensitive to the price¹⁹. Impatient or not, the steady state stock level will never be zero, unless the price is equal to infinity. This case we ought to discard as it implies that the marginal utility of the manufactures good is zero in the country as in the rest of the world. Also, note that for a high enough price the country will always optimally conserve a level of the stock lower than the Maximum Sustainable Yield, but always higher than the discounted MSY.

The latter result can be contrasted with Brander and Taylor (1997b) results. These authors show in a static context, that the country that fully internalizes the open access externality always chooses an optimal stock level that is greater than the maximum sustainable yield. We find in a positive but finite discount scenario, that the steady state stock level that a country would like to conserve is always greater than the discounted maximum sustainable yield.

The steady state supply of manufactures is infinitely elastic, therefore it provides no producer surplus. The steady state supply of the resource good is positively sloped, but always backward bending for high enough prices. Assuming that the steady state relative supply curve (R/M) is backward bending²⁰, then there is a critical price that achieves

¹⁹ In Brander and Taylor (1997b) the author show that the country that completely ignores the open access externality, or equivalently has an infinite discount rate, has a steady state stock level of $1/\theta p$. The previous analysis shows that when the discount rate is just greater than γ , the country will behave optimally in a similar fashion to the full externality, infinite discount rate country.

²⁰ In Chapter 3, Section III.4, we explore in details the conditions for a backward bending relative supply (R/M) curve. However the intuition is straightforward, a backward bending supply curve requires that at some point, additional efforts reduce steady state output more than proportionally to the increased effort.

maximum steady state relative output. At higher prices, the stock would be driven to lower levels which can only sustain lower steady state resource good output. From the previous argumentation it must be clear that the price at which the resource supply becomes backwards bending is also the steady state welfare maximizing price. This special price is $p^* = \frac{\gamma}{r\theta C} + \frac{2}{\theta C}$, that not surprisingly is inversely related to the discount rate and to the productivity of labor in the resource good, and less surprisingly inversely related to the carrying capacity.

It is tempting, then, to make welfare comparisons and say that a price higher than p^* yields a lower steady state welfare, but this is misleading, if not completely wrong. To understand why, let us introduce the optimal value function:

$$J(p) = \int_0^{\infty} \left\{ \left[p\theta S(p)L^R(p) + (L - L^R(p)) \right] e^{-rt} + S(p)\dot{\lambda}(p) + \lambda(p) \left[\gamma S(p)(1 - S(p)/C) - \theta S(p)L^R(p) \right] \right\} \cdot dt + \lambda_0(p)S_0(p) - \lambda_{\infty}(p)S_{\infty}(p) \quad (29)$$

where $L^R(p)$, $S(p)$, and $\lambda(p)$ are all the optimal control, state and co-state variable from solving the economy's problem (7). If we want to know, how this value function changes with p , then we calculate:

$$J'(p) = \int_0^{\infty} \left[\theta S(p)L^R(p) \right] e^{-rt} \cdot dt = \int_0^{\infty} R \cdot e^{-rt} \cdot dt \geq 0 \quad (30)$$

that is strictly positive when the resource good is produced, that is for all $p > 1/\theta C$. Therefore, the optimal present value of revenues is increasing in p . So, if the economy is at a p lower than p^* , and prices rise to a level that is higher than p^* , then, even if the resource output reaches a steady state that is lower than the original, and even though the steady state real revenue is lower than the initial, the present value of revenues would be

higher, and equivalently discounted welfare would also be higher. For this reason we do not take steady state welfare comparisons any further.

2. Further Comparative Statics and Comparative Dynamics

In the previous section we described the behavior of the country and the change in their production decisions given changes in the price. Here we review briefly how the model responds to changes in other parameters.

First, the steady state stock level, as we saw above is very sensitive to increases in the discount rate. Additionally, increases in the discount rate will not only reduce the stock, but it will reduce the discounted value of revenue, and therefore present discounted welfare. As we did before we can define the optimal value function in terms of the discount rate:

$$J(r) = \int_0^{\infty} \left\{ \left[p\theta S(r)L^R(r) + (L - L^R(r)) \right] e^{-rt} - \theta S(r)L^R(r) + \lambda(r) \left[\gamma S(r)(1 - S(r)/C) \right] + S(r)\dot{\lambda}(r) \right\} \cdot dt + \lambda_0(r)S_0(r) - \lambda_{\infty}(r)S_{\infty}(r) \quad (31),$$

where again $L^R(r)$, $S(r)$, and $\lambda(r)$ are the optimal values for the variables. From this function we can see that increasing the impatience, obviously diminishes the discounted value of revenue, and the discounted welfare achievable with that revenue flow:

$$J'(r) = -\int_0^{\infty} t \cdot \left\{ \left[p\theta S(r)L^R(r) + (L - L^R(r)) \right] e^{-rt} \right\} \cdot dt = -\int_0^{\infty} t \cdot \left\{ [pR + M] e^{-rt} \right\} \cdot dt < 0 \quad (32)$$

As we saw in the previous section, the steady state stock level is very sensitive to increases in the discount rate. As a matter of fact an increase of the discount rate will unambiguously reduce the steady state stock level, sending the economy in a convergence path, in which all of its resources are exclusively used in the production of

the resource good. In the phase diagram, after the impatience rises the $\dot{\lambda} = 0$ schedule shifts up and to the left, while the $\dot{S} = 0$ schedule does not move. That accounts to an unambiguous reduction of the stock after the discount rate increases, and higher steady state employment in the resource sector.

On the other hand a technological improvement will also decrease the steady state stock level. The intuition of the result is rather straightforward. Given that labor is more productive in the resource sector, the cost of opportunity of having labor in the manufactures sector increases, and therefore there are incentives for labor to migrate from one sector to another. This effect is captured by the shift in the $\dot{\lambda} = 0$ schedule from the continuous to the dashed line in Figure 8. However, at the same time, the amount of labor required to maintain any steady state stock level is reduced, which reduces or offsets the incentive to move labor from manufactures to resource. This latter effect is captured by the downward shift of the $\dot{S} = 0$ schedule. The end result is an unambiguous reduction of the stock, but an uncertain effect over labor. During the transition, all labor is employed in the resource sector as the stock of the resource is being reduced. Once the new steady state stock level is achieved L^R falls to a level that could be higher, lower or the same as the one prior to the technical progress. Note that for any given price the technically advanced country will be consuming more stock at equilibrium. At lower prices this means higher resource good output, but when the price leads the stock to the left of the MSY, the technically advanced country can have a lower resource output than the backward country, which is a rather counter-intuitive result.

We now review the effects of the relaxation of the biological constraints. It is hard to argue that the uncongested growth rate of the resource γ could change, as we assume

that the natural growth rate is given by nature. However, if we think of managed renewable resources, for example agriculture, genetical manipulation is able to achieve this natural productivity enhancement.

Regardless of the feasibility of this, an increase in γ immediately expands R output, and expands the Maximum Sustainable Yield of the sector. As the biological constraint is relaxed, more labor is necessary to maintain a constant steady state stock level, which attracts more labor into the resource sector, as reflected by an upward shift of the $\dot{S} = 0$ schedule in Figure 9. Additionally, relaxing the biological constraint makes the same amount of labor employed in the resource sector more productive, which also attracts more labor, remember that in steady state growth of the stock equals resource output (equation (5)). This latter effect is captured by the shift in the $\dot{\lambda} = 0$ schedule to the new dashed curve. As it comes clear from the picture both effects increase the steady state employment of labor in the resource sector. From the picture however, the effect on the steady state stock level is uncertain. However, we prove in Appendix 1, that when the natural growth rate of the stock augments, the steady state stock also increases. Finally, as both L^R and S increase, we get the rather intuitive result that steady state resource output has also, unambiguously increased; regardless if the economy is to the left or to the right of the Maximum Sustainable Yield. The transition to the new steady state is given by a reduction in L^R to zero while the stock grows until it reaches its new steady state level; at that point in time L^R grows to a level larger than the original, and the resource output is bigger than the initial.

IV. Trade and Welfare. Concluding Remarks

As stated above, the resource rich country, with autarky price lower than the international price will export the resource good throughout the transition period. However, at the new steady state the country could end up producing less or more resource output. Thus in the new equilibrium the same country that initially exported the resource good could perfectly end up importing it, or not trading at all. If the latter is the case this country exported the resource good only during the transitional dynamics, but not at equilibrium. This is a very important result of the model because it seems to capture an observed behavior of some developing countries. Severe deforestation in tropical countries seems to be more consistent with a transitional dynamics phase, than a behavior consistent with biological equilibrium (steady state). By definition at equilibrium stock levels do not change. Also the model can be consistent with a scenario where one small country supplies the world with the resource good, until its stocks are diminished to low productivity levels, at which point another country has to open to supply the natural good.

As we explained above, this behavior that appears so extreme, in the limited view of the model could be not only optimal, but welfare improving. When property rights are not well enforced, however, this behavior is not optimal, and we showed that a country with these kinds of problems will miss the optimal equilibrium level, always, by overexploiting it. It is therefore, an empirical issue to determine if the behavior of the country rapidly consuming its natural stocks is externality free or not. We recognize, anyhow, that the passionate response against trade among many, and in many parts of the world may be reflecting that the natural stocks have economic value above and beyond

their productive value. If this is the case we should be thinking about expanding the model to include this existence values.

Figure 1 Resource Stock Dynamics

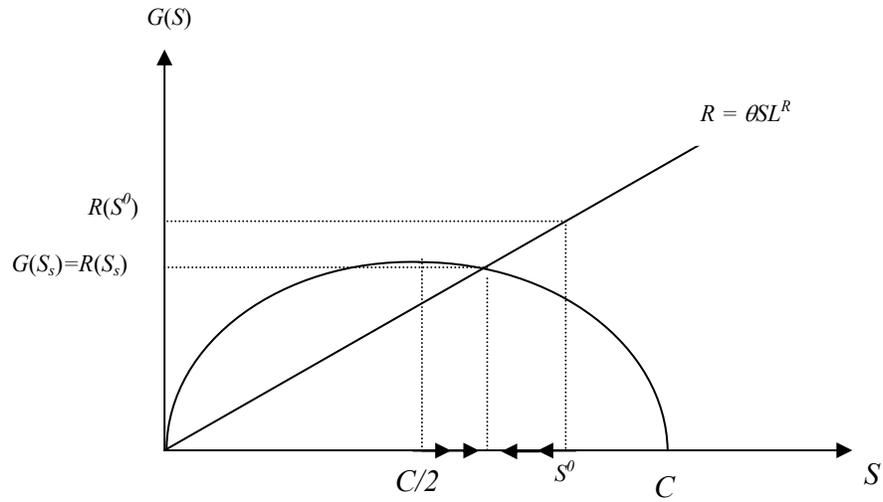


Figure 2 Convergence to Steady State from the Pristine Environment Scenario

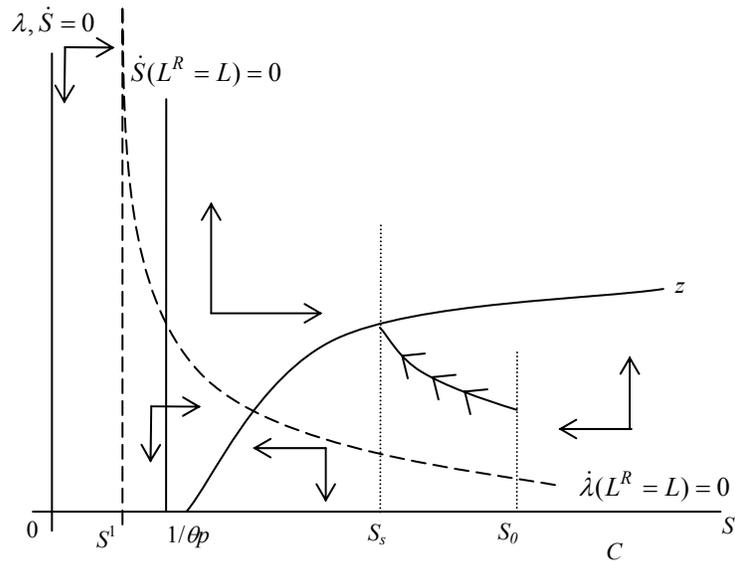


Figure 3 Steady State

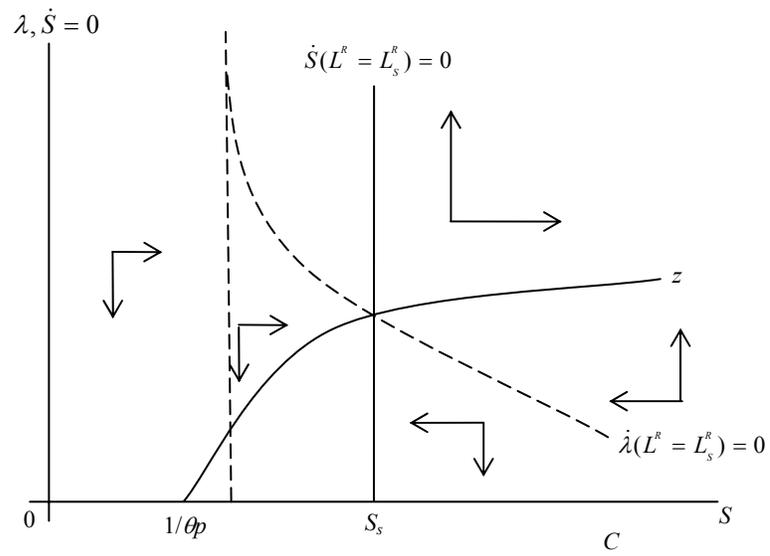


Figure 4. Depleted Environment Scenario

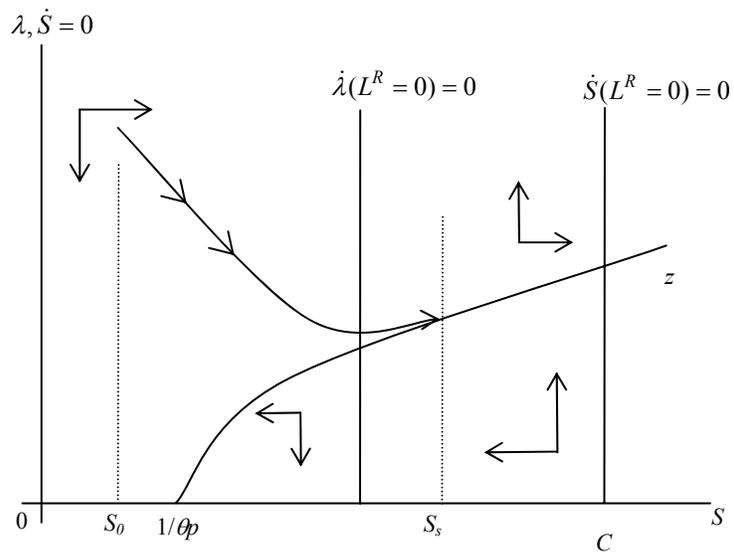
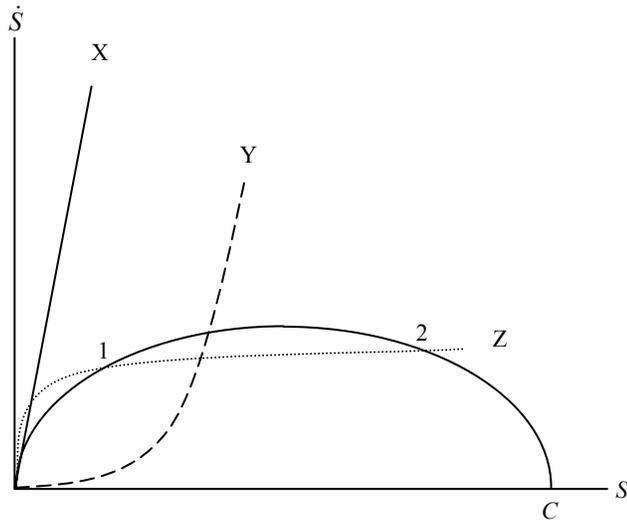


Figure 5 Equilibrium in the Resource and the Resource Good in the Closed Economy

a)



b)

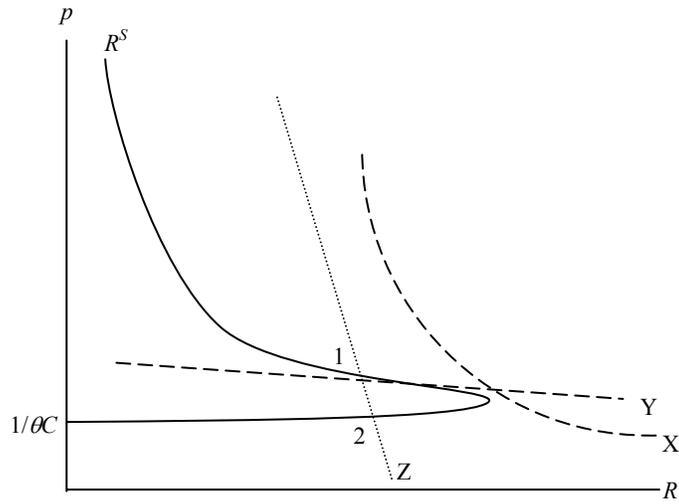


Figure 6. Stock – Labor Dynamics

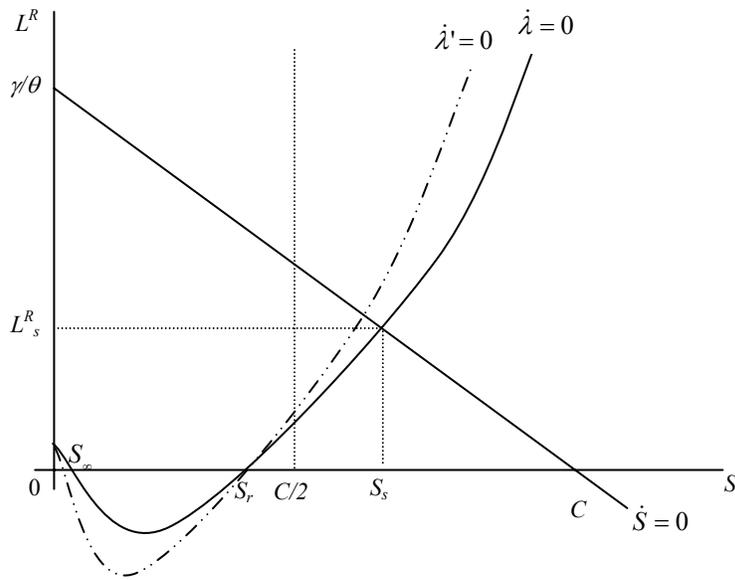
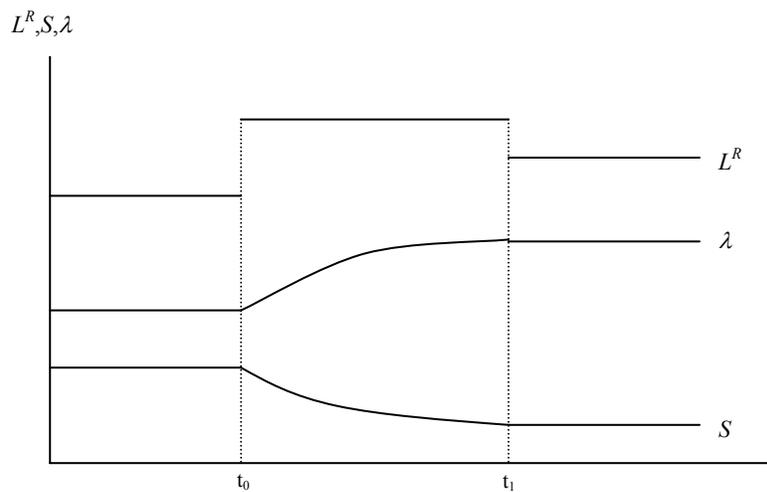
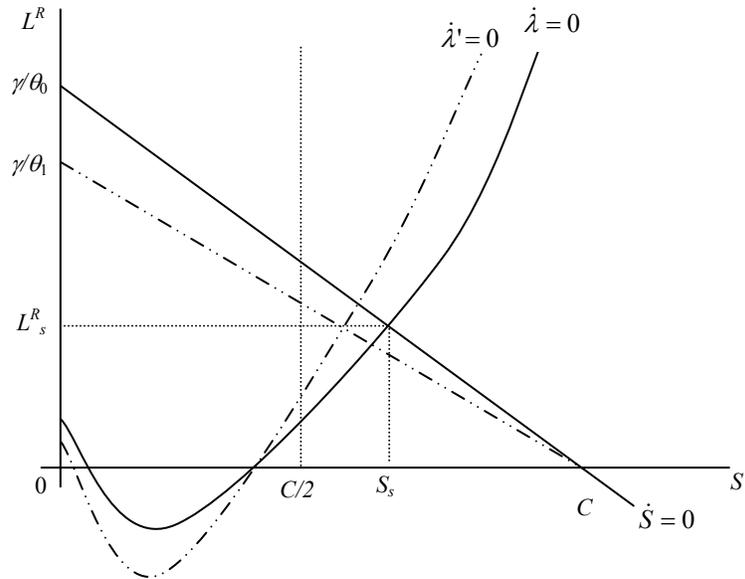


Figure 7 Dynamics of Labor Stock and Shadow Value Following a Price Increase



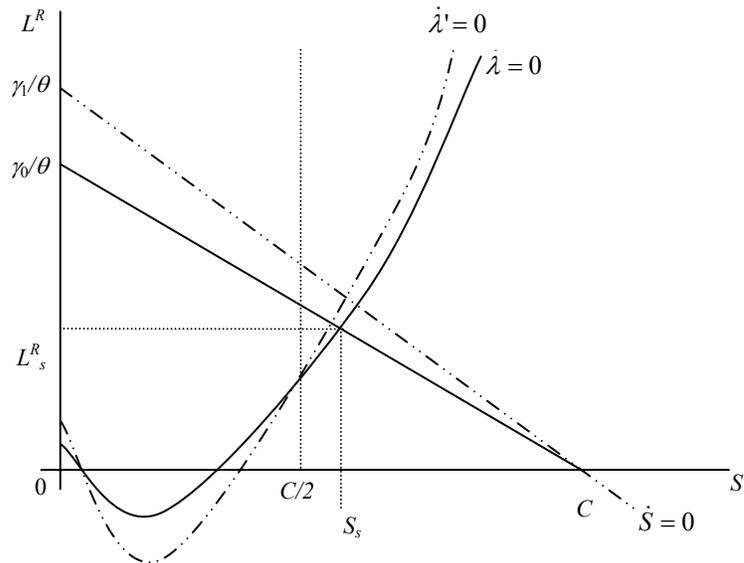
Note: At time $t=t_0$ the price increases, at $t= t_1$ a new steady state is achieved.

Figure 8 Effects of Technological Progress



Technology improves with increased labor productivity from θ_0 to θ_1 with $\theta_1 > \theta_0$.

Figure 9 Effects of Increased Natural Growth Rate of the Resource



The natural growth rates augments from γ_0 to γ_1 .

Table 1 Normalized Steady State Stock Level

δ	DMSY	Σ_{∞}									
		1.00	0.99	0.90	0.75	0.50	0.25	0.12	0.05	0.01	0.00
0	0.500	1.000	0.995	0.950	0.875	0.750	0.625	0.560	0.525	0.505	0.500
0.01	0.495	1.000	0.995	0.950	0.874	0.748	0.622	0.556	0.520	0.500	0.495
0.10	0.450	1.000	0.995	0.947	0.868	0.734	0.596	0.522	0.480	0.456	0.450
0.25	0.375	1.000	0.994	0.944	0.859	0.713	0.556	0.467	0.415	0.383	0.375
0.50	0.250	1.000	0.994	0.939	0.847	0.683	0.500	0.387	0.315	0.264	0.250
1.00	0.000	1.000	0.993	0.933	0.828	0.640	0.422	0.277	0.171	0.073	0.000
1.25	-0.125	1.000	0.993	0.930	0.821	0.625	0.395	0.243	0.134	0.039	0.000
1.50	-0.250	1.000	0.993	0.928	0.815	0.612	0.375	0.220	0.111	0.028	0.000
3	-1.000	1.000	0.992	0.919	0.793	0.569	0.315	0.163	0.072	0.015	0.000
5	-2.000	1.000	0.991	0.913	0.780	0.545	0.289	0.144	0.061	0.012	0.000
10	-4.500	1.000	0.991	0.908	0.767	0.524	0.269	0.131	0.055	0.011	0.000

Table 2 Normalized Steady State Stock Level in the South when the Open Access Level, Σ_{∞} , is 1/4.

$\delta \setminus \phi$	0.01	0.1	0.25	0.5	0.75	0.9	1
0	0.625	0.625	0.625	0.625	0.625	0.625	0.625
0.01	0.422	0.596	0.613	0.619	0.621	0.622	0.622
0.10	0.269	0.422	0.521	0.569	0.587	0.593	0.596
0.25	0.258	0.328	0.422	0.500	0.536	0.549	0.556
0.50	0.254	0.289	0.347	0.422	0.469	0.489	0.500
1.00	0.252	0.269	0.299	0.347	0.388	0.409	0.422
1.25	0.252	0.265	0.289	0.328	0.364	0.383	0.395
1.50	0.251	0.263	0.282	0.315	0.347	0.364	0.375
3	0.251	0.256	0.266	0.282	0.299	0.309	0.315
5	0.250	0.254	0.259	0.269	0.279	0.285	0.289
10	0.250	0.252	0.255	0.259	0.264	0.267	0.269

Appendix 1. Effects of an Increase in the Natural Growth Rate in the Steady State Stock Level.

We want to show that there is a positive relation between the intrinsic growth rate of the resource and the steady state stock. We begin by differentiating the normalized steady state stock as defined by (24):

$$(A-1) \quad \frac{\partial \Sigma_s}{\partial \gamma} = \frac{1}{4} \left[\begin{array}{l} -\frac{\partial \delta}{\partial \gamma} - \frac{\partial \delta}{\partial \gamma} 2(1 - \delta + \Sigma_\infty) \frac{1}{2} \left((1 - \delta + \Sigma_\infty)^2 + 8\delta \Sigma_\infty \right)^{-1/2} \\ + \frac{\partial \delta}{\partial \gamma} 8\Sigma_\infty \frac{1}{2} \left((1 - \delta + \Sigma_\infty)^2 + 8\delta \Sigma_\infty \right)^{-1/2} \end{array} \right]$$

Using the definition of δ , that is r/γ , the partial derivative can be simplified to:

$$(A-2) \quad \frac{\partial \Sigma_s}{\partial \gamma} = \frac{\delta}{4\gamma} \left[\frac{\sqrt{(1 - \delta + \Sigma_\infty)^2 + 8\delta \Sigma_\infty} + (1 - \delta - 3\Sigma_\infty)}{\sqrt{(1 - \delta + \Sigma_\infty)^2 + 8\delta \Sigma_\infty}} \right],$$

First note that what is inside the square root of (A-2) is always positive, as it can be equivalently written as: $\sqrt{(1 - \delta)^2 + 6\delta \Sigma_\infty + \Sigma_\infty^2 + 2\Sigma_\infty}$. Of course this is necessary to guarantee that the steady state stock is a real number. Then, the numerator of (A-2) will determine the sign of the derivative. We can show that it is always positive:

$$\sqrt{(1 - \delta + \Sigma_\infty)^2 + 8\delta \Sigma_\infty} > (1 - \delta - 3\Sigma_\infty);$$

$$(1 - \delta + \Sigma_\infty)^2 + 8\delta \Sigma_\infty > (1 - \delta - 3\Sigma_\infty)^2;$$

$$-8\Sigma_\infty^2 + 8\Sigma_\infty > 0.$$

The last inequality holds by definition of $\Sigma_\infty \in (0,1)$, which proves our

result, $\frac{\partial \Sigma_s}{\partial \gamma} > 0$.

Chapter 3:

North-South Trade in the Ricardo-Schaefer Model

I. Introduction

When dealing with dynamic problems, economists, too often, end up choosing from two unsatisfactory options. The first option is to focus in the equilibrium or steady state behavior, and draw the conclusions from that analysis. The other option, and probably less desirable, is to limit the analysis to the smaller set of problems that can be portrayed by the reduced set of dynamic equations with solutions that are known to us (i.e. can be analytically integrated, or in the case of discrete dynamic programming, the value function can be found).

The allure of equilibrium / steady state analysis is quite obvious. In some cases only the equilibrium analysis is relevant. Growth models come immediately to mind, where the equilibrium behavior is what explains growth and better reflects the observed stylized facts like relatively fixed long run assets' rates of returns. Furthermore, steady states can be solved for analytically using first order conditions. This allows the

economist to make unambiguous statements of the sort: if the rate of returns rises, the equilibrium consumption level falls.

The problem with equilibrium analysis is that in most problems one is interested in the whole planning horizon. The researcher usually wants to know the behavior of the economic agent given initial conditions, not how to maximize equilibrium levels nor the behavior given equilibrium conditions. Furthermore, as we show in this chapter, not all problems converge to equilibrium or have equilibrium, which can make the whole equilibrium analysis misleading. This difference between equilibrium and the whole horizon is well-known to economist, but too often they ignore it; as in the example above, the fall in equilibrium consumption is acknowledged, but not the fact the over the whole horizon the agent is better off.

Let us compare the economist with what the engineer does. The proverbial rocket scientist, for example, solves problems with a mathematical representation very similar to the economist problems. Some of the parameters of his equations are given by nature, i.e. gravity, and others he controls like mass and thrust. Although, like the economist, he can not solve his problem symbolically, he will find the trajectory of his rocket using numerical approximations. The rocket scientist can fine tune his calculations until he gets the exact trajectory. The intrinsic difference between the engineer and the economist problem solving is that while the first is generally interested in the solution itself, the economist is more ambitious, he is interested in describing the solution; that is, how the solution changes when we change any given parameter.

Given that economists want to *describe* the solution to dynamic problems, we admit that numerical methods are really not very efficient for the purpose. As we do in

this chapter, it requires to numerically study the solution around all the relevant parameter space. This amounts to, as we say in Spanish, hit around with a stick like a blind man. However, this option is better than to be completely blind to the real problem: the solution to the *whole* planning horizon, not just the equilibrium.

In this chapter we deal with trade in a dynamic context, as both trading partners manage a renewable resource. We assume both countries produce two goods, one of them using a renewable resource as a production factor; and that both countries are equivalent in every respect except for open access to the resource in one of them (the South). By definition, even if we assume, as we do, that countries start from autarkic equilibrium, when trade begins, trade encompasses off-equilibrium behavior. Even though we use very simple dynamic equations, the path countries follow when they open to trade can only be compared using numerical methods. The exercise of describing the solution numerically across all relevant parameter space is only possible because we possess nowadays machines that can perform, literally, millions of tedious arithmetic operations within the blink of an eye. It is nonetheless, a cumbersome and tedious endeavor, but we believe it is a small step in the right direction.

Given that we use ‘well behaved’ concave utility and resource growth functions, the numerical approach should not provide results that are completely unexpected. Nonetheless, we present a good share of surprising results. First of all, we find that equilibrium analysis of these type of 2x2 trade models that uses a renewable resource as factor of production is not always valid, as done for example in Brander and Taylor (1997b), because the steady states are not attainable as we will show. Also, we find that this lack of equilibrium can lead the externality free country to lose with trade. This

unexpected result can occur because the externality free country does not plan for the lack of equilibrium in which it ends up; this lack of equilibrium can some times benefit or in others hurt this country.

Furthermore, we discover that in this ‘externality based’ trade the reduction in the overall environmental stock is very small, always less than $\frac{2}{3}$ of 1% if we assume a rather plausible share of consumption of resource intensive goods of less than 50%. If we accept that consumption share, we also find, to our surprise, that the trade induced losses in the country with the externality are rather small, always less than 6%, and much smaller for plausible parameters.

We invite the reader to find more insightful results from our numerical exercise below. In the next section we present the autarky and trade behavior of both countries. We follow by presenting the results of the numerical exercise of simulating trade between the countries, as well as delving into the question of why steady states are not achievable. Finally we conclude, highlighting many policy implications that can be derived from the theoretical and numerical exercises.

II. The Model

1. Countries’ General Characteristics

We assume that both countries have the same technology, preference and nature, i.e. environmental endowment. The only difference between the North and the South lies in their management of their natural resources, or equivalently the property regime prevailing over natural resources. Both countries produce two goods with constant returns

to scale to the competing factor, labor, as in the standard Ricardian trade model. The two goods are, a natural resource intensive good, R , and an alternative sector we call manufactures for exposition purposes:

$$\begin{aligned} R_i &= \theta S_i L_i^R ; \\ M_i &= L_i^M \end{aligned} \quad (1),$$

for $i=N, S$; North and South, and θ is a productivity factor²¹. Labor is in fixed supply, $L = L_i^R + L_i^M$, which ensures that when both competing sectors are producing, i.e. there is no specialization, wages are equalized. For further simplification we assume that M is the numeraire, which ensures that wages are equal to 1 when there is diversification in these economies.

Note that in (1), S_i the stock of natural resources, behaves as a sector specific factor of production in the resource sector. If S_i was available in fixed supply, this would still be a standard Ricardian economy, however, natural resources have dynamics determined by the interaction of nature's ability to regenerate, and the demands exerted by men exploiting these resources.

$$\dot{S}_i = G(S_i) - R_i(S_i) \quad (2)$$

These interactions are captured in (2) which indicates that the change in the stock is determined by the difference of its own natural capacity to grow and the output of resource intensive good. The natural growth function $G(S_i)$, possesses the

²¹ The choice of Ricardian technology, in this chapter where we use numeric methods, is not founded in the simplicity and the availability of solutions. Even with this simplest of technologies, the description of the trade dynamics requires the use of numerical approximations. We nonetheless stick to the linear technology assumption because: (i) it allows the formal algebraic analysis to proceed further; and (ii) as we explained in the previous chapter it is very popular in the renewable resources literature, and also in the trade and renewable resources literature (see for example Brander and Taylor (1997b) or McAusland (2005)).

characteristics usually attributed to renewable resources growth functions: $G(0) = G(C) = 0$; $G''(S_i) < 0$; when the resource becomes extinct it can not grow; at its maximum stock capacity, C , known as the carrying capacity, it can not grow either; and it is concave. Concavity, reflects the nature of renewable resources as usually at low stock levels growth should be increasing in S_i , but once the stock is large enough there is overcrowding and the natural growth levels become decreasing in the stock. For analytical and evaluation purposes we will be using indifferently the general functional form or the most widely used renewable resources growth function, the logistic form,

$$G(S_i) \equiv \gamma S_i (1 - S_i / C), \quad (3)$$

where γ , is the uncongested growth rate, and C the carrying capacity.

Workers are also consumers, and we define their utility function with homothetic Cobb-Douglas preferences,

$$U(r, m) \equiv r_i^\alpha m_i^{1-\alpha}; \quad \alpha \in (0, 1), \quad (4)$$

where lower case is used for the goods to differentiate demand from production quantities.

2 The Closed South Economy

What defines the South is an open access to the natural resources, that is: either there are no complete property rights on natural resources, which makes producers consider only their private costs and not the costs that their production decision imposes on the renewable resources; or there are no property rights and a government fails to impose an optimal tax (or tax equivalent) to make producers internalize the costs of their production decisions on the stock of the resource. Realistic modeling should imply that the myopia

of producers' current decisions on future availability of resources should not be absolute, but somewhere in between complete blindness and optimal dynamic management. However, to ease on notation and to simplify numerical computations we will assume that in the South the myopia is complete²². Note however that this simplifying assumption does not change the qualitative results presented below.

Thus, the workers-producers in the south, ignoring the restrictions imposed by nature (2), maximize revenues:

$$\text{Max}_{L_S^R} \{ p\theta S_S L_S^R + (L - L_S^R) \}. \quad (5)$$

The first order conditions for their problem indicates that:

$$p_S = 1/(\theta S_S), \quad (6)$$

the supply price should be equal to the marginal rate of transformation for this economy, or the per unit cost of production of the resource good. On the other hand, these same producers want to consume at an optimal ratio. From the consumers' maximization problem we know that,

$$p_S = \frac{\alpha m_S}{(1 - \alpha)r_S} = \frac{\alpha(L - L_S^R)}{(1 - \alpha)\theta S_S L_S^R}, \quad (7)$$

where the right hand equality comes from the goods market clearing conditions for this closed economy. Equating (6) and (7) we discover that $L_S^R = \alpha L$ always, regardless of the scarcity or availability of the resource or the prevalent market price.

The transition in the closed economy is depicted in Figure 10 with the bold line a-a. It shows that regardless the stock level, labor in the resource sector is fixed at αL . Also,

²² The intermediate case was analyzed in the previous chapter.

although the dynamics of the resource stock are ignored, for each effort level there is only one equilibrium (steady state) stock level; solving for $\dot{S}_s = 0$ in (2):

$$L_s^R = \gamma / \theta \cdot (1 - S_s / C) \quad (8)$$

If the initial stock is above the autarky steady state level $S_s^* = C(\gamma - \theta\alpha L) / \gamma$, the fixed amount of labor employed will reduce the stock of natural resources until its steady state level is achieved²³. Throughout this transition the price is increasing as S_s diminishes.

If this economy opens to trade, then the transition would be different. In autarky this economy is forced to produce both goods at all times because the two of them are essential. However, if trade is allowed and the international price is different from its marginal rate of transformation this economy will specialize, allocating all the labor resources to either one of the goods like in a standard Ricardian trade model. If the international price p^* is greater than producers' unit cost $1/(\theta S_s)$, then revenues are maximized by producing only R , while South's demand for manufactures is covered by foreign producers.

The transition for an open South economy is described by the disconnect schedule b-b. It shows that during transition L_s^R takes either extreme value 0 or L . If initially the international price p^* is higher than the domestic price then L_s^R becomes L and the economy remains specialized in the production of R until the new optimal resource stock level is achieved S_s^1 , which is simply equal to $1/(\theta p^*)$. Note that even if the rate of extraction was unsustainable, as drawn in Figure 10 with $L > \gamma / \theta$, the stock would not

²³ From the formula of steady state stock level, the reader can see that if $\theta\alpha L > \gamma$, the natural resource would be extracted unsustainably until extinction. Thus we assume here forth that $\gamma > \theta\alpha L$.

be driven to zero. Extinction under trade requires $p^* = \infty$, which is not reasonable or interesting.

3 The Closed North Economy

In the North the effects of resource extraction on future availability are accounted for, thus they maximize the North equivalent of revenue function (5), which adds current and all future revenues discounted by a constant rate, r ,

$$\text{Max}_{L_N^R, S_N} \int_0^{\infty} \{p\theta S_N L_N^R + (L - L_N^R)\} e^{-rt} \cdot dt, \quad (5)'$$

but also subject to the resource availability constraint,

$$\dot{S}_N = G(S_N) - \theta S_N L_N^R \quad (2)'$$

From the first order conditions of the revenue maximization we find that the producers' price is:

$$p_N = \frac{1}{\theta S_N} + \lambda \quad (9).$$

In the North the producers price is equal to the marginal rate of transformation $1/(\theta S_N)$ plus a premium λ which represents the marginal user cost. This premium, which can be viewed as a tax, accounts for both, the relative scarcity of the resource as well as the effect of current extraction on future availability.

Equating the producers price (9), to the demand price, which is equivalent to the South's demand price (7), as preferences are identical, we find that labor employed in the resource sector is:

$$L_N^R = \frac{\alpha L}{1 + (1 - \alpha)\theta S_N \lambda} \quad (10).$$

This expression shows that during transition labor employed in the resource sector is changing (unlike in the South), but at no point is resource extracting effort in the North as high as in the South. From this latter result, $L_S^R > L_N^R$, it follows that the steady state level of the resource in the North is higher than in the South: $S_N^* > S_S^*$.

To describe the transition to steady state for the North we first note that the dynamics of the optimal tax λ are given by:

$$\dot{\lambda} = \frac{-L_N^R}{S_N} + \lambda[r - G'(S_N)] . \quad (11)$$

To view the transition in the multiplier-state space we draw in Figure 11 a phase diagram with the schedules which represent the equilibrium for λ and S_N :

$$\begin{aligned} \lambda|_{\dot{S}=0} &= \frac{\theta\alpha L - G(S_N)/S_N}{(1-\alpha)\theta G(S_N)} \\ \lambda|_{\dot{\lambda}=0} &= \frac{-1 + \sqrt{4(1-\alpha)\theta\alpha L}}{2(1-\alpha)\theta S_N} . \end{aligned} \quad (12)$$

A feasible transition to steady state for the closed North economy is shown by the saddle path a-a schedule. If the stock of the environmental resource was initially below its equilibrium point, during the transition the stock of the resource would be growing towards equilibrium accompanied by a falling optimal tax. This implies that during transition the relative price of goods is falling as well. Note also, that in Figure 11 it is

²⁴ Equation (11) follows from the first order condition for the multiplier of the revenue maximization problem after incorporating condition (9).

²⁵ The schedules in (12) are obtained solving for λ at $\dot{S}_N = 0$, from (5)' and $\dot{\lambda} = 0$ from (11), after replacing labor in the resource sector as function of the state and the multiplier from (10)

graphically shown that $S_N^* > S_S^*$, as the positively sloped schedule for equilibrium in the resource intersects the S_N axis at S_S^* .

To describe the path of labor we show in Figure 12 equilibrium in the L_N^R, S space. In the figure, the restriction imposed by the growth of the resource, the North equivalent of (8) is shown as the negatively sloped schedule together with the schedule that describes equilibrium in the optimal tax:

$$L_N^R \Big|_{\dot{\lambda}=0} = S_N [p_N - 1/(\theta S_N)] [r - G'(S_N)]. \quad (13)$$

The path of labor in the resource sector in the closed economy is describe by schedule a-a. The schedule, shows that while the stock is growing towards equilibrium, labor in R is increasing. However, schedule a-a assumes that during transition λ is falling at a higher rate than S_N is growing, which needs not be always the case. Thus, a negatively sloped a-a transition schedule is also possible.

If the North opens to trade it will, like the South, try to specialize, as shown by the trade transition schedule b-b. When the country opens to trade it will specialize in either good production to maximize revenue, while the demand for the good not produced is covered by foreign producers. If the trading price is lower than the autarky price, the North will specialize in the production of manufactures, allowing the stock to grow until its new optimum in S_N^1 is achieved which is defined by $p^* = 1/(\theta S_N^1) + \lambda(S_N^1)$. The details of this transition have been extensively described in the previous chapter where we studied the case the North being a small open economy, unable to affect international prices. Before, we proceed to analyze this 2x2x2 model we need to recall this optimal response, which like in the South is specialization.

The optimal level of accumulation of the natural resource, in autarky, assuming the logistic growth function (3), can be expressed in its simplest form by:

$$S_N^* = \frac{C}{2(1+\alpha)} \cdot \left[2\Sigma_S^* + 2\alpha - \delta - 1 + \sqrt{(2\Sigma_S^* + 2\alpha - \delta - 1)^2 + 4[(1+\alpha)(\delta-1)\Sigma_S^* + (1-\alpha^2)]} \right] \quad (14),$$

where $\delta \equiv r/\gamma$ and Σ_S is the South steady state stock level with the carrying capacity (maximum stock level) normalized to 1, i.e. $S_S^*/C = (\gamma - \theta\alpha L)/\gamma$. Although, it is not immediately apparent from (14) that $S_N^* > S_S^*$, exploring the limits of this expression we can learn something about the behavior in the north. For example, $\lim_{r \rightarrow \infty} S_N^* = S_S^*$ which shows that South's myopia of not accounting for their production decisions on the environment is only optimal when the discount rate is infinity, in other words when the value of future welfare is zero. Furthermore, we find that when manufactures are not valued, i.e. alpha tends to 1, the optimal stock tends to $\frac{1}{2}$ of its maximum level: $\lim_{\alpha \rightarrow 1} S_N^* = C/2$. This latter result suggests that the optimal stock in the North would never fall below this level, however this is not true. If the discount rate r is larger than nature's maximum marginal ability to reproduce γ , then it is possible for the optimal stock to be less than $C/2$ (note that the growth function is maximized at $C/2$). What is always true though, as can be viewed in Figure 12, the discount rate is always greater than the marginal ability of the resource to regenerate ($r > G'(S_N)$).

III. North-South Trade

In the previous section we described the autarky equilibrium for the North and South economies. To limit the initial conditions (for the purpose of numerical simulations)

when countries engage in trade we will only use their autarky equilibrium starting levels, instead of other arbitrary positions.

To analyze the different welfare outcomes for both countries we propose a taxonomical analysis. The first division, of course is the direction of trade. Under “normal” or expected conditions, the over-extraction in the South is also accompanied by a cheaper relative resource price. Under these circumstances the South would export the resource good and import manufactures. If additional assumptions are made (to be detailed below), and the resource is extremely depleted in the South it is possible for the resource good to be more expensive initially in the South; in which case the direction of trade would be reversed, with the South importing the resource good. At a next level of classification we examine the trade paths during which countries specialize, and those where they can not. Given the linear technology of this Ricardian model, static welfare gains during trade can only be achieved if the country can specialize in the production of either good. Additionally, trade will alter the levels of accumulation of natural resources, imposing dynamic gains or losses which occur regardless of static effects of trade. Sometimes, static and dynamic effects act together and on other occasions they compensate each other as we will see below.

The prevalent price during trade must be such that there is equilibrium in both good markets. From, Walras’ Law, we know that in this two market model, it is enough to look at one of them, thus market clearing requires $p^*(r_N + r_S - R_N - R_S) = 0$, which is:

$$p^* \left(\frac{\alpha(p^* \theta S_N L_N^R + L - L_N^R)}{p^*} + \frac{\alpha(p^* \theta S_S L_S^R + L - L_S^R)}{p^*} - \theta S_N L_N^R - \theta S_S L_S^R \right) = 0 .$$

The price that guarantees equality of international supply and demand in both good markets can be expressed as:

$$p^* = \frac{\alpha(2L - L_N^R - L_S^R)}{(1 - \alpha)(\theta S_N L_N^R + \theta S_S L_S^R)} . \quad (15)$$

Assume that initially as expected, $p_N > p_S$, and that as trade starts, the North with comparative advantage in manufactures, specializes in this sector, i.e. $L_N^R = 0$, then in such a case, the international price would simplify to: $p^* = \alpha(2L - L_S^R)/[(1 - \alpha)\theta S_S L_S^R]$. As can be seen from this latter expression, any increase in South's production of the resource good (i.e. an increase in L_S^R), would reduce the international price. The limit to this price reductions is the original price in the south, p_S ; profit maximizing behavior in the South bars producers from selling at below their cost of production. Recalling, that the price in the South is $(\theta S_S)^{-1}$, it can be shown that the maximum level of employment in the resource sector, which equates the international price to that prevalent in the south is $L_S^R = 2\alpha L$. Thus, if $\alpha < 1/2$, the South can not specialize in the resource good, where it has comparative advantages.

Perhaps, a more intuitive explanation of the same result may be achieved examining the manufactures market. Demand for manufactures always is $m_i = (1 - \alpha)Y_i$, where Y_i is national income of country i . For a specialized North, national income is simply L . While in the South, national income is $p^* \theta S_S L_S^R + L - L_S^R$, however if the international price is equal to the price in the South (which would happen if the South can not specialize in the resource good), then income would also be L . In this case, total demand for manufactures would be $2(1 - \alpha)L$. If $\alpha < 1/2$, demand can not be satisfied by

one country (North) even if it is fully specialized producing L manufacture units, the other country (South) has to produce the remainder $L - 2\alpha L$ units. That production level of manufactures is achieved in the South when $L_S^R = 2\alpha L$. Thus, when there is a preference bias for manufactures ($\alpha < 1/2$), trade will be initially characterized by one country specializing in manufactures (North), and with the other (South) being unable to specialize in the production of the resource good. This is the case we proceed to analyze first.

1. Case 1: South Exports the Resource Good, But can not Specialize. The case of Manufactures Preference Bias ($\alpha \leq 1/2$).

As explained above, when there is a preference bias for manufactures, and assuming as in most cases that initially $p_N > p_S$, then as the countries begin trade, labor is reallocated in the trade partners to $L_N^R = 0$, $L_S^R = 2\alpha L$, and the international trading price is established at: $p^*(0) = p_S = (\theta S_S^*)^{-1}$. The increased harvesting effort in the South will start reducing the stock of natural resources which was at steady state before trade started, with a lower extractive effort level αL , as shown in path *b* in Figure 13. The South, effectively blind to the dynamic effects of their production decision will continue this production pattern as the international price rises together with the fall in S_S .

In the North, when trade starts, they observe that the trading price is p_S , a price for which they develop a revenue maximizing program for the harvesting premium λ . This program consists in setting the premium high enough, so as to make the resource sector not profitable, guaranteeing specialization in manufactures, but allowing this

premium to fall and to equal exactly $p^*(0) - 1/(\theta S_N)$, when the stock in the north has grown to its new optimal S_N^F (optimal for the prevalent price), as shown in path a in Figure 13. However, as time passes by, the price of the resource will grow, and a new program for a smaller optimal stock level is designed. This recalculating effort is repeated infinitely as the international price rises, and the domestic natural asset grows, until a moment (t_1) in which the current trading price and accumulated stock makes it optimal to diversify production, at stock level like S_N^D where harvesting is renewed with effort level L_N^{RD} , as shown in Figure 13. This behavior of continually reassessing the revenue maximizing program is rather awkward, but the only consistent with price taking behavior, which is the essential assumption of perfect markets. A “non-awkward” behavior of internalizing the best response of the South, and its implied effects on stock and prices, from the beginning, is monopoly behavior. However, it is important to note, that although the optimal program has to change as the international price grows, the policy is always the same: specialize in manufactures, until a diversification stock level is achieved.

It is relevant to note that diversification will be achieved, before there is extinction in the South (even if $2\alpha L > \gamma/\theta$), and before the stock in the North reaches its maximum carrying capacity C , in fact $p_N > p^*(t_1) > p_S$. The fact that the diversification price is higher than the price in the south initially follows from the fact that the international price is always equal to the terms of trade in the South, i.e. $(\theta S_S)^{-1}$, which are increasing as the stock is depleted. On the other hand, the price at which the North

will diversify is falling during transition. To show this we define the diversification price in the North, which is:

$$p_N^D = \frac{1}{\theta S_N} + \lambda^* = \frac{1}{\theta S_N} + \frac{L_N^{R*}(S_N)}{S_N (r - G'(S_N))}, \quad (16)$$

where λ^* and $L_N^{R*}(S_N)$ are the harvesting premium and labor in the resource sector evaluated at steady state, because diversification only occurs at steady state. The change in the diversification price with respect to the stock in the North is:

$$\frac{\partial p_N^D}{\partial S_N} = \frac{-1}{\theta S_N^2} + \frac{\partial L_N^{R*} / \partial S_N \cdot S_N (r - G'(S_N)) - (r - G'(S_N)) \cdot L_N^{R*} + S_N G''(S_N) \partial L_N^{R*}}{[S_N (r - G'(S_N))]^2} < 0,$$

which is unambiguously negative because: (i) $r \geq G'(S_N)$ always in steady state; (ii) $\partial L_N^{R*} / \partial S$ is always negative, because in steady state $L_i^{R*} = \theta^{-1} \cdot G(S_i) / S_i$ which has a negative derivative due to the concavity of the growth function; and (iii) $G''(S_N) < 0$, again, due to the concavity of the growth function. Thus, as the stock grows in the North during transition, while the country remains specialized in manufactures, the price at which diversification becomes optimal is falling. Altogether, this shows that the price at which the north diversifies after trade begins, will lie between the initial North and South prices. So as countries trade during transition, the international price, which is equal to the terms of trade in the South, is rising, while the price at which the North is willing to diversify is falling. At a moment we label t_1 , both prices are equalized and the North diversifies.

We assume, as we did when trade started, that the good markets clear instantaneously. Hence, when the North diversifies, employing $L_N^{RD} = \gamma / \theta(1 - S_N^D / C)$ in

the resource sector (where $S_N^D \equiv S_N(t_1)$ is the stock level in the north at the time of diversification), the South reduces harvesting effort to:

$$L_S^{RD} = \alpha(2L - L_N^{RD}) - (1 - \alpha)L_N^{RD} \cdot S_N^D / S_S^D \quad (17),$$

which is the maximum effort that the South can employ in producing the resource good without decreasing the international trading price below its own terms of trade (i.e. higher effort would cause negative profits in the South). From the perspective of the North, steady state has been reached, and the country is willing to maintain stock and production quantities as long as the price is $p^*(t_1)$. However, this will not be the case, and the price will change, because the stock of natural resources in the South has not reached a steady state. As can be seen in Figure 13, when the South re-adjusts its labor allocation to L_S^{RD} , the stock level could be in a point like A, where extraction is greater than growth, or in appoint like B, where growth is greater than extraction. Let us assume for now that we are in case like that depicted by point A, but we will later argue that this always the case.

When extraction of the resource in the South is higher than natural regeneration after diversification in the North, stock in the South will, although at a slower pace, still be falling. This fall in the stock means that the terms of trade in the South have changed, and that the comparative advantages have been reverted and the South now can produce manufactures more cheaply than the North. So immediately after diversification, when the terms of trade in the South marginally increased to $(\theta S_S^{D-})^{-1} > p_D^* \equiv p^*(t_1) = (\theta S_S^D)^{-1}$, the South will specialize in the production of manufactures, with the North responding, by trying to specialize in the Resource sector, but, like the South before, it can only produce as much R as possible without reducing its

current terms of trade, i.e. $L_N^R \Big|_{t_1^*} = 2\alpha L / [\alpha + (1-\alpha)\theta S_N^D p_D^*]$, which is lower than $2\alpha L$, because $S_N^D > S_S^D$ —the North is more productive than the South in the production of R , and therefore less effort is required by the North to fill the international market for R .

The pattern of trade just described, which we will call phase 1, is also not stable, and is followed by another unstable phase 2. During phase 1, the stock in the South grew to about S_S^D , because there was no extracting effort, while in the North, the attempted specialization in R decreased the stock of renewable resources to S_N^{D-} . So in phase 2, comparative advantages have been reverted again, which will cause the South to produce R with maximum effort at $2\alpha L$, while the North specializes in manufactures. Again this phase is not sustainable because, S_N will grow and S_S will fall reverting comparative advantages to a situation like in phase 1.

In conclusion, diversification can only last an instant, before the trading partners enter what we will call a bang-bang disequilibrium (as the control variable, labor, jumps while the state variable, the stock, remains relatively stable in both countries). This disequilibrium is characterized by comparative advantages and production patterns forever shifting, but with prices and stock levels remaining in a close neighborhood of their values at the time of diversification. During transition, trade follows a stable pattern, but once the terms of trade of both countries equalize, the current South terms of trade, and the North's steady state terms of trade, there is no more room for accommodation for the accumulated levels of renewable resources. Obviously this bang-bang ending to North-South trade can not be qualified as equilibrium even under the most lax definition of the concept. The bang-bang disequilibrium has important consequences for the trade

evaluation: it invalidates the steady state analysis of trade, simply because it is unattainable by the market. As we will show below it may change the expected results of trade being always beneficial for the country that optimally manages natural resources. In section 5 we explain what causes the lack of an equilibrium, showing that it is not an artifact of the linear technology as may initially be thought.

1.1 Welfare Analysis

Let us start with the North. As explained before, when the trade regime is established welfare in the north jumps (is *reduced*) to the welfare level in the South. In Figure 14, we depict the welfare level in both countries during autarky. We know that the level of natural resources is higher in the North, which means that the production possibility set is larger in the North than in the South, which in itself should mean higher welfare in the North. However, the premium λ paid on the resource good implies that the North does not consume at the welfare maximizing level for their production possibilities set, as depicted in the figure. At least in the graph there is an apparent ambiguity, the tax paid on the resource good can mean that the North could be initially worst off than the South in terms of welfare. This is not the case; in fact the North is initially always better off than the North. The intuitive explanation for this is that the North takes into account the restrictions given by nature in their maximization decision, and thus chooses a steady state stock level that maximizes welfare given this restriction, while South ignores the limits imposed by nature.

We can show this latter result more formally. First we note that in steady state, welfare is a concave function, over the accumulated stock possible set $[0,C]$. In steady

state, $R_i = G(S_i)$ and $M_i = L - \theta^{-1}G(S_i)/S_i$. Using, these definitions, we can solve for the stock level that maximizes steady state welfare:

$$S_i^{**} = \frac{C}{2(\alpha+1)} \left[2(\Sigma + \alpha) - 1 + \sqrt{4\Sigma^2 + 4\Sigma\alpha - 8\Sigma - 4\alpha + 5} \right] \quad (18).$$

This optimal stock is achieved exactly by the North when $r = 0$, that is $\lim_{r \rightarrow 0} S_N^* = S_i^{**}$. As, the discount rate increases, the accumulated level of natural resources diminishes²⁶. In the opposite limit is the South with a behavior which mirrors an $r = \infty$. As the discount rate increases, less valuable is future welfare, thus the stock is accumulated to a level lower than the steady state maximum. Since the North accumulates natural resources to a level lower than the maximum, and the South accumulates natural resources to a level below the North, and given concavity of welfare over S_i , it is always the case that initial steady state welfare level in the North is higher than in the South.

So as the North engages in trade with the South it reduces its welfare to the present level of the South. Note that this reduction in welfare occurs in spite of an improvement in the terms of trade of the North. The income effect of leaving untapped a productive asset dominates, and welfare initially falls. This initial losing is consistent with the nature of the dynamic trade-off, the North is trading present losses for future gains; while it attains less welfare today, it is accumulating wealth by increasing its resource stock level, which will allow in the future better utility levels than in autarky.

²⁶ The easiest way to show that $\partial S_N^* / \partial r$ is negative is to look at expression (13), or its graphical manifestation in Figure 12, to see that as r increases, so does the steady state effort in extraction. Higher extraction effort levels are always accompanied by a reduction of the steady state stock level, given nature's restriction, (2).

Furthermore, as the natural resources are diminished in the South and the trading price increases, welfare in both countries is actually decreasing during transition.

During transition, in the North, the stock of natural resources left un-harvested grows according to its logistic growth function: $S_N(t) = S_N^* / \left[S_N^* / C + e^{-\gamma t} (1 - S_N^* / C) \right]$.

The path of the stock in the South is also known²⁷, and given the path of $p^*(t)$ and p_N^D , there is only one t_1 in \mathfrak{R}^+ , however to obtain it we step from analytical solutions into numerical solutions²⁸. Our numerical simulations indicate as expected, that the time required for diversification to be achieved is longer when the extractive capacity in the South is reduced: low L , low θ , and low α ; as well as the growth of the resource is slow in the North: low γ . However, a surprising result was to discover that $\dot{S}_S \Big|_{t=t_1} < 0$, always, which means that when diversification is achieved, the stock and effort combination in the South is an point like A in Figure 13 and never in a point like B. This result has implications for the initiation of the final bang-bang phase as we discussed above. Our simulations show that although $\dot{S}_S \Big|_{t=t_1}$ is always negative it tends to zero when the difference between S_N^* and S_S^* is small, that is when r is high, and when the difference in \dot{S}_S between initial steady state (0) and the beginning of transition is small. An inspection of Figure 10 indicates that the latter occurs when γ is large and θ , α and L are small.

The welfare level of the North when it diversifies is higher than in transition, and higher than its initial autarky welfare level, so as to compensate for the transition period

²⁷ $S_S(t) = \left[S_S^* (\gamma - \theta 2\alpha L) \right] / \left[S_S^* \gamma / C - e^{-(\gamma - \theta 2\alpha L)t} (\theta 2\alpha L - \gamma + S_S^* \gamma / C) \right]$

²⁸ Please see Appendix 2 for technical details of the numerical simulations.

losses. But as we explained above diversification is not sustainable, and what really matters for our welfare analysis is the welfare attained during the bang-bang phase.

To analyze welfare post-diversification note that we can express it as: $U_i = (\alpha/p)^\alpha (1-\alpha)^{(1-\alpha)} Y_i$. Given that in the bang-bang phase the price remains stable around the neighborhood of $p^*(t_1)$, welfare will depend on income in the different phases. Income on the other hand, depends positively on the amount of labor in the resource sector: $\partial Y_N / \partial L_N^R \Big|_{t \geq t_1} = (p_D^* \theta S_N^D - 1) > 0$, as $p_D^* \approx (\theta S_S^D)^{-1}$ and $S_N^D > S_S^D$. So when the North tries to specialize in the Resource good, adjusting its stock downwards, it is actually achieves higher current welfare than in steady state for the diversification stock level²⁹. Again this behavior is consistent with the dynamic trade-off as the North trades current gains for future losses. During phase 2, the opposite happens, the North by specializing in Manufactures returns, to a lower welfare level, equivalent to the instant before diversification, which is even lower than the South's initial welfare level. Given that the North is going to be half of the time worst-off than the diversified equilibrium and the other half of the time better off, it is not clear that trade is better program than autarky anymore.

We have three programs to compare. Under program A, autarky, we have: $A \equiv \int_0^\infty U(L, S_N^*) e^{-rt} \cdot dt = U(L, S_N^*) / r$. We also have program B, which is the ideal

²⁹ That welfare is higher during phase 1 than in steady state equilibrium at diversification follows from the fact that extractive effort is higher in the former case. To see this consider that effort has to be higher in phase 1, because the South is specialized in Manufactures, as opposed to the diversified equilibrium, where both countries produce the resource good. Therefore, it has to be the case that the labor in the resource is higher during phase 1, than the ephemeral diversified equilibrium.

trade plan for the North, that represents welfare that would have been attained if the diversified trade equilibrium was stable:

$$B \equiv \int_0^{t_1} U(L, p^*(t))e^{-rt} \cdot dt + \int_{t_1}^{\infty} U(L, S_N^D)e^{-rt} \cdot dt = \int_0^{t_1} U(L, p^*(t))e^{-rt} \cdot dt + U(L, S_N^D)e^{-rt_1} / r .$$

We know from theory that program B is better than program A. Finally, there is the real result of trade with a bang-bang final disequilibrium:

$$\begin{aligned} C &\equiv \int_0^{t_1} U(L, p^*(t))e^{-rt} \cdot dt + 1/2 \left\{ \int_{t_1}^{\infty} U_{D1}e^{-rt} \cdot dt + \int_{t_1}^{\infty} U_{D2}e^{-rt} \cdot dt \right\} \\ &= \int_0^{t_1} U(L, p^*(t))e^{-rt} \cdot dt + \frac{(U_{D1} + U_{D2})e^{-rt_1}}{2r}, \end{aligned}$$

where U_{D1} and U_{D2} refer to the welfare levels during phase 1 and 2 respectively. Given that we can rank utility levels: $U_{D1} > U(S_N^D) > U_{D2}$, it is not immediately clear that path C, is better than B, and for that matter better than A. We will answer this question after discussing the welfare implications of trade for the South.

For the South, trade is always a losing proposition under case 1, $\alpha \leq 1/2$. The South never earns static gains from trade, as it is unable to specialize in the Resource good, where its comparative advantages lie; and on the other hand, while it trades it is incurring in dynamic losses, as the depletion of its renewable resource stock diminishes its production possibilities set (i.e. real income). After diversification, utility levels in the South remain stable, as nominal income remains independent of L_S^R , given $p_D^* \approx (\theta S_S^D)^{-1}$, and real income does not change, with price stable around p_D^* .

To compare the South different programs, trade and autarky over the whole planning horizon, we assume that the South's over-harvesting behavior is due to an open access externality, and not due to optimal behavior of a country with an infinite time

discount rate. We assume that the relevant time discounting factor, as well as in all other aspects, is identical to the North's time preferences.

In Table 1 we present some results of the numerical simulations, which help us compare the difference between programs and the magnitude of the gains and losses that trade causes on the trading partners. In the first row of the table we present an arbitrary benchmark case that can be used to compare other results. This benchmark case is characterized by equality of the relative labor, to growth to natural resources, equal productivity of labor in both sectors ($\theta = 1$), a small discount rate, and an arbitrary preference factor for the resource good of $\frac{1}{3}$. In this benchmark case, the South losses of about 3% vis-à-vis the autarky plan, are much higher than the potential gains from trade of only 0.8% for the North, but roughly equivalent to the real gains of the North accounting for the post-diversification bang-bang disequilibrium.

The losses of the trade regime in the South approach a maximum of about 5.9%; we present in rows 2 and 3 two cases representative of the greatest losses for the South. We observe three common characteristics in the cases when the South losses are greatest: (i) slow rate of depletion of the stock in the South, (ii) low discount rate, and (iii) highest preferences for resource good without allowing for static trade gains in the South. As rows 2 and 3 show, it is not important the nominal level of labor or growth rate of resources, but what actually matters is a slow reduction of the stock in the south, which rate is determined by: $|\gamma - \theta 2\alpha L|$ (see footnote 6). Also, a low discount rate will penalize more severely the losses which start accumulating for the South as soon as trade starts. A lower discount rate also means that the fall in level of welfare between autarky and the final diversification level will be lower (because the difference in initial stock levels

between countries is smaller), but the effect of accounting those smaller losses for a longer time dominates. On the other hand the losses in the South, and at the same time gains in the North approach zero, when preference for the resource good is very low, and either discounting of gains/losses is very high relative to growth of the resource (row 5), or extractive capacity (α, θ, L) is very low relative to available resources (γ) (row 4).

In all the rows of Table 3, as well as all the iterations performed, we found that the gains from trade in the bang-bang disequilibrium are higher or equal to the gains from trade obtained if diversification was a steady state equilibrium. Furthermore, while the hypothetical gains of the latter case approach 1.7%, the gains of the former case approach 7.2%. The potential gains approach 1.7% under similar conditions to that that make South's losses greatest: preferences for the resource good as high as possible without allowing static trade gains for the South, low time discount and low rate of depletion in the South. However as opposed to rows 2,3; in rows 6,7 where the potential gains in the North are highest, the rate of depletion is a bit higher, and the level of L and γ appears relevant: when L and γ are highest, the actual bang-bang gains reach a maximum (rows 8,9), while when L and γ are at intermediate values the potential gains reach a maximum rows 6,7. We finally note that although the examples in our table show that the actual gains in the North are larger than the losses in the South, this is not always the case, as the opposite case is perfectly possible and observed. So from the perspective of the World welfare (aggregate South and North welfare) trade can be good or bad.

An important question usually raised against trade in the trade and environment debate is that trade destroys the environment. This is possible in a world were the environment itself is valuable, but its level is not considered in society's objective

function, like in our model. We find that the changes in the stock level of natural resources can be large, losses reaching up to 11.5% for the South, and gains of up to 8.8% for the North. However, we observe that the net effect over the global environment ($S_N + S_S$) is of a much lower range: between -0.6% and 0.4%, and can be actually positive. In rows 10 and 11 we show cases where the negative net effect on the environment is greatest. These scenarios have in common, low preference for the environmental good, low time discount, and high $\theta L/\gamma$ ratio. In rows 12 and 13 we show that the net effect of trade on global environment is positive and largest when there is high preference for the environmental good, $\alpha = 1/2$, together with a low natural growth rate of the resource and low $\theta L/\gamma$ ratio. These are the cases when S_S is lowest, so it is encouraging to observe that there can be a positive net effect of trade on the environment when the depletion of resources is highest in the South.

2. Cases 2 and 3: South Exports the Resource Good and Specializes in It. The cases when the Resource Good is Preferred ($\alpha > 1/2$).

We continue the taxonomical analysis of the North-South trade with the case when $\alpha > 1/2$ and $p_N > p_S$, which as we explained in the previous section allows for specialization and static gains from trade in the South. Under these circumstances, it is possible that the North can also initially specialize, a possibility we label case 2; or only the South initially specializes, in what we label case 3. Of course the welfare implications are that in both cases the South earns static gains from trade, while the North is constrained in its dynamic trade-off in case 3.

Case 2 occurs if the international price (see (15)) when both countries specialize, lies between the initial autarky prices:

$$p_S = \frac{1}{\theta S_S^*} < p^* = \frac{\alpha}{(1-\alpha)\theta S_S^*} < p_N = \frac{\alpha(L-L_N^{R*})}{(1-\alpha)\theta S_N^* L_N^{R*}}. \quad (19)$$

One can show that case 2 occurs when: (i) $\alpha > 1/2$, from $p_S < p^*$; and (ii) $\frac{S_N^*}{S_S^*} < \frac{(L-L_N^{R*})}{L_N^{R*}}$,

from $p^* < p_N$. Case 3, on the other hand, occurs when $\alpha > 1/2$, and

$$\frac{S_N^*}{S_S^*} > \frac{(L-G(S_N^*)/(\theta S_N^*))}{G(S_N^*)/(\theta S_N^*)}.$$

We examine the dynamics of case 3 first. When trade begins, the North observes a cheaper price of the resource good in the South, so the country tries to specialize in manufactures, while the South has specialized in the Resource good. However, given the low preferences for manufactures, the North covers the market for manufactures without being able to specialize in the sector, finding that before allocating all labor to manufactures, the new international price has reached its initial terms of trade. Initially, labor in the resource good is derived from:

$$p_N = \frac{1}{\theta S_N^*} + \lambda^* = \frac{1}{\theta S_N^*} + \frac{G(S_N^*)}{\theta S_N^{*2} (r - G'(S_N^*))} = \frac{\alpha(L-L_N^R)}{(1-\alpha)\theta(S_S^* L + S_N^* L_N^R)} = p^*, \quad (20)$$

that is, initially North's labor in the resource sector equalizes the initial price in the North, with the international price (15) when the South has specialized in the resource sector, i.e., $L_S^R = L$. Although the North could not specialize, the harvesting effort as trade starts is lower, and therefore the country begins accumulating environmental resources. Thus, although the country is not obtaining any static gains from trade, it is accumulating wealth, and obtaining dynamic benefits. As the North stock grows, its diversification

price, in other words, its steady state terms of trade are falling; and at the same time the stock in the South is falling which pressures the international price upwards. Altogether, this means that during transition harvesting effort is increasing in the North, when the optimal is to bring it down to zero, but at all time from (20),

$$L_N^R(t) = \frac{L(\alpha S_N^2 (r - G'(S_N)) - (1 - \alpha) S_S(t) [(r - G'(S_N)) S_N + G(S_N)])}{S_N [(1 - \alpha) G(S_N) + (r - G'(S_N)) S_N]} \quad (21),$$

where the environment in the South is depleted at maximum rate so that:

$$S_S(t) = [S_S^*(\gamma - \theta L)] / [S_S^* \gamma / C - e^{-(\gamma - \theta L)t} (\theta L - \gamma + S_S^* \gamma / C)].$$

Finally, the path of the resource in the North is determined by (2), $\dot{S}_N = G(S_N) - \theta S_N L_N^R(t)$, where harvesting effort (L_N^R) is as determined by (21), the minimum possible without driving the international price above its own steady state price. There is really no hope of analytically integrating this differential equation (solving for $S_N(t)$), which usually stops the dynamic analysis from happening. However, there are very well known numerical methods to describe the path of this differential equation, most notably the Runge-Kutta method, developed at the end of the XIX century, variations of which we apply subsequently to analyze the complete dynamics of this North-South trade model³⁰.

Eventually, as the North's diversification price, which is equivalent to the international price falls, while the South's terms of trade rises, the two countries will equalize their terms of trade:

³⁰ For technical details on the Runge-Kutta method please see Stengel (1994), pp. 77-79.

$$\frac{1}{\theta S_S^D} = \frac{1}{\theta S_N^D} + \frac{G(S_N^D)}{\theta (S_N^D)^2 (r - G'(S_N^D))} \quad (22).$$

At this point, like explained with more details above for case 1, the countries will enter in a bang-bang final dis-equilibrium unable to maintain both stocks at steady state. In the first stage, as soon as the South (specialized in the resource good), reduces its stock of natural resources below S_S^D , the relative comparative advantages revert and the South tries to specialize in manufactures. The difference when comparative advantages revert is that now, the South, unlike the North, may be able to specialize in manufactures. This could happen because the North is more productive in the resource sector than the South, and could fill the market for the resource good at the final trading price without specializing. Looking at the market for manufactures we have that $m_S + m_N \geq M_S$, or:

$$(1 - \alpha)L + (1 - \alpha)p^* \theta S_N^D L = (1 - \alpha)L + (1 - \alpha)(S_N^D / S_S^D)L \geq L_S^M.$$

Which means that South specializes in manufactures, i.e. $L_S^M \geq L$, when $\alpha / (1 - \alpha) \leq S_N^D / S_S^D$. The left hand side of this inequality lies in the range $(1, \infty)$, while the right hand side of the inequality is greater than one. As expected, when the bias for the resource good is not large enough, it is possible for the South to specialize in manufactures during this phase. Thus, if $\alpha / (1 - \alpha) \geq S_N^D / S_S^D$, then the North is specialized in the resource good during the first stage of this bang-bang disequilibrium, while if the inequality is reversed the North does not specialize during this stage, allocating only:

$$L_N^R = \frac{2\alpha L}{(1 - \alpha)(S_N^D / S_S^D) + \alpha},$$

to the production of the resource good. This result is important, because as we noted in the previous section, given that $p^*(t_2) = 1/(\theta S_S^D) > 1/(\theta S_N^D)$, welfare (real income) in the North is positively correlated to the amount of labor in the resource sector; unlike the South where welfare is independent of the labor allocation.

Again, like in case one, this brief phase is unsustainable. The accumulation of stock in the South and the depletion of the stock in the North will revert comparative advantages to a situation equivalent to the trade and production patterns prevalent when the countries' terms of trade equalized: South specialized in the resource good, with the North filling the demand gap, producing some resource good too.

Under case 2, both countries initially specialize, and trade at a price which lies between both of their initial terms of trade. Initially the trading price is $p^* = \alpha / [(1-\alpha)\theta S_S]$, which is growing as the South specialized in the resource good depletes its environmental resources. Also, the North's diversification price is falling, as the country specialized in manufactures accumulates renewable resources. Eventually, the North's diversification price, which is falling, will intersect the rising international price, at this point, case 2 becomes the same as case 3, and the North is unable to specialize in manufactures, and produces, increasingly, some resource good as well. Also, the international price as dictated by the North, starts falling. As we show in Figure 15, in case 2, the international price has two discontinuous changes, when the international price equalizes the price in the North, and when both countries equalize terms of trade. When the latter happen, the countries enter a final bang-bang disequilibrium, which is equivalent to the one explained above for case 3.

2.1 Welfare Analysis

In the North, the more manufactures the North produces, the worse off the country will be once trade is initiated. Income in the North, assuming non-specialization (Case 3) is: $L_N^R(1 + \theta S_N \lambda) + L - L_N^R$, and adding that without specialization the original autarky price does not change, proves that the higher the manufactures output in the North, the worse the country will initially be. In the limit when it specializes in manufactures, case 2, the country is even worse off, consuming at a budgetary restriction which is effectively lower than their autarky income (remember that in the North, the marginal rate of transformation, and the terms of trade of the country are different). However, the inability to specialize in manufactures makes the North overall (the planning horizon) worse off, because what is best for the North is to achieve their new steady state as soon as possible, trading deeper, but lesser in duration, welfare losses for future gains. That is the nature of the dynamic trade-off. Again, the North is getting dynamic gains, increasing its wealth by accumulating more natural resources.

In case 3, when the North does not specialize, the country trades even when the initial autarky price does not change. The country does so, because it allows it to accumulate wealth through accumulation of natural resources. One could propose that the North allocates labor as to leave the international price infinitesimally below its initial autarky price, which would not affect the welfare levels but perhaps help understand the optimality of the North's behavior. Even though the price may not change initially trade is still optimal for the North because it allows accumulation of resources which increases the productivity of labor in the resource good, without affecting the overall supply of the resource good. So in a new steady-state the gains from the North are unambiguous,

however, again we face the question if in a bang-bang final disequilibrium, jumping from higher and lower welfare than in steady state: is trade still a better proposition than autarky?

In the South, both under case 2 and case 3, the country specializes in the resource sector and receives a higher price for it than in autarky. Thus, the country earns standard Ricardian gains from trade, which will be higher the higher the price received, i.e. gains are larger in case 3 when the international price is limited by the North's autarky price. As trade continues this gains from trade are diminished and completely eliminated when the final bang-bang is achieved, at which point the terms of trade in the South and the international price equalize. At some point in between, however, the South reaches a welfare level lower than autarky, because as time passes by, the reduction in the stock of natural resources reduces the South's real income, as well as the reduction in the international price reduces profits in the South to zero when both international price and South's terms of trade equalize. All other characteristic being equal, there will always be a high enough discount rate that makes trade a preferable plan over autarky in the South. Thus, the numerical exercise for the South is more interesting for a given time discount rate: how do other characteristics determine if trade is preferable to autarky or not?

Our numerical simulations indicate that gains from trade in the South are always negative. This losses approach zero when there are not many differences between South and the North; e.g. when the discount rate is high, low extractive capacity θL , and high preference for the resource good, as shown in the second row of Table 4. However, these negative gains from trade are negligible for even lower levels of preference for the resource good as shown in row 3. Both cases have in common high discount rates, which

lowers the intrinsic difference between the South and the North, and a low extractive capacity which implies very little difference between steady state initial extraction, and full extraction during trade transition. On the other hand, trade losses in the South reach an astounding maximum of almost 63% (compare to the maximum of 6% in case 1) when the discount rate is at its lowest, there is a high preference for the resource good and the ratio of extractive capacity to growth of the resource ($\theta L/\gamma$) approaches 1 from below, as can be seen in rows 3 and 4 of Table 4³¹. Note, that the fall is dramatic precisely because the starting level of utility and resource level is very low. In these cases, the low discount rate penalizes the final losses in which the South incurs by trading, while the small difference between θL and γ makes transition last longer, and the high preferences for the resource penalize more heavily the losses in the stock of the resource which can be greater than 63%.

The fact that the South does not attain gains from trade over the time horizon comes as a surprise because the country does obtain static gains from trade always in cases 2 and 3. These gains from trade can represent a jump in welfare of up to more than 20% versus the autarky steady state level, when the preference for the resource is around 2/3, and the discount rate is very low. What our numerical simulations indicate is that the final losses always dominate the initial gains. When the initial gains are highest, the accompanying low discount rate penalizes over a longer horizon the final losses. When the discount rate is high and does not penalize heavily the final losses, the initial gains are not large enough. Note that this does not mean that trading initial gains for future losses

³¹ As we show in the next section, when the $\theta L/\gamma$ is greater than 1, and the demand for the resource good is high enough, the initial comparative advantages are reverted, that is why the greatest losses in the south are achieved when this ratio approaches 1.

is not optimal, as a matter of fact, as we will see in the next section this dynamic trade-off can be done optimally. On the other hand, we could discount welfare differently in both countries, in which case a low discount rate in the North together with a high enough discount rate in the South would make trade beneficial for both parties. However, this would be trade based on the environmental externality *and* differences in preferences. What our numerical simulations tell us is that trade resulting from the environmental externality alone is never beneficial for the country with the externality, even when there are standard gains from trade.

The potential gains from trade for the North, i.e. the gains from trade that would be attained if a steady state was feasible when the terms of trade equalize, reach a maximum of about 3.8%, which pales in comparison to the South's actual losses which approach 64%. This maximum is achieved when preferences for the resource good are around 3/4, when the discount rate is minimum, and the $\theta L/\gamma$ ratio is also around 3/4, see rows 6 and 7 of Table 4. The actual gains, which account an average of the bang-bang final equilibrium, where the country jumps between welfare levels above and below that of steady state equilibrium, is always positive, and approaches 50%, which is more similar to the South losses. The actual gains are maximized when $\theta L/\gamma$ is close to 1 from below and θL is high, as when South losses are maximized, see row 4; but close to their highest for much lower levels of extractive capacity, as in row 8.

The stock of natural resources suffers its greatest losses mirroring the greatest welfare loss in the South, see rows 4 and 5 of Table 4. The maximum gains of stock in the North is achieved when the discount ratio is above the intrinsic rate of growth of the environmental resources, the extractive capacity is low, and the bias in preference for the

resource good is highest, as shown in rows 9 and 10 where the stock in the North is shown as growing almost by 20%. Global environment, i.e. $S_N + S_S$ as shown in case 1, can increase or decrease with trade, as Table 4 shows, the changes can be more pronounced in cases 2 and 3. When the discount rate is low, together with a $\theta L/\gamma$ ratio around 9/10, and high preference bias for the resource good, as shown in rows 11 and 12, the fall in global environment can be as much as 12%. Obviously this case is characterized by a fast reduction in the stock in the South, and slow accumulation in the North. On the opposite spectrum, rows 13 and 14 show that the global environment can improve in as much as 6% when the $\theta L/\gamma$ ratio approaches to 1 from below, the extractive capacity is low, the r/γ ratio is greater than 1, and there is high demand for the resource good.

3. When the South Exports Manufactures

The South will initially export manufactures when in spite of the environmental externality, it is cheaper to produce manufactures in the South, i.e. $p_S > p_N$. As Brander and Taylor (1997) noted when they analyzed the steady state of a similar model, a backward bending steady state relative supply (R_S/M_S) is a necessary condition for $p_S > p_N$. The sufficient condition is that the relative demand is high enough, for there to

be an equilibrium in the North and in the South markets, with manufactures cheaper in the latter country³².

Two conditions are required for the South's steady state relative supply curve to be backward bending. First, the natural growth function of the resource must have the concave, inverted "U" shape, which is usually assumed for renewable resources. This condition assures that for high enough levels of extraction effort, additional expansions in the extraction of the renewable resource will actually render lower steady state output levels of the resource good, rather than more. The second condition is that the fall in the production of the resource good that follows from the reallocation of one unit of labor from the manufactures to the resource sector has to be greater than the fall in the production of manufactures. We define South's relative supply:

$$\frac{R_S}{M_S} = \frac{\theta S_S^* L_S^R}{L - L_S^R} = \frac{\theta C(\gamma - L_S^R) L_S^R}{\gamma(L - L_S^R)} \quad (23),$$

where in the second equality we have used the definition of the steady state stock level.

Thus, this relative supply will have a negative slope, $\partial(R_S / M_S) / \partial L_S^R < 0$, when:

$$\gamma < \frac{\theta L_S^R (2L - L_S^R)}{L} \quad (24).$$

The right hand side of (24) has a maximum at θL , therefore the steady state relative supply can have a negative slope only if $\theta L > \gamma$. If this condition is not met the relative supply in the South is always positively sloped, and for any price, the country offers relatively more resource good than the North.

³² Note that in Brander and Taylor the North is an extreme version of what we call the North. In their study they implicitly assume that the North has a discount rate of zero, while we study a more general case where the discount rate is less than infinity.

This second condition was completely missed by Brander and Taylor (1997b); so much so that they specifically assume $\theta L < \gamma$, to avoid extinction, which denies the possibility of the negative sloped supply curve they work with. As we have shown this condition to avoid extinction is too stringent, what is required to avoid extinction is $\theta\alpha L < \gamma$. Hence, the possibility of the relative scarcity of the resource overwhelming the environmental externality and reverting apparent comparative advantages ($p_S > p_N$) opens the possibility of extinction, and may occur within a rather small window:

$$\theta L > \gamma > \theta\alpha L \quad (25).$$

The window is rather small because the left hand inequality of (25), opens the possibility of a backward bending supply curve, while demand α needs to be large enough, ($\alpha > 1 - \sqrt{(1 - \gamma / (\theta L))}$), to ensure initial equilibrium in the backward bending section of the supply curve³³.

As in the case when the South exports the resource good, when the South exports manufactures there are three initial possibilities. Either country can specialize in the good it exports, or both countries specialize. We will briefly characterize when each of the three possibilities occurs.

We examine first the case when the South specializes in manufactures, while the North can not specialize in the production of the resource good. First, for the relative price of the resource good to be higher in the South, condition (25) has to be met and,

³³ Note that the steady state relative supply curve in the North can also be backward bending. When r is high enough, particularly greater than γ , then S_N can fall well below the maximum growth level, $C/2$ (remember that $r > G'(S_N)$ always). If additionally if $\theta L > \gamma$ then the relative supply curve will be backward bending, for the same reasons than in the South, but the bending will always start at a higher price than in the South.

$$\alpha > \frac{1}{1 + (S_S^*/S_N^*)(L/L_N^{R*} - 1)},$$

which ensures initial equilibriums above the point where the North and the South's relative supply curves intersect. When the South specializes in manufactures the international price becomes: $p^* = [\alpha(2L - L_N^R)] / [(1 - \alpha)\theta S_N^* L_N^R]$. Comparing this price, to the North's steady state price, we can show that the North will not be able to specialize in the production of the resource good if:

$$L > 2\alpha L \left[\frac{S_N^*(r - G'(S_N^*))}{S_N^*(r - G'(S_N^*)) + (1 - \alpha)G(S_N^*)} \right] = 2\alpha L \left[\frac{1}{1 + (1 - \alpha)\lambda^* \theta S_N^*} \right] \quad (26).$$

As expected, when the demand for the resource good is low, α is small, then the North will not be able to specialize in the production of the resource good. In this case, the international price is constrained by the price in the North, which will rise through transition as the stock of environmental resources becomes scarcer in the North. At the same time, the accumulation of stock in the South will lower the terms of trade in the South until both equalize, and after this a bang-bang final equilibrium follows as described in the previous section.

On the other extreme, the North will be able to specialize in the production of the resource, and the South will produce both goods, when the international price that would prevail if both parties specialize, i.e. $p^* = \alpha / [(1 - \alpha)\theta S_N^*]$, lies below the initial price in the South. Thus, when

$$\frac{\alpha}{(1 - \alpha)} > \frac{S_N^*}{S_S^*} \quad (27),$$

the South will be unable to specialize in manufactures. Note that, since the stock in the North is always initially higher than in the South, condition (27) implies that $\alpha > 1/2$,

which is expected, higher demand for the resource good inhibits the South from specializing in manufactures. In this case, the international price throughout transition will be constrained by the price in the South, which is falling as the country accumulates environmental stock. At the same time the diversification price in the North is rising, and eventually when both prices equalize the countries enter a final disequilibrium phase.

The third case, when both countries initially specialize occurs when both conditions (26) and (27) are met with reversed sign. In this case, the international price will rise, as the stock in the North is diminished, but after the international price eventually intersects the terms of trade in the South, the international price starts falling, constrained by the South's terms of trade that fall as the country accumulates environmental stock. As time goes by, the terms of trade of both countries will intersect, at which point the countries enter a final bang-bang disequilibrium.

3.1 Welfare Analysis

In the case of the South the welfare consequences of initially exporting manufactures are unambiguous. The country may gain static gains from trade if it initially specializes in manufactures, but will always gain dynamic benefits from accumulating natural stock, which increases its real income. Therefore in the end, the South will always gain from trading when it exports manufactures. Our numerical exercise can provide the magnitude of these gains.

The North will always trade present gains for future losses, but optimally as long as it can hold a future steady state. As we saw in the previous section, the South was unable to make this same dynamic trade (present gains for future losses) in an advantageous manner, even when it earned initial profits, it ended up worse off over the

whole planning horizon. However, the North accounts for the dynamics of the stock and its own time preferences so it can make this dynamic trade and earn from it. It is not clear, nonetheless, that the country would still be better off considering that it is not able to maintain a steady state when the international price and its own diversification price equalize.

In Table 5 we take an arbitrary benchmark case in row 1, and present the main consequences of trade. The result that immediately strikes is the negative gains in the North in the Actual Gains column. The potential gains, if a steady state was attainable are positive (2.3%), as expected, as the North is behaving optimally. However, the actual gains which is a simple average of two states, one of them higher and the other lower than in steady state, needs not be actually higher, as in this case, -2.8%. When the North initially exported manufactures, the country accumulated natural stock and increased real income, with a lower minimum income (that occurs when the country specializes in manufactures) of L/p^* that is higher than the initial minimum. However, when the North initially exports the resource good, the opposite happens, real income falls, and the new minimum real income is lower than in autarky, which opens the possibility for the actual gains for trade to be negative.

The effects of trade are minimal and almost null as shown in row 2 when both the $\theta L/\gamma$ and the r/γ ratios are highest and α is lowest. A low demand for the resource good ensures that the welfare effect of the changes in stock will have little effect on welfare. When α is low, a high extractive capacity $\theta L/\gamma$ is required to be in the backward bending section of the relative supply. Also, a high r/γ will ensure that the initial differences between north and South are very small. As long as r is extremely high

the differences between countries will be small enough and dynamic gains and losses are not accounted heavily and thus trade will have almost no effect for higher levels of α and lower $\theta L/\gamma$ ratios, as shown in row 3.

In rows 4 and 5 we show when the actual losses in the North are maximum. These cases are characterized by a $\theta L/\gamma$ ratio approaching 2 from below, a very low time discount rate and α equal to $1/2$. We can make sense of these figures. First, the North lowest welfare level during the bang-bang phase is achieved when the country exports and specializes in manufactures. $1/2$ is the highest level of α , that weighs the losses in the resource stock, at which the North remains specialized in manufactures. Furthermore, if $\alpha = 1/2$, the $\theta L/\gamma$ has to be lower than 2, higher extractive levels would extinguish the resource stock in the South (in autarky). Finally, the lower discount rate penalizes more heavily the real income losses incurred by the country. These trade induced losses can amount to 24% compared to an autarky program, and represent an unexpected result of the inability to achieve equilibrium: the country that optimally manages the resource loses with trade.

It is fair to ask: how is it possible that the externality free country loses with trade? The answer is that the North is free from the environmental externality, but it suffers, in a sense, from an information failure. This information failure is twofold; the country does not know its trading partner optimal behavior but more importantly, does not know that it will be unable to sustain a new equilibrium.

On the other hand, the North can have actual gains positive and very high, approaching 27%, as shown in rows 6 and 7. These cases are characterized by a $\theta L/\gamma$ ratio slightly above 1, lowest time discount and high demand for the resource good. As

shown by the very low potential gains, the extreme actual gains therefore are due to gains during the bang-bang phase. Note, that stocks changes very little, less than .5% although initially countries are very different, with the North having initial stock level above 50% of maximum C , while the South only 7%. In spite of these differences in stock level, terms of trade equate very fast without much change in stocks/real income. Also, in the North during the bang-bang phase, the minimum level of production of the resource good (when the country exports manufactures), given the high demand, is not too low below the steady state level, which allows an average for the bang-bang phase which is actually above the steady state optimal.

The gains for the South compared to autarky can be limitless. This happens, because the autarky benchmark in terms of stock and welfare can be very low, just above zero as the resource stock approaches the point of extinction. In row 8 of the table we display the largest welfare gains for the South in our round of iterations, 276%. However, in row 9 we show that adjusting demand around that maximum we see that welfare gains can amount to more than 4,000%, and if we continued fine tuning we would approach infinity, as we reduce the initial stock in the South to ε above zero. Nonetheless, row 8 gives hints of when the South is likely to earn more from trade. This happens, when α approaches $\frac{1}{2}$ from above, when $r > \gamma$, which means that the initial positions of both countries are not too far apart, and the $\theta L / \gamma$ ratio approaches 2 from below.

What happens with the environmental stock is very interesting. When the South initially exports the resource good, stocks diverge, but in this case stock converge. However they never intersect, when terms of trade equalize, still $S_N^D > S_S^D$. The change in the stock in the South, as we have shown, can vary from almost zero to almost infinity.

The change of the resource stock in the North can be very high approaching -90% and higher as shown in row 9. The latter happens precisely when the stock in the South is very low, which gives as an end result that the total world environmental stock drops dramatically more than 86%, when the physical limit is 100%. In this case row 9 is very revealing, because both countries gain from trade even after accounting for the bang-bang final state, but there is an environmental catastrophe. Note that the problem here is not that the environment is not included in the welfare function explicitly. The problem is the externality. If instead of modeling the environmental externality in the production side, we would have included it in the demand side we would still get the same result, welfare improvement accompanied with environmental destruction. The North would manage optimally *their* valued environment, but not the world environment and we would end with a similar result both countries can gain from their perspective, while serious environmental destruction (from the point of view of the world is brewed). Of course, trade can be beneficial for the world's environmental stock, but these gains go as high as 10% as shown in rows 10 and 11 (when demand for the environmental good is extremely low), versus lows that can go to almost total destruction of the environment.

4. Global Steady States and the Inability to Achieve Them

4.1 Global Steady States

The reader will have noticed that while we have argued that a trade steady state is not feasible starting from autarkic equilibrium, we have really not shown or explained why this happens. In this section we first show that a trade equilibrium is not possible, and in

doing so we describe and discuss the available equilibriums. Then we explain why the market is unable to achieve them, and discuss the implications for real world trade in goods intensive in renewable resources.

We will have to accept the inability to formally *prove* that an equilibrium is unattainable by the market, given that we are unable to solve symbolically for key variables of the trade outcome. Nonetheless, we can *show* that trade steady states are not possible: using numerical methods as shown in the previous section; and we can *explain why* this type of equilibrium is not possible, as we later do. First, we discuss different type of trade equilibriums, and we discuss their stability, and if they can be achieved by market behavior.

We begin by defining a global steady state, which is simply a production pattern that can sustain a natural equilibrium in both countries at the same time; i.e. $\dot{S}_S = 0$ and $\dot{S}_N = 0$. Clearly, any production arrangement with $L_i^R \in (0, \gamma/\theta)$ can provide a global steady state. However, not any of these feasible global steady states will satisfy the market conditions. We define a global steady state consistent with free-market trade (GSCM), as an equilibrium that is a global steady state in the sense that provides natural equilibrium in both partners, but additionally complies with the market conditions, which can be collapsed to three requirements: (i) the trading price has to be equal to the rate of transformation in the South (6), to eliminate any incentive in that country to deviate from production patterns; (ii) equivalently, the international price has to be equal to the North's optimal price for its own steady state stock level (16); and (iii) the labor allocation, and the global steady state stock levels of both countries must be such that they provide a

trade balancing international price (15), equivalent to that of the South (*i*) and the North (*ii*).

We can thus mathematically define the GSCM as a set $\{L_N^R, L_S^R, S_N, S_S\}$ which simultaneously satisfies:

$$G(S_N) = \theta S_N L_N^R \quad (28);$$

$$G(S_S) = \theta S_S L_S^R \quad (29);$$

$$p^* = 1/(\theta S_S) \quad (6);$$

$$p^* = \frac{1}{\theta S_N} + \lambda^* = \frac{1}{\theta S_N} + \frac{L_N^R}{S_N[r - G'(S_N)]} \quad (16); \text{ and}$$

$$p^* = \frac{\alpha(2L - L_N^R - L_S^R)}{(1-\alpha)(\theta S_N L_N^R + \theta S_S L_S^R)} \quad (15).$$

If we equate (6) and (16) we get:

$$L_N^{RG} = [r - G'(S_N)](S_N - S_S)/(\theta S_S) \quad (30),$$

which is the minimum harvesting effort that the North can employ in harvesting natural resources without raising the international trading price. Similarly, equating (6) and (15) we obtain:

$$L_S^{RG} = 2\alpha L - [(1-\alpha)S_N/S_S + \alpha][r - G'(S_N)](S_N - S_S)/(\theta S_S) \quad (31);$$

which is exactly equivalent to (17) (evaluated at L_N^{RG}): the maximum effort that the South can employ in producing the resource good without decreasing the international trading price below its own terms of trade. Thus we can reduce the GSCM, to two dynamic equations, valid only at steady state:

$$\dot{S}_N = G(S_N) - \frac{S_N}{S_S}[r - G'(S_N)](S_N - S_S) = 0 \quad (32); \text{ and}$$

$$\dot{S}_S = G(S_S) - 2\alpha\theta S_S \bar{L} + [r - G'(S_N)](S_N - S_S)[\alpha S_S + (1 - \alpha)S_N] / S_S = 0 \quad (33).$$

We have to stress that these equations are only valid at steady state, because any deviation from equilibrium will cause both partner to adopt their extreme transition production patterns. In Appendix 3, however, we show that this equilibrium will always be stable (around a very narrow neighborhood of the steady state) when it occurs at stock levels for both countries higher than $C/2$, and could be unstable when stock levels are very low, and / or the intrinsic environmental growth rate is very high.

Equations (32) and (33) also can help us graphically represent the GSCM. We can solve for S_N in (32) to obtain:

$$S_N|_{\dot{S}_N=0} = \frac{C}{4} \left[\frac{S_S}{C} - \frac{r-\gamma}{\gamma} + \sqrt{\left(\frac{r-\gamma}{\gamma} - \frac{S_S}{C} \right)^2 + \frac{8S_S r}{\gamma C}} \right] \quad (34).$$

We can also solve for S_N in (33), however, please note that the answer involves the solution of a cubic function, and therefore the solution is an extensive formula which we do not show explicitly; nonetheless, it is graphically represented together with (34) in Figure 16.

The figure shows that, given the cubic nature of (33), there can be up to 3 different equilibriums. However, given the constraint imposed by nature, only equilibriums that occur within $\{S_S, S_N\} \in \{(0, C), (0, C)\}$ are feasible. Thus, the number of feasible equilibriums may range between 0 and 3. This raises many interesting questions. Will a feasible GSCM always exist when trade is possible? Does a feasible GSCM exist that is contained between the initial autarky (S_N^*, S_S^*) and diversification stock levels (S_N^D, S_S^D) always, or at all? Clearly if a GSCM is going to be feasible, there must exist a

solution that is a GSCM and contained within the range within which the stocks move during trade; that is: $S_N^* > S_N^G > S_N^D$ and $S_S^D > S_S^G > S_S^*$ (in the case South exports the resource good).

We proceed to try to give an answer to these questions with numerical methods again. With the help of a symbolical algebra engine (Maple 9 or Mathematica 5) we can solve explicitly for the 3 possible GSCM solutions, however the answers require several pages of algebraic expressions (quite an achievement for a deceptively simple problem!), so they are not shown here. The feasibility of a GSCM solution has two parts. On one hand both stocks must be contained within nature's bounds $(0, C)$ (*naturally feasible*). Also, as explained above, it must be feasibly attained by the market, thus both stocks must be contained within the autarky and diversification levels (*economically feasible*). Finally, a GSCM would only be possible if in addition to being economically feasible, both equilibrium stock levels where *attained at the same time*, by the market determined extraction rates (as shown in previous sections). The exercise done in previous sections, which traced market behavior, showed that this last requirement is never met. We proceed to explore the issue one step back, by analyzing if economically feasible GSCM exist or not.

The numerical exercise consists of iterating across all the parameters space, and finding all the feasible GSCM, together with testing the stability of these types of equilibriums. To limit the calculations, we limit the iterations to the case when the South exports the resource good. We can readily summarize our most important findings. There always exists at least one naturally feasible GSCM, and a maximum of three. However, on the other side, we did not find one single economically feasible GSCM. In most cases,

there is at least one GSCM that consists of one country stock level contained within the autarky and diversification boundary, while the other one was outside. While in other fewer cases we found that none of the individual country stocks of the naturally feasible GSCM were contained within the range the stocks move during trade (more details below). These last two results are very compelling in demonstrating, beyond a doubt, that trade starting from autarkic equilibrium, can occur without conducting countries to a global equilibrium.

The GSCM appears to approach economical feasibility, without ever reaching it in our iterations, but only when the difference between autarky prices among countries is very small, or equivalently, the change between autarky and diversification stock levels is very low.

In Table 4 we illustrate with some examples the results of our numerical exercise. The most common result is for there to be 1 naturally feasible GSCM, but 2 and 3 naturally feasible GSCM are possible. The least expected result is to have 3 naturally feasible GSCM. One such example is given in the first row of the table. Note that in the table the individual country stock levels that are contained between the autarky and diversification boundary are highlighted in bold. If an economically feasible GSCM existed, both columns of the GSCM would be in bold. Three GSCM exist within a narrow parameter window, when the discount to natural growth rate ratio r/γ lies between 0.4 and 2.5, and the effective labor to natural growth rate $\theta L/\gamma$ is not too large. Rows 2 and 3 provide further examples of trade scenarios where only 2 and 1 naturally feasible GSCM exist.

In row 4 we present a less likely but interesting case, where none of the naturally feasible GSCM stock levels are contained between the autarky and diversification levels. This latter type of cases only occurs when the discount to natural growth rate ratio r/γ is extremely high, and it is therefore more of an interesting theoretical curiosity than an expected observable empirical regularity. However, it demonstrates quite strongly how trade can happen, without achieving a global steady state.

On the other hand, our simulations showed that all the naturally feasible equilibriums are stable. In the last column of Table 4, we indicate the amount of negative roots of the system (28) - (29) evaluated at each equilibrium point. All the examples in the table have at least one negative root, and indeed, that is also the case with all equilibriums found in our simulations. This result complements the analysis done in Appendix 3, where we showed that all equilibriums with stock levels above one half of the carrying capacity behaved at least as a saddle path. So with the caveat, that due to the non-linear response of trade partners, within a very narrow neighborhood of steady state the GSCM is always stable.

Of course the possibility of multiple equilibriums provides theoretical foundations for the environmentalists concerns. We discussed multiple equilibriums in chapter 1, and showed how it serves as a theoretical support for the claim that trade can cause environmental collapse. Here the multiple equilibriums are a result of the externality in the South. As shown, for example by case 1 in Table 6, one of the equilibriums represents an environmental collapse in the South and a near environmental collapse in the North. Additionally, these “extremely low” equilibriums can occur when the diversification level can lie at almost no extraction. From the perspective of the analysis carried out here,

where we only consider autarky equilibrium as starting points, these environmental collapses are not relevant, because these collapse equilibriums are not achievable. However, these equilibriums could be attainable if the countries were off their own autarky equilibriums, and in the vicinity of these environmental collapse equilibriums.

Of course, free trade is not the only possibility. If both countries knew each other's best response, then they would play a game in which each tries to behave as a monopolist, *à la* Cournot. However, a more relevant possibility is that the North, due to better information or political power behaves as a monopolist, while the South remains as a price taker. In this case, only the North knows the South's best response, and the South's environmental restrictions, in addition to the trading price, and can create a trade and production plan that accounts for this information, which may potentially lead to an equilibrium.

Thus, when the North behaves like a monopolist, the country knows the South's best response, which can be obtained from the South's rate of transformation:

$$p_S = 1/(\theta S_S) \quad (6);$$

and the trading price:

$$P^* = \frac{\alpha(2L - L_N^R - L_S^R)}{(1-\alpha)(\theta S_N L_N^R + \theta S_S L_S^R)} \quad (15).$$

By equating these conditions we can obtain (17) which is South's best response. Given that the monopolist knows the South's best response, the environmental restrictions in the South as seen by the monopolist are:

$$\dot{S}_S = G(S_S) - 2\alpha\theta L + L_N^R[(1-\alpha)S_N / S_S + \alpha] \quad (35)$$

The objective function for the monopolist is different, given that he knows that the price is limited by the South's rate of transformation (6), the objective function is now:

$$\text{Max}_{L_N^R, S_N} \int_0^\infty \left\{ \frac{S_N}{S_S} L_N^R + (L - L_N^R) \right\} e^{-rt} \cdot dt \quad (5'')$$

Therefore, the North monopolist program can be obtained by solving the current value Hamiltonian:

$$H = \frac{S_N}{S_S} L_N^R + (L - L_N^R) + \lambda [G(S_N) - \theta S_N L_N^R] + \mu [G(S_S) - 2\alpha\theta L + L_N^R [(1 - \alpha)S_N / S_S + \alpha]] \quad (36).$$

The objective function (5'') is quite revealing. The North obviously wants to maximize its stock and minimize stock in the South. Therefore, the value of the stock in the South is zero; and the equilibrium if it exists will be defined with the shadow value of the South's stock, μ , is equal to zero. Such an equilibrium, let us call it the monopolist global steady state (GSM), could not be found symbolically using computer aided algebraic engines, but we can find it numerically. This means, we collapse all the first order conditions derived from (36) into 1 equation, assuming that multipliers and stock levels are at equilibrium, and with the computer aid we find the floating point number(s) that makes the equality hold, within the feasible range (i.e. $S_i \in (0,1)$).

Again to investigate the GSM, we iterated across all parameter space to see how this equilibrium behaves, and to check its stability properties. We are not presenting the results of this last exercise; however, we refer to the main findings. Again, three equilibriums are possible, but in contrast to GSCM the possibility of no feasible GSM exists. No feasible solutions tend to occur when the effective labor to natural growth ratio ($\theta L / \gamma$) is low. However, given the monopolist controls its own extraction rates, as well

as its trading partner extraction rates (indirectly), the feasible revenue maximizing equilibriums are most likely attainable, when they exist.

4.2 Why Are Global Steady States Consistent with the Market Not Attainable?

We now explain why equilibrium can not occur in this model in the context of price taking, market behavior. First we note that, this result is not the product of the assumptions made about the beginning of the process, nor it is a result about the assumptions about production (linear) technology. In brief, economic and biological equilibrium (Global Steady State Consistent with the Market) can not be attained at the same time, because when the terms of trade of both partners equalize (thus exhausting the economic incentives for trade) it is impossible for *both* partners to change the production decisions from their transition levels to respect their own biological equilibrium, *and at the same time* respect the international price which must remain equivalent to their equalized terms of trade, to negate economic incentives to deviate from equilibrium. To illustrate this, let us focus in Case 1.

We assumed, because it seemed plausible and most reasonable, that once the terms of trade equalize, the North observes that the international price equals its own long-term terms of trade and decides to diversify as if in a steady state. Further, we showed that the South to maintain market equilibrium has to choose a production level that further reduces its stock and reverses its comparative advantage, initiating the bang-bang disequilibrium. Assume that our numeric simulations were wrong and that after the North diversifies, the South to respect market equilibrium is in a point like B in Figure 13, where the extraction is less than natural regeneration. In this case, the stock in the South would grow, which means that again the South can produce the resource good

cheaper than in the North. Thus, the South specializes in the resource intensive good, the North produces more manufactures, which reduces the environmental stock in the South and increases it in the North; which reverts comparative advantages, the North now has the comparative advantage in the Resource good and we have entered a bang-bang final disequilibrium again. Hence, the observed result that the South after the North diversifies is at position where extraction exceeds regeneration does not determine the final bang-bang disequilibrium.

On the other hand, the assumption that it is the North that diversifies and establishes its own biological equilibrium when the terms of trade of both countries equalizes, also does not drive the lack of equilibrium result. One could alternatively argue that it is the South that observes North's long-term terms of trade and decides to stop maximum extraction and establish its biological equilibrium. Alternatively, one can argue that production patterns remain at transition levels until the South has over-extracted the resource and essentially has higher costs of producing the resource good than the North. These different assumptions will change how the bang-bang disequilibrium begins, but does not alter the fact that it will happen.

The bang-bang disequilibrium happens because once the terms of trade equalize (the South's short term, and the North's long term marginal rate of substitution), condition (22), it is impossible for *both* countries to establish their steady state (environmental equilibrium) production levels, i.e. $L_i^R = G(S_i(t_1))/(\theta S_i(t_1))$, and at the same time maintain the international price at the diversification level, i.e. $p^*(t_1)$. Needless to say, the international price (which depends on both extraction and stock levels) can not change, otherwise there are economic incentives to deviate from those

equilibrium production levels. During transition countries maintain levels of extractions that are not consistent with biological equilibrium. Once the terms of trade equalize, to achieve environmental equilibrium extraction levels must change. This would affect the international price, which is not consistent with equilibrium. Only by chance can the international price be the same, holding stock levels fixed, at the transition extraction levels, and at the environmental equilibrium levels³⁴; which is what a GSCM requires. Essentially, when the terms of trade equalize it is required that 3 equilibriums hold (both biological equilibriums, and the international price which must stay constant), but there are only two degrees of freedom, the extraction rates.

Note how this result is not caused by the linearity in the production functions, a prime suspect of bang-bang behavior. If technology was not linear, then during the bang-bang disequilibrium there would not be any specialization, but it would not avoid the problem that to achieve market equilibrium only one country can produce at biological equilibrium level. After that, the stock in the other country changes and causes a change in comparative advantages, which triggers the bang-bang disequilibrium. Thus if technology exhibited decreasing returns to labor, the jumps would be more moderated, but would still occur as comparative advantages are reverted back and forth.

Also note that the lack of equilibrium is also not dependant in the starting points we assumed (i.e. autarky) in our numerical simulations.

Thus, two characteristics determine the bang-bang disequilibrium. First, there is the market price taking behavior which means that countries do not know each other's response and can therefore not plan anticipating the response of their trading partner. And

³⁴ Although it is theoretically possible, because when terms of trade equalize extraction levels in both countries must move in opposite directions to re-establish the environmental equilibrium

the second characteristic is that the trading partners represent a large share of the world market and their production decisions affect the international price. On the extreme of no market share, we have basically what we described in Chapter 2 where North and South had no problem achieving steady state market equilibrium. In the model we study in this chapter, for the sake of understanding, assume that once the terms of trade equalize between North and South, the international price remains constant regardless of the production patterns. In this case after the North establishes its equilibrium production level, the South would see its production level decrease whilst its extraction exceeds regeneration, however, eventually both equalize and a global steady state is achieved. This impossible example highlights the fact that it is the ability to affect market price what is partially responsible for the bang-bang disequilibrium.

As surprising as the lack of equilibrium may seem, this is not a new result in the renewable resources literature. In the case of one agent managing one renewable resource, it takes just a fixed cost (which *de facto* eliminates the convexity of the production possibilities) to create the possibility of non-equilibriums. Lewis and Schmalensee (1977) showed this result; in the presence of a fixed cost it may be optimal to perpetually abandon the resource, let it grow and then re-exploit it; what has later been called a “chattering” equilibrium. Also in the context of one agent exploiting one renewable resource, Hommes and Rosser (2001) showed that when price expectations follow an AR(1) process, both convergence to equilibrium and chaos are possible for differing parameter values. “Chaos” in these authors work is comparable to our lack of equilibrium, a perpetual jump between low and high extraction levels. Note however, that in our analysis the source of the lack of equilibrium (or “chaos”) is much simpler than a

complex expectation structure; simply, in the trade model it is impossible to achieve economic equilibrium (in this case maintain their production structure) after terms of trade equalize, and at the same time achieve biological equilibrium in *both* resources at the *same* time.

So this lack of equilibrium is just a mathematical curiosity? Does it have implications for the real world? Let us start by noting, that economist as early as Malthus have been worrying about potential disequilibrium in the resource extraction and potential environmental collapses. In the modern analysis these potential environmental collapses are described as convexities within the natural growth function, or by multiple equilibriums. In our model, there is no environmental collapse during the final disequilibrium, as the stock levels remain stable (around a neighborhood; i.e. there is a pseudo biological equilibrium) during the final bang-bang phase. However, there are welfare jumps in the case of the North. Thus, the model does seem to reflect periods of welfare with periods of misery as Malthus feared long ago, but surprisingly for the case of the country that optimally manages the resource, not the country with the externality. The disequilibrium phase should pose a concern: Even if there was the smallest of transition / friction costs associated with moving from one stage of production to another, the permanent disequilibrium could amount to catastrophic losses in the long term. It is always assumed in trade models that transition costs are null (i.e. no unemployment occurs when migrating from primary rural industries to urban manufacturing industries). While this assumption may not be crucial when only one change in production structure occurs, it may not be a good assumption when there is permanent change in asset allocation. We recognize however, that if this transition costs were large enough,

probably there would be economic incentives, for both countries not to change production structure after the terms of trade equalize.

IV. Conclusions

The results of the numerical simulations provide very important implications for the policy maker. Perhaps the most important one is that an excessive worry over externality based trade causing excessive losses in the South and causing excessive environmental damage is probably misplaced. First, externality based trade is likely to cause a very minor reduction in the environmental quality (if at all) because there is a transfer of environmental quality from the South to the North. The possibility of a global environmental collapse exists, but is really a theoretical curiosity that can happen, surprisingly, when trade patterns reverse (when the North exports the environmental intensive good), which we are yet to observe and can only occur under limited parameter combinations.

Of course externality based trade harms the South. However, it is important to get an idea of how large this damage is. Our simulations showed that the a key parameter in determining the size of this damage is (α) the share of resource intensive goods in total consumption. For middle income countries, where the share of consumption of environmentally intensive goods, like food, and high polluting industries, lies around 1/3, the trade induced welfare losses reach only a maximum of 3.3% for plausible discount rates in the range of 5-10%. This damage is larger, the greater the relative size of the resource intensive sector; thus, assuming that for a middle income country the share environmentally intensive output lies between 15 and 60% the trade induced losses range

between 0.5 and 3.3% for the same plausible discount rates (compare these losses with the externality losses of the South with respect to the North without trade, which can be as high as 33% for the same $\alpha = 1/3$). Thus for countries like Malaysia, Philippines and Brazil, that although have a relative large “environmental” sector, the trade induced losses are very small. Thus, development funds may be better spent dealing with other more urgent needs in these type of countries than tackling the trade induced environmental losses. This conclusion is also supported by Anríquez, Lopez and Gulati (2001) who show that in the presence of three productive assets (the environment, plus human and physical capital), growth is possible when there is an open access externality in the environmental asset, but it is not possible when there is an externality in either accruable asset.

However this conclusion is totally different for the poorest countries, where the share of consumption of mainly primary goods rises over 50%. For an archetypical country with a share of consumption of primary goods in the range of 66%, and assuming plausible discount rates of around 10%, losses in terms of welfare amount to 9% as compared to an autarky basis. Even in these cases the global environmental losses are rather small, less than 0.5%. However, given the welfare losses in the case of very poor countries like Congo, Albania and Laos, where the share of the primary sector in total GDP climbs above 50%, aid and development institutions should be focusing in environmental externalities as a serious burden to development.

Figure 10. Transition in the South.

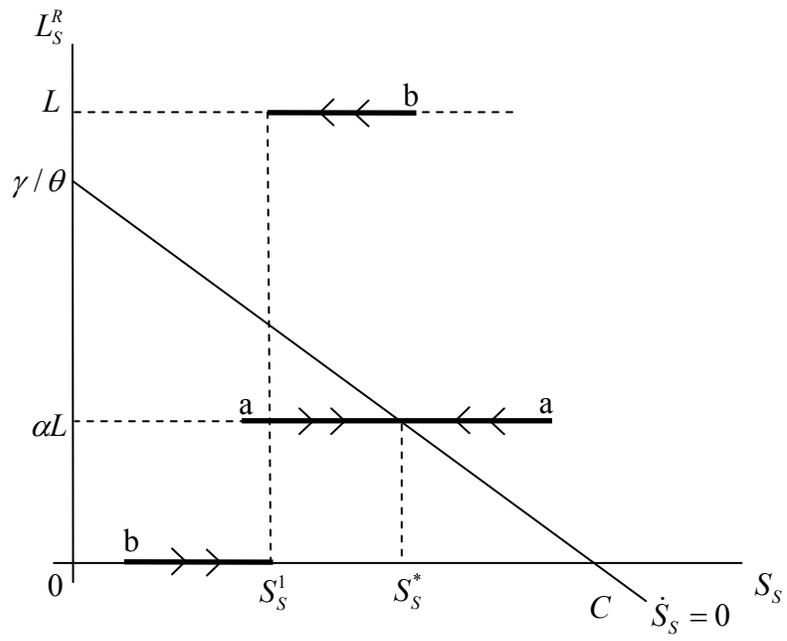


Figure 11. Transition in the North. Closed Economy Case.

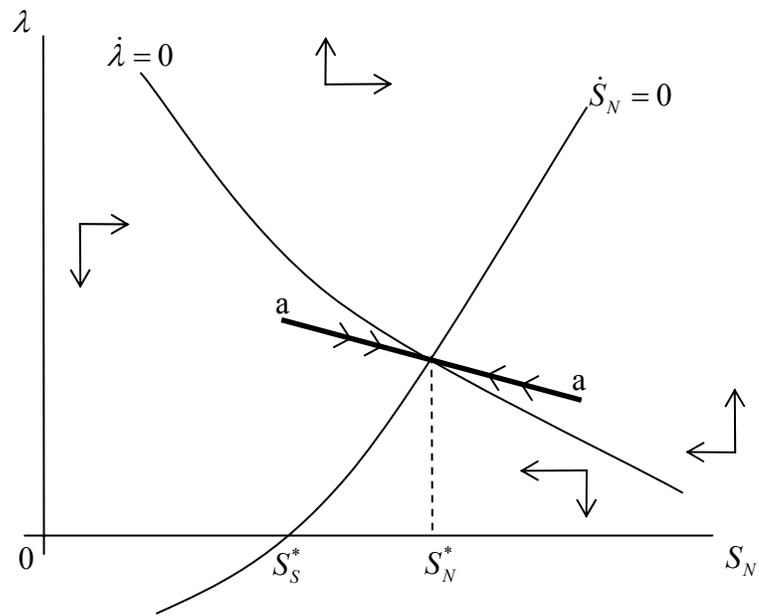


Figure 12. Transition in the North

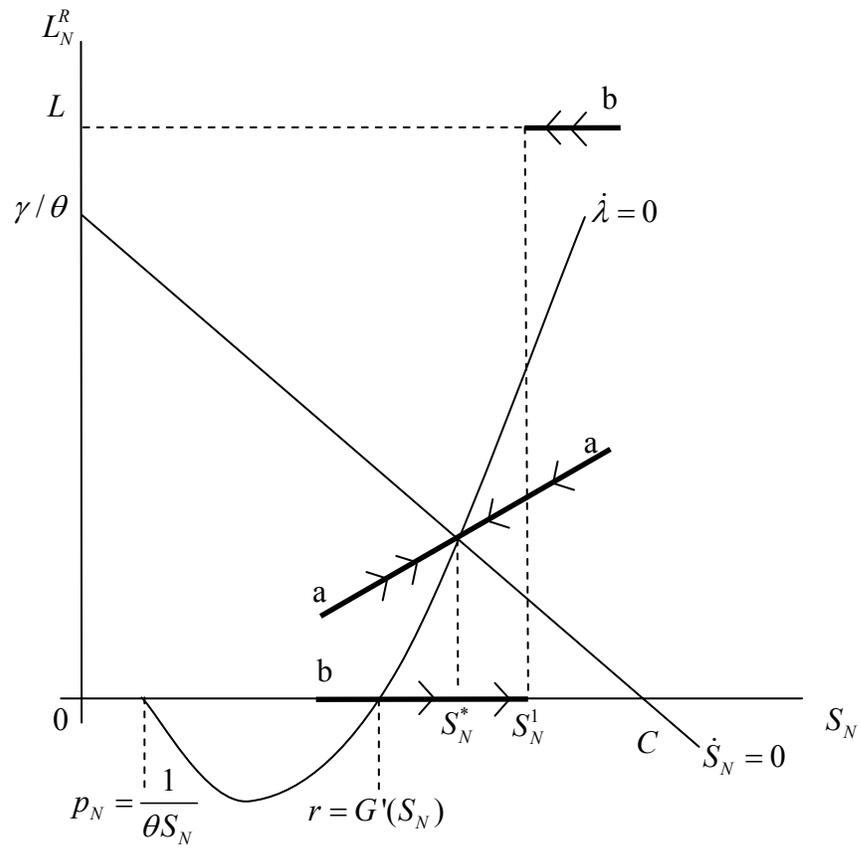


Figure 13. Transition During Trade. Case 1 (No Specialization in the South)

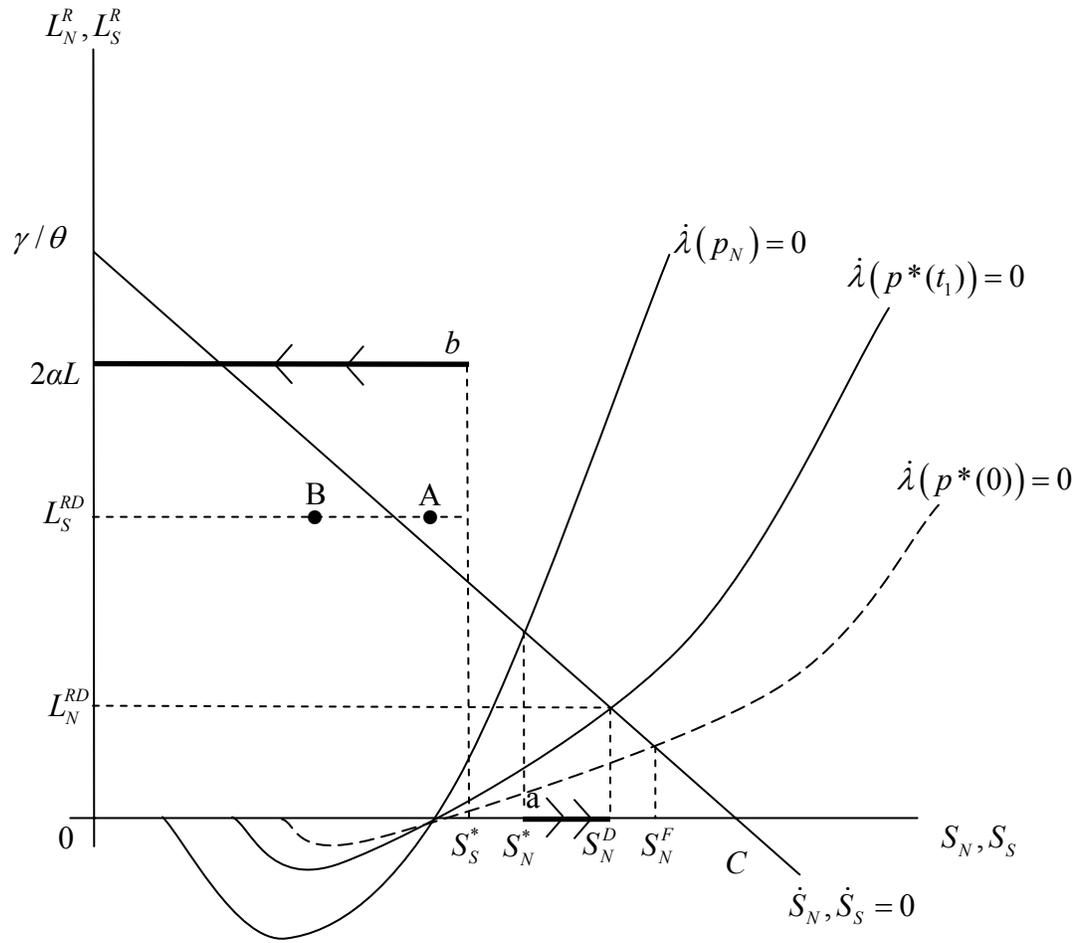


Figure 14 Initial Welfare During Autarky

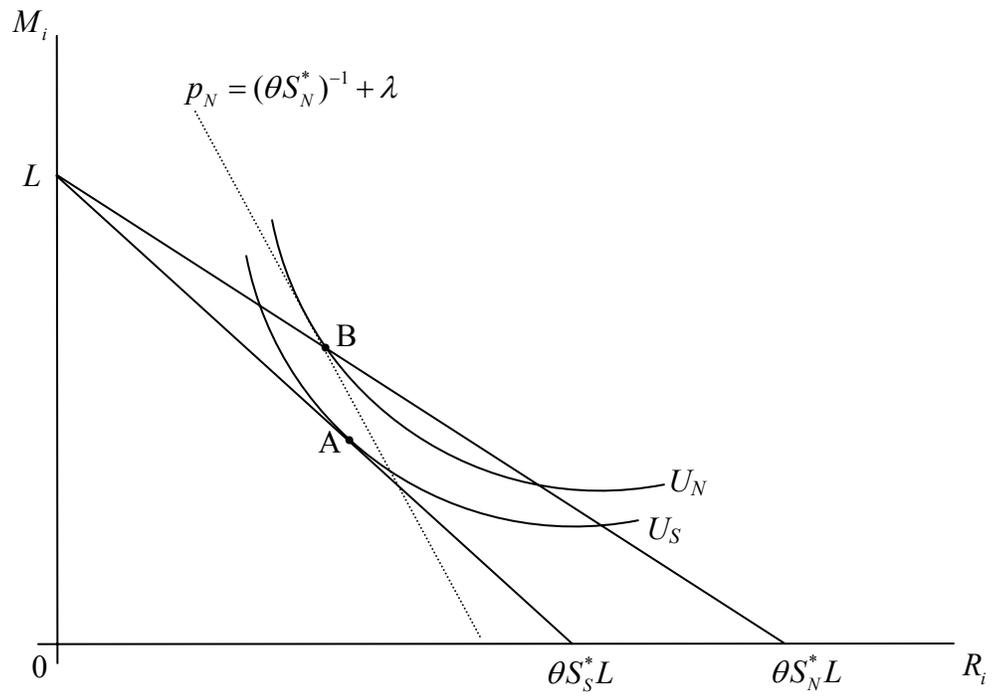


Figure 15 The Path of the International Price

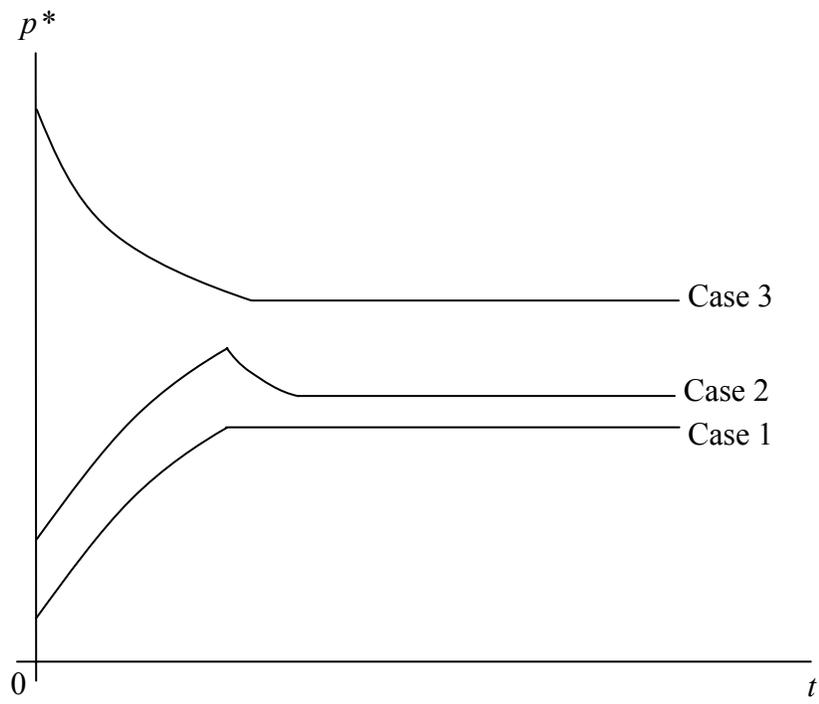


Figure 16 Global Steady States Consistent with Market Behavior

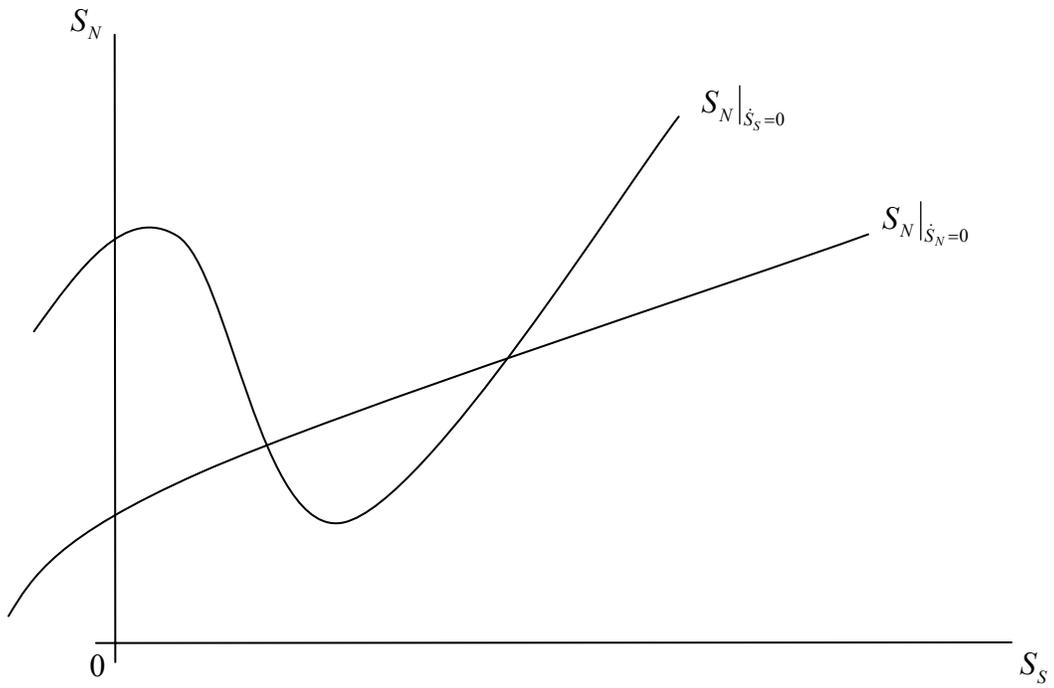


Table 3. Gains from Trade: Case 1

	θ	L	γ	r	α	South Gains %	North Gains % (potential) (B-A)/A	North Gains % (actual) (C-A)/A	Change in S_S %	Change in S_N %	Change in $S_S + S_N$ %
	<i>Benchmark</i>										
1	1	1	1	0.05	$\frac{1}{3}$	-2.9578	0.8163	2.9863	-8.6739	7.0336	-0.3791
	<i>Some Extremes</i>										
2	0.99	1000	1000	0.001	$\frac{1}{2}$	-5.8997	1.6055	7.1087	-11.4514	8.2651	-0.2208
3	1.1	0.9	1	0.001	$\frac{1}{2}$	-5.8960	1.6030	7.0948	-11.4459	8.2652	-0.2195
4	0.001	0.25	1000	50	0.001	0	0	0	0	0	0
5	0.001	0.01	0.01	1000	0.001	0	0	0	0	0	0
6	1.05	20	25	0.001	$\frac{1}{2}$	-5.7584	1.6705	6.5627	-11.1852	8.7214	-0.3215
7	1.1	20	25	0.001	$\frac{1}{2}$	-5.8397	1.6700	6.7479	-11.3384	8.6666	-0.3059
8	1.05	1000	1000	0.001	$\frac{1}{2}$	-5.8219	1.5290	7.1941	-11.3049	7.8970	-0.1487
9	1.05	500	500	0.001	$\frac{1}{2}$	-5.8219	1.5290	7.1940	-11.3049	7.8970	-0.1487
10	1.1	500	1.5	0.001	0.001	-0.0078	0.0017	0.0079	-7.4642	5.2688	-0.5471
11	0.9	1000	2.5	0.001	0.001	-0.0077	0.0018	0.0079	-7.4537	5.2995	-0.5471
12	1.05	1	0.75	0.1	$\frac{1}{2}$	-2.9427	0.3330	3.4659	-5.8316	3.5816	0.3897
13	1.05	$\frac{1}{3}$	0.25	0.05	$\frac{1}{2}$	-2.7126	0.2672	2.8613	-5.3936	3.4211	0.3833

Note: 0 is used for values smaller than $|5 \times 10^{-05}|$.

Table 4. Gains from Trade: Cases 2 and 3

	θ	L	γ	r	α	South Gains %	North Gains % (potential) (B-A)/A	North Gains % (actual) (C-A)/A	Change in S_S %	Change in S_N %	Change in $S_S + S_N$ %
	<i>Benchmark</i>										
1	1	3/4	1	0.05	$\frac{2}{3}$	-8.3467	2.8265	15.3624	-12.7545	11.3223	0.7293
	<i>Some Extremes</i>										
2	0.001	0.01	3/4	1000	0.99	0	0	0	0	0	0
3	0.01	0.01	100	1000	$\frac{2}{3}$	0	0	0	0	0	0
4	0.99	1000	1000	0.001	0.98	-63.2263	0.0017	47.9812	-63.9724	0.0429	-3.5232
5	1.1	0.9	1	0.001	0.98	-60.4139	0.0021	38.2198	-63.9350	0.0431	-3.5241
6	0.75	1000	1000	0.001	0.75	-13.4026	3.8886	22.4986	-17.4584	11.5491	-0.5651
7	1	.75	1	0.001	0.75	-13.3731	3.8789	22.4328	-17.4400	11.5588	-0.5544
8	1.25	1.25	1.5	0.001	0.9	-4.0560	0.1960	47.3107	-4.4973	1.0232	0.4351
9	0.99	0.75	0.75	1	0.99	-0.2929	0.0002	0.0002	-21.5305	19.0150	5.9603
10	1.1	0.9	1	1.5	0.99	-0.2682	0.0001	0.0001	-17.9827	18.9414	5.8282
11	1.1	1.25	1.5	0.1	0.9	-30.6186	0.5381	2.1186	-51.8056	2.0354	-11.8402
12	1	20	25	0.001	0.8333	-34.6591	1.5781	26.9247	-39.9972	5.8367	-11.1343
13	0.99	0.75	0.75	1	0.99	-0.2929	0.0002	0.0002	-21.5305	19.0150	5.9603
14	1.1	0.9	1	1.5	0.99	-0.2682	0.0001	0.0001	-17.9827	18.9414	5.8282

Note: 0 is used for values smaller than $|5 \times 10^{-05}|$.

Table 5 When the South Initially Exports Manufactures

	θ	L	γ	r	α	South Gains %	North Gains % (potential) (B-A)/A	North Gains % (actual) (C-A)/A	Change in S_S %	Change in S_N %	Change in $S_S + S_N$ %
	<i>Benchmark</i>										
1	1	1	3/4	0.05	0.7	10.5773	2.3199	-2.8762	15.1628	-4.7729	-2.5663
	<i>Some Extremes</i>										
2	1.05	1/2	0.001	1000	0.001	0	0	0	0	0	0
3	0.01	1.1	0.01	1000	0.7	0	0	0	0	0	0
4	0.99	1000	500	0.001	0.5000	166.7529	8.4206	-24.3699	611.5711	-7.3800	3.1419
5	0.99	100	50	0.001	0.5000	166.7540	8.4206	-24.3686	611.5742	-7.3803	3.1417
6	1/3	5	1.5	0.001	5/6	0.3485	0.0063	27.0397	0.4183	-0.2046	-0.1292
7	1/3	2.5	3/4	0.001	5/6	0.3542	0.0064	27.0133	0.4251	-0.2080	-0.1313
8	1.05	0.9	0.5	0.75	0.525	276.96	2.1314	1.6939	500.52	-59.7461	-43.6054
9	1.05	0.9	0.5	0.75	0.5291	42597.8	2.2695	2.2695	920028	-90.0759	-86.4917
10	0.99	1000	1	0.001	0.001	0.2523	0.0292	-0.0485	1142.44	-9.2163	9.1000
11	0.99	500	1/2	0.001	0.001	0.2523	0.0292	-0.0482	1142.67	-9.2370	9.0913

Note: 0 is used for values smaller than $|5 \times 10^{-05}|$.

Table 6 Global Steady States Consistent with Free Market

	θ	L	γ	r	α	North Trade Range		South Trade Range		GSCM		Roots <0
						S_N^*	S_N^D	S_S^*	S_S^D	S_S^G	S_N^G	
1	1	1	3/2	3/2	8/10	0.5129	0.5720	0.4667	0.4162	0.4049 0.9787 0.0348	0.5624 0.9857 0.1409	1 1 2
2	1	1/2	3/4	5/2	5/6	0.4594	0.4859	0.4444	0.4205	0.4185 0.3736	0.4839 0.4389	1 1
3	10	1.1	10	10	3/5	0.4639	0.4883	0.34	0.3204	0.3119	0.4805	1
4	1	5/4	1.5	500	4/5	0.3336	0.3338	0.3333	0.3331	0.3378	0.3385	1

Note: 0 is used for values smaller than $|5 \times 10^{-05}|$. GSCM stock levels contained within the autarky and diversification levels are highlighted in bold.

Appendix 2. Notes on the Numerical Simulations

All numerical calculations were implemented in Mathematica 5. Code is available upon request. Maple V was also used, but proved to be much slower in its numerical integration routines, so it was not used for the iterations phase. As we were interested in uncovering the behavior of the model in a five parameter space, we iterated over the following parameter set:

$\gamma(17)=\{1/1000, 1/100, 1/20, 1/10, 1/4, 1/2, 3/4, 1, 3/2, 5/2, 5, 10, 25, 50, 100, 500, 1000\}$;
 $r(17)=\{1/1000, 1/100, 1/20, 1/10, 1/4, 1/2, 3/4, 1, 3/2, 5/2, 5, 10, 25, 50, 100, 500, 1000\}$;
 $\theta(17)=\{1/1000, 1/100, 1/10, 1/3, 1/2, 3/4, 9/10, 99/100, 1, 21/20, 11/10, 5/4, 3/2, 5/2, 5, 10, 100\}$;
 $L(21)=\{1/100, 1/10, 1/4, 1/3, 1/2, 3/4, 9/10, 1, 11/10, 5/4, 3/2, 5/2, 5, 10, 15, 20, 25, 50, 100, 500, 1000\}$; and
 $\alpha(26)=\{1/1000, 15/1000, 1/100, 1/40, 1/20, 1/10, 2/10, 3/10, 1/3, 2/5, 9/20, 49/100, 1/2, 501/1000, 515/1000, 51/100, 21/40, 11/20, 3/5, 2/3, 7/10, 4/5, 5/6, 9/10, 19/20, 99/100\}$.

This parameter set amounts to 2,682,498 iterations, for each exercise. Of course not all parameter combinations are possible, for example in Case 1, only $\alpha \leq 1/2$ is considered, and other parameter combinations, results in $p_S > p_N$. However, for each exercise all parameter combinations are checked.

Notice that step sizes differ for each parameter set. We deliberately chose smaller step sizes for parameter levels that our previous analysis determined to be relevant, for example around $\alpha = 1/2$, or $\theta = 1$. Also, step size was much larger toward the parameter extremes: $0, \infty$. We used maximums of 1,000 and 1/1,000, which allows for ratios of 6 significant digits to both sides of the decimal point.

Most calculations were performed at 16 digits of precision, but some numerical integrations were performed at a minimum precision of 12 significant digits to manage

the trade-off between speed and precision in Mathematica. Since these variables (stock, time) calculated at 16 or 12 digits of precision are used to calculate other indicators, like change in welfare, the final precision would be less than 12 digits; however, there is ample headroom in the 4 significant digits we are reporting in our tables. That is, the reader can rest assured that if symbolical integration was possible, and other variables like time were also solved for symbolically, we would achieve the *exact same numbers* presented in the tables.

The raw data (roughly 2 giga-bytes) obtained from Mathematica was transferred to MS ACCESS a database management engine to sort and explore the results. At this stage further manual iterations around some interesting or surprising results were performed to better understand the behavior of the model. The numerical computations required several weeks of CPU usage. Several 2 GHz processors were joined into the computation effort.

How to implement the numerical simulations: An example with Case 1.

In this section we provide a brief roadmap to reproduce the results presented, using as an example Case 1. What is necessary to describe the whole model is to first find the path (integrate the differential equations) of both stocks. Next we use those stock paths to solve for the time t_1 at which the both the North long term and South's instantaneous terms of trade equate (i.e. time of diversification). With this information we proceed to integrate welfare during transition (function of the stocks and t_1). Finally, we calculate labor efforts in the two states of the bang-bang final disequilibrium to calculate welfare in the North during both states.

We provide more details with case 1 as an example. This case is characterized by constant extraction effort in the South, $L_S^R = 2\alpha L$, which allows us to analytically integrate the South's stock differential equation:

$$S_S(t) = \frac{[S_S^*(\gamma - \theta 2\alpha L)]}{[S_S^*\gamma / C - e^{-(\gamma - \theta 2\alpha L)t} (\theta 2\alpha L - \gamma + S_S^*\gamma / C)]},$$

where $S_S^* = C(\gamma - \theta\alpha L) / \gamma$ of course is the starting stock level in the South, steady state under autarky. With a known path for the stock in the South we also know the international price, $p^*(t) = 1/(\theta S_S(t))$, throughout transition.

In Case 1, the North specializes in Manufactures during transition, therefore the path of the stock in the North can also be obtained analytically, it is simply the logistic growth rate:

$$S_N(t) = \frac{S_N^*}{S_N^* / C + e^{-\gamma t} (1 - S_N^* / C)},$$

that depends on the starting point S_N^* , the autarkic stock equilibrium level described in (14). At this point we note that it is not always possible to obtain analytical expression for the stock levels, and that in the other cases it is necessary to numerically integrate the stock dynamic equations. Thus, we also know the long term terms of trade of the North, (16), as a function of time only. The next step is to obtain a numerical representation of t_1 , the time of diversification when p^* and p_N^D equalize. We can obtain this time, because we have expressions for the stock levels as a function of time, and thus we can express both prices as a function of time only.

With a known finishing time for transition, we can calculate welfare accrued during transition (we use the indirect utility function), which in case 1 is equal for both countries:

$$\int_0^{t_1} (1-\alpha)^{(1-\alpha)} (\alpha / p^*(t))^\alpha L e^{-rt} \cdot dt$$

which we integrate using numerical approximations.

We conclude by calculating welfare accumulated during the disequilibrium phase.

In the case of the South, that has a constant welfare this is simply:

$$(1-\alpha)^{(1-\alpha)} (\alpha / p^*(t_1))^\alpha L e^{-rt_1} / r.$$

In the case of the North it is a little bit more complicated. Welfare accumulated during the disequilibrium is an average of the two states that define disequilibrium:

$$\frac{(1-\alpha)^{(1-\alpha)} (\alpha / p^*(t_1))^\alpha \left[p^*(t_1) \theta S_N(t_1) L_N^{R+} + (L - L_N^{R+}) \right]}{2r} e^{-rt_1} + \frac{(1-\alpha)^{(1-\alpha)} (\alpha / p^*(t_1))^\alpha L}{2r} e^{-rt_1}$$

where $L_N^{R+} = \frac{2\alpha L}{[\alpha + (1-\alpha)\theta S_N(t_1)p^*(t_1)]}$, is the extraction level when the North tries to specialize in the Resource good.

Appendix 3. Stability of a Market Global Steady State

In this appendix we review if convergence is possible around a global steady state consistent with market behavior. We begin with the two equations that describe a GSCM, equations (32) and (33).

$$\dot{S}_N = G(S_N) - \frac{S_N}{S_S} [r - G'(S_N)] (S_N - S_S)$$

$$\dot{S}_S = G(S_S) - 2\alpha\theta S_S \bar{L} + [r - G'(S_N)] (S_N - S_S) [\alpha S_S + (1 - \alpha) S_N] / S_S$$

First we make a first degree Taylor-Series approximation to the stock dynamics equations:

$$\begin{aligned} \dot{S}_N &\approx a \cdot (S_N - S_N^G) + b \cdot (S_S - S_S^G) + h.o.t. \\ \dot{S}_S &\approx c \cdot (S_N - S_N^G) + d \cdot (S_S - S_S^G) + h.o.t. \end{aligned} \quad (A1)$$

Where we use the subscript G to identify the stock levels at a GSCM, and the coefficients a, b, c, d to identify the following constants:

$$a \equiv G'(S_N^G) - [r - G'(S_N^G)] \left(\frac{2S_N^G - S_S^G}{S_S^G} \right) + G''(S_N^G) \frac{S_N^G}{S_S^G} (S_N^G - S_S^G);$$

$$b \equiv \frac{(S_N^G)^2}{(S_S^G)^2} [r - G'(S_N^G)];$$

$$c \equiv [r - G'(S_N^G)] \left(\frac{2(1 - \alpha)S_N^G - (1 - 2\alpha)S_S^G}{S_S^G} \right) - G''(S_N^G) (S_N^G - S_S^G) \left[\frac{\alpha S_S^G + (1 - \alpha)S_N^G}{S_S^G} \right]; \text{ and}$$

$$d \equiv G'(S_S^G) - 2\alpha\theta \bar{L} - [r - G'(S_N^G)] \left[\frac{\alpha S_S^G + (1 - \alpha)S_N^G}{S_S^G} \right] - [r - G'(S_N^G)] (S_N^G - S_S^G) (1 - \alpha) \frac{S_N^G}{(S_S^G)^2}$$

In order to sign these coefficients, let us assume we are analyzing the case where the South initially exports the resource good, the most natural case. In this instance we

have that the stock grows in the North and decreases in the South, so we have that $S_N^G > S_S^G$; also $r > G'(S_N^G)$, because we know that in autarky $r > S_N^*$, so after trade this latter inequality is enlarged. Also, recall that given the concavity of the growth function, $G''(S_N) < 0$. Thus, the second and third term in a are negative, while the first term does not have a determined sign. Similar is the case of d , the second and third term are negative, while the first term does not have a determined sign. Coefficient b is clearly positive, while coefficient c is also positive.

The signs of the roots of system (A1), can be determined by the sign of the trace and the determinant of the matrix of coefficients of the system. The trace of the matrix of coefficients will be unambiguously negative if the GSCM is achieved at stock levels in both countries higher than $C/2$. In this case, both coefficients a and d would be unambiguously negative, and the system would have at least one negative root. That is as far as we can go with unambiguous statements. The second root will be negative if $bc > ad$, which for any S_S^G and S_N^G will depend on the model parameters. Also, by looking at the coefficients, we can say that higher intrinsic growth rates combine with low stock levels makes convergence less likely.

So we know for sure that the system converges to steady state around a neighborhood at least with a saddle-path when both S_S^G and S_N^G are greater than $C/2$, although a stable node is also possible. When either S_S^G and S_N^G are less than $C/2$, the system may or may not be convergent. The numerical analysis provided in section 4 provides more insight.

Finally, it is important to stress that this is a very narrow analysis only valid in the close neighborhood of the GSCM. Given the linearity of production functions, any

departure from equilibrium forces each country to zero and maximum labor in the resource sector, which of course substantially changes the stock dynamics equations (32) and (33).

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