Theoretical Issues in the Economics of International Trade and Environment

Meeta Keswani Mehra

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Thesis Supervisor : Prof. Satya P. Das

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To

Papa

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Chapter 1

Introduction and Summary of Major Findings

In the wake of substantial trade liberalization in the world economy over the last two decades and growing environmental consciousness, the issues of the impacts of international goods trade and foreign direct investment (FDI) on local and global environment are becoming increasingly contentious. Whilst trade and FDI have been said to bring higher incomes and well-being for all, these are seen to act as "magnifiers" of environmental deterioration - especially in the developing countries. On the other hand, growing environmentalism is perceived to act as an impediment to freer trade and investment flows across countries. Hence, the central issues are how free trade and FDI affect sovereign nations' environmental policies and thereby their environment and welfare.

To understand why and how international trade issues get linked to concerns of environmental degradation requires a careful study of the origin of environmental problems. Environmental degradation typically arises from economic (production and consumption) activities, but tends to get accentuated due to either "market failures" (i.e. absence of markets for environmental goods and services or poorly defined property rights over common pool resources) or "policy failures" (i.e. distortions in governmental pricing and regulatory policies) that often exaggerate (rather than correct) market failures. Both kinds of failures result in either 'under' or 'over' utilization of the environmental good. In the idealized world where first-best policies for internalizing the 'full' environmental costs and benefits of economic activities are present, trade liberalization would always enhance welfare. Present these distortions, trade could potentially exacerbate the consequences of poor environmental policies by impacting both the level and geographical distribution of pollution even generating 'pollution havens'.

Similar to the international commodity trade-environment debate, the deliberations on links between FDI and environment also address concerns of environmental degradation. These would generally arise from increase in the scale of economic activities, and creation of 'pollution havens' in jurisdictions having low environmental standards, both associated with private investment decisions of firms. In the context of FDI, however, two additional aspects require careful analysis: first, FDI as a conduit for transfer of environmentally sound technologies, and second, environmental effects of international competition for FDI. The latter relates to the popular debate on potential for 'race to the bottom' in environmental regulation as foreign investors seek out countries with less stringent environmental standards. Both of these issues are particularly relevant for developing countries.

Another important concern that has now emerged under the trade-environment debate pertains to the influence of special-interest politics on governments' policies. Driven by 'competitiveness' concerns, industries often appeal to the government against raising of environmental standards. The environmental lobbies do just the opposite. In the context of the ongoing debate on trade-environment linkages, the moot question is whether, on account of political-economy considerations, the efficacy of international trade to attain larger welfare for all, whilst ensuring sustainable use of environmental and natural resources, is being impeded.

All of these issues call for formal analysis.

By drawing motivation from the entire gamut of issues alluded above, the thesis focuses on three selected topics in the economic theory of international trade and environment. The first is an analysis of the effect of free trade in goods between developed (North) and developing (South) countries in the factor endowment framework. Compared to the analysis of Copeland and Taylor (1994)(henceforth C-T) – which is the central theoretical work so far on this subject – the novelty of our analysis lies in internalizing the commodity terms-of-trade impact of individual environmental policies. It is shown – as opposed to C-T (1994) – that free trade between North and South may lead to *improvement* of environment in *both* countries. Thus, free trade between developed and developing countries may not harm the environment in either country.

Traditional formal analysis of trade and environment policies typically assumes that the government is a benevolent maximizer of social welfare. In reality, however, it is influenced by special-interest groups. The second analysis of the thesis extends the well-known Grossman and Helpman (1994)(henceforth G-H) framework of political economy in the context of a small open economy by considering both trade and environment policies – particularly the interdependencies between them. First, it characterizes the policy levels in the political equilibrium in comparison to the benchmark case of free trade and a Pigouvian pollution tax. Next, it examines the sensitivity of these policies with respect to various parameters such as changes in terms-of-trade facing the country, preference for environmental quality, and government's concern for the industrial lobby's welfare. Amongst other interesting conclusions it is shown that, in comparison with the benchmark case, the government "concedes" in respect of trade policy – i.e. offers positive tariff protection. But, it *may not* concede on environment policy – i.e. it may impose a pollution tax higher than the Pigouvian tax. Moreover, as the government gets more political, it always gives in to lobby's demand for higher import tariff but, interestingly, it again may not relent in respect of environment policy.

The third topic deals with the effect of foreign direct investment (FDI) by capital-abundant developed country (North) in the capital-scarce developing country (South). In contrast to trade in goods and local pollution analyzed in the first two topics, the focus here is on the effect of FDI flows on transboundary pollution. Specifically, it revisits the hypothesis that free movement of capital from North to South worsens the global environment. It is found that zero to positive level of FDI damages the global environment. However, if countries move from non-cooperation to cooperation in setting environment polices, world environment quality improves, and there is *more* FDI. Hence, stringent environment policy is not necessarily an impediment for FDI, as is commonly believed.

The individual subsections below provide an overview of the model framework and the major findings of each of these three topics covered by the thesis.

1.1 North-South Trade and Pollution Migration: the Debate Revisited

An examination of the effect of North-South goods trade on local environment in each country is covered in Chapter 3. It builds on the well-known work by Copeland and Taylor (1994), briefly C-T. The C-T model suffers from an important limitation: it ignores the *commodity terms-of-trade* effect of environment policy. The authors justify the 'small-country assumption' on the premise that governments do not manipulate the terms-of-trade through environment policy. However, this assumption does not hold strong ground. Environmental restrictions have been frequently used as non-tariff barriers to trade: "tuna-dolphin" or "shrimp-turtle" cases are widely quoted examples of use of environmental regulation as barriers to trade. Moreover, for specific product groups, some countries or a group of them may be large suppliers relative to the world market, e.g. Brazil for coffee, Sri Lanka or

India for tea. Gulf countries for crude oil and petroleum products, and could potentially exercise market power to influence the terms-of-trade. Hence environmental policy changes would affect the terms-of-trade. This chapter departs from C-T by internalizing the *commodity terms-of-trade* effects of environment policy. It is demonstrated that many different possibilities emerge when the small-country assumption is relaxed.

The Chapter 3 develops a 2x2x2 factor-endowment model of trade. The two factors are skill-embodied labor and a natural resource whose use generates pollution. The production sectors vary in their pollution intensity. North and South are distinguished by their relative endowments of the two factor inputs: South is relatively more natural resource abundant and North relatively more human skill abundant. The respective governments are assumed to own the stock of the natural resource and optimally choose the national environment policy in terms of the quantity of the resource to be released to the economy. The pollution effects are local, i.e. pollution damages remain confined to the country of origin.

The respective governments in the North and South optimally decide on the supply of the natural resource, by trading-off the real income gains from its use against the marginal disutility from pollution caused by it. Governments choose the optimal resource supply in a non-cooperative Nash fashion. The resource is then auctioned-off competitively in the factor market, production and consumption takes place and markets clear. Relative endowment differences cause countries to choose differing pollution standards, as well as form the basis for differences in comparative advantage.

In terms of the sequence of analysis, the autarky equilibrium is characterized first, followed by free trade. The model structure is a variant of the standard factor-endowment model, except that the supply of one factor (natural resource) is determined endogenously; as mentioned already, this is governed by government's decision rule for optimal release of the resource input.

In autarky, North is shown to have a comparative advantage in the production of the "cleaner" good and South in the "dirtier" good. In the free trade regime, different equilibria could emerge – (a) both North and South remain incompletely specialized, (b) North specializes (in the cleaner good) whilst South produces both the goods, (c) North continues to produce both the goods whilst South becomes completely specialized (in the polluting good), and (d) both North and South specialize in goods they have comparative advantage in. Our analysis is restricted to two extreme cases: incomplete specialization (as in (a)) and complete specialization (as in (d)) in both countries. Characterization of the two partial specialization cases seemed analytically intractable. Compared to autarky, there are two main differences: first, there is global, rather than domestic, market clearing, and second, the national environmental policies of the two countries are strategically linked with each other. Here also, the non-cooperative Nash concept is used.

We first study the case of diversification in production in both countries, which is associated with factor price equalization (FPE). This occurs when the relative endowments of North and South are not too apart. In this case, all the results derived by us are qualitatively similar to C-T (1994), barring one, that relates to the change in the commodity terms-of-trade. Whilst C-T (1994) predicts that both countries will experience a terms-of-trade improvement, we derive that the effect on the terms-of-trade of one (of the two) countries remains ambiguous, whilst the other experiences an improvement. Both North and South have standard gains from trade. However, as international trade impacts the regional pollution policies and, hence, the magnitude of release of the natural resource (and pollution) at the global level (as compared to autarky), the commodity terms-of-trade effects are also affected. More specifically, a higher (lower) global release of the natural resource implies a larger (smaller) relative output (and supply) of the resource-intensive good in the world market. This depresses (raises) its relative price and is a source of terms-of-trade decline (improvement) for the South (North). Thus, depending on the direction of change of global resource use (and hence pollution) in response to trade, the terms-of-trade of one of the two countries may decline.

More interesting results emerge in the case where the factor endowments of two countries are sufficiently apart and trade leads North to specialize in the "cleaner" good and South in the "dirtier" good. Not only does pollution fall in the North in moving from autarky to free trade, *but this happens in the South as well.* It is interesting and paradoxical that South also reduces its pollution, despite specializing in the pollution-intensive good. This is due to the commodity terms-of-trade effect of environment policy. As South specializes in the pollution-intensive good a marginal increase in the release of the polluting resource leads to higher relative production of the pollution-intensive good, which is South's exportable. This, by itself, is a source of terms-of-trade decline. When countries are completely specialized, this effect would dominate over the standard terms-of-trade gains from trade (that occur when total factor employments in a trading country are given) and induces the South to reduce its pollution along with the North.

Moreover, contrary to C-T (1994), free trade may entail an overall terms-of-trade loss for the North, whilst South will always have a positive change in the terms-of-trade.[1] This is because the commodity terms-of-trade are also impacted by change in North and South's pollution policies as they open up trade. *Ceteris paribus*, as trade induces both the countries to adopt a more stringent pollution policy (and release less natural resource) in comparison with autarky, there would be a decline in the relative output of the exportable good in each country. This exerts a positive (negative) influence on the country's own (other country's) terms-of-trade. In the case of the North, the loss imposed by the stricter pollution policy of the South may turn out to be the dominant effect, and this may deteriorate North's overall commodity terms-of-trade. On the other hand, in the South, the standard terms-of-trade gains dominate.

Finally, in spite of better environment, free trade may cause both the countries to gain

[1]Observe that overall changes in the aggregate terms-of-trade are different from the terms-of-trade effect of environment policy discussed in the previous paragraph.

or lose in aggregate welfare. In the terminology of Newbery and Stiglitz (1984), this is yet another illustration of *Pareto inferior trade*. Thus, with complete specialization, our results differ significantly from C-T. Most strikingly, we find that freer trade may not be bad for the environment of either country.

1.2 Interaction between Trade and Environment Policies with Special Interest Politics

The interdependence between trade policy and environment policy, in the presence of special-interest politics, is considered in Chapter 4. A small open economy with two production sectors is postulated. One of them, the numeraire sector, uses only labor, and produces a "clean" good. The other uses three inputs - labor, (pollution causing) natural resource, and a third factor, say 'capital' which is sector-specific. Both sectors produce under constant-returns production technology. Following C-T (1994) pollution is modelled as a by-product of a joint production technology, and it is local in nature.[2] The polluting good is the country's importable.

The political interactions are confined to the importable sector alone. The owners of capital, the specific factor, benefit from trade protection (through import tariffs) and prefer low (to high) pollution taxes. They attempt to influence the policy stance of an electorally-motivated government by offering political contributions to it. The specific factor owners, thus, constitute the industrial lobby. On the other hand, the government is not entirely benevolent: its welfare is a weighted sum of average welfare and campaign contributions from the industrial lobby. This framework follows Grossman and Helpman (1994), briefly G-H.

[2]Since our focus is on policy determination in the home country alone (rather than on policy interactions between countries), whether pollution is local or global does not have any qualitative bearing on the results.

Given factor and goods prices, profit maximization yields the supply function, factor demands (note that one of the factor demands is the demand for pollution by firms) and the producer surplus. The representative agent's utility is quasi-linear in the two goods and additively separable in pollution damage. Utility maximization, subject to the budget constraint, gives linear a demand function. The government can potentially use two policy instruments: pollution tax and import tariff. As expected, the industrial lobby's welfare, equivalent to the producer surplus, is increasing in the import tariff and decreasing in pollution tax.

There are three stages of the game played between the incumbent government and lobby. In the first, government and lobby jointly decide on the political-contribution schedule through a process of Nash-bargaining. This implies an expression for the contribution function in terms of the two policy instruments. In the second, government announces its trade and environment policies, and accordingly receives the contribution from the lobby. In the third, consumption and production decisions are made.

The sequence of analysis is as follows. First we consider optimal trade and environment policies in the absence of lobbying. The economy being small, the solutions are free trade combined with the Pigouvian tax on the pollution causing natural resource. These constitute our reference point or our "benchmark" case.

We next consider the situation where there is lobbying and the government is politically motivated. Three cases are analyzed – (a) there is free trade but the pollution tax is political, (b) the pollution tax is set at the Pigouvian level whilst the import tariff is political, and (c) both tariffs and pollution tax are set politically. The last one – the full political equilibrium – is the centerpiece of our analysis.

It is found that, when only the environment policy is political, the pollution tax is set at a level lower than the Pigouvian tax. In the other extreme, if the lobby can influence trade policy only, the government provides a positive level of protection to the domestic import competing sector. These implications are intuitive. Since the government cares for political contributions, its policy stance reflects a compromise in terms of social welfare. In either case the effect of politics on environment is negative.

When both trade and environment policies are political, compared to the benchmark case, in equilibrium the government "concedes" with respect to trade policy - i.e. it offers a positive tariff protection. But surprisingly it *may not* concede on environment policy, i.e. it may supplement a protectionist trade policy with a pollution tax higher than the Pigouvian level. This happens because an incremental rise in the pollution tax (above the Pigouvian level) offers a first-order welfare gain and a first-order loss in terms of political contributions. If the gain outweighs the loss the government is induced to raise the tax. Nevertheless, the level of pollution is higher. On the other hand, a marginal increase in import tariff (above zero tariff) generates a second-order welfare loss whilst a first-order gain in political contributions, implying a positive tariff level.

Additionally, comparative statics with respect to model parameters yield the following results. Irrespective of whether one or both the policy instruments are political, the relative bargaining strengths of the government and the lobby do not impact the equilibrium level of tax or tariff. They merely determine the division of the surplus between the two groups.

The following results refer to (c), the full political equilibrium.

An exogenous increase in the preference for "cleaner" environment induces the government to raise the tax on pollution and lower the tariff protection. Naturally, the quality of environment improves.

As the world price of the importable good rises, the absolute level of import protection, measured in terms of the wedge between the domestic and the world price of the importable good, increases. However, the pollution tax may increase or decrease depending on the elasticity of output of the importable good. A high (low) value of output elasticity leads to raising (lowering) of the pollution tax. When higher import protection is combined lower pollution tax, the impact on environment is negative, as expected. Interestingly, however, even when the pollution tax is raised, the net effect on the environment is negative.

The relative weight on political contributions in the government's welfare function captures the extent of how politically inclined is the government. If there is an increase in this parameter, i.e. the government becomes more politically inclined, it raises the level of tariff protection, but may increase or lower the pollution tax. An interesting outcome that emerges is that even as the government gets more political, it may not relent in respect of environment policy. Nevertheless, combined with the change in trade policy, environment quality always worsens.

The upshot of this chapter is that when there is bargaining over more than one policy instrument, the government has the flexibility to trade-off one policy for the other. It may combine higher tariff protection with stricter environmental regulation or reduce import protection to offset the adverse environmental effect of a laxer environment policy.

1.3 North-South Capital Movement and Global Environment

Chapter 5 revisits the "pollution haven" debate in the context of FDI by the capital-abundant "Northern" to capital-scarce "Southern" countries, when pollution has transnational spillover effects. The model derives that the pollution policy of South may be less stringent than North's not because of difference in preference toward environment but due to factor endowment differences. In each country the government sets the pollution policy optimally. Then, capital movement (from North to South) would affect the environment policies of regions. It is not *a priori* clear whether global pollution would increase or reduce – or whether more pollution would be associated necessarily with higher level of FDI. Also it is not clear how FDI would affect the welfare of the two countries. Moreover, given several attempts by countries to cooperate on global environmental issues, it is also pertinent to ask what pattern of pollution policies would cooperation imply (as opposed to non-cooperation) and whether it would be a deterrent to FDI. All these issues are formally scrutinized in Chapter 5.

The model assumes that both North and South produce and consume one good alone. Thus it ignores the standard commodity terms-of-trade effects and sectoral factor intensity differences, and focuses on the implications of FDI entirely. The production process uses three inputs: labor, capital and a pollution generating natural resource. Countries differ in their endowments of capital: North is more capital abundant. Country rankings in respect of natural resource endowments or endowments of labor may or may not differ. The production function is linearly homogeneous in the three inputs, Cobb-Douglas in form and identical in both the countries. Perfect competition and profit maximization lead to factor rewards equalized to the respective marginal products.

The social welfare function is quasi-linear in respect of the consumption good and strictly concave in the environmental good. This implies a zero income effect on the demand for environmental good. (In an extension of the model, this assumption is relaxed and environment is assumed to be a "normal" good; however, the results remain the same qualitatively.)

The government in each country controls the total supply (release) of the polluting resource to the production sector (by weighing its marginal economic benefit and its marginal cost toward social welfare). It is then leased to the private sector in a competitive market. The private sector pays a market-determined per-unit 'pollution tax' to the government for the use of the resource. The environmental 'good' is proportional to how much is preserved of the resource, that is, the difference between the (exogenous) endowment of this resource and the amount released for production.

The analysis captures the following effects relating to how environment policies affect welfare. In the absence of capital movement between countries, the benefit from increasing the amount released of the resource lies in its expansionary impact on national output; this is the *output effect*. In the presence of capital movement, if governments behave non-cooperatively there is an additional effect, the *factor terms-of-trade effect*. These two effects, in relation to the marginal cost of pollution, determine the optimal pollution policy of a particular country. When regions cooperate the factor terms-of-trade effects wash out and the *public good* nature of global environment is fully internalized.

The sequence of analysis is as follows: as the benchmark, the case of autarky is studied first. Next international mobility of capital is allowed, where both non-cooperative and cooperative behavior (in setting environment policy) are examined separately.

It is found that, as FDI is allowed, the movement of capital from North to South induces the North to reduce its pollution, and correspondingly South's pollution increases. This is dictated by complementarity in the use of capital and natural resource. But not surprisingly, the sum of regional pollution, that is, global pollution, increases. In comparison with autarky, it is the South which unambiguously gains in terms of welfare, whilst the North may gain or lose. If the equilibrium FDI is small enough – i.e., the capital endowment differences are small enough, North unambiguously suffers a loss in welfare. In this case the global welfare falls. If the level of FDI is not 'small' the global welfare may increase or decrease.

The above conclusions are derived assuming that governments regulate their environments in a non-cooperative Nash fashion. With cooperation, implying joint welfare maximization, a 'surprising' result is that there is greater FDI, not less. Moreover, the cooperative solution (compared to non-cooperation) *may not* imply pollution reduction in the South, although pollution originating from the North decreases. The underlying intuition lies in the two effects arising from cooperative behavior: internalization of the public good nature of pollution and washing out of the factor terms-of-trade effects. Unlike non-cooperation, cooperation implies that each country takes into account the disutility of pollution imposed on the other country as well. Hence, on this account alone, less pollution is released in each country. Secondly, under cooperation, the factor terms-of-trade gains of one country completely cancel out against the losses of the other, such that the decline (increase) in marginal benefit for North (South) from pollution is more pronounced as compared to non-cooperation. This leads to a fall in pollution in the North and an increase in it in the South. Based on the sum of the two effects, there is a definite decline in North's pollution, whilst the South's may increase or decrease. However, the global pollution – or the sum of regional pollution levels – is less as one would expect.

The above results hold qualitatively irrespective of how the labor endowments of countries compare with each other (i.e., whether countries are symmetric or asymmetric in terms of skilled labor endowments) *or* whether or not there are income effects on the demand for environmental good. However, the following results are sensitive to differences in labor endowments or to the presence/absence of income effects on the demand for environment quality.

In general equilibrium pollution contribution of the North to global pollution is higher than that of the South at both autarky and capital mobility (with non-cooperation) equilibria. However, when there are income effects on the demand for environment (whilst labor endowments are symmetric) the country rankings in terms of their contribution to global pollution are changed. Whilst in case of autarky the pollution levels of North and South are equalized, under the FDI (with no-cooperation) regime North pollutes less than the South.

Further, at the cooperative equilibrium pollution levels and capital in use in both the countries are equalized in the case where labor endowments are symmetric between North and South and income-effects are absent. However, the asymmetry in the labor endowments (alone) causes this result to differ from the symmetric case. In this case, although the move from non-cooperation to cooperation leads additional capital to flow from North to South, this is not enough for pollution levels to get equalization between the two countries. Thus, at the cooperative equilibrium North continues to be a larger polluter. Moreover, the complementarity ensures that it also employs more capital than the South. When there are income effects (but countries have the same skilled labor endowments) then, similar to the non-cooperative equilibrium, the relative ranking between the North and South in contributing to global pollution is reversed. That is, North pollutes less than the South.

The most impressive conclusions of this chapter are that whilst zero to positive level of FDI damages the global pollution, a move to cooperation in setting environmental policies reduces global pollution. Furthermore, it induces *more* FDI, not less. Thus, stringency in environment policy is not a disincentive to FDI, as is commonly feared.

A survey of recent literature on each of three topics ensues in the following chapter.

Chapter 2

Review of Literature

This chapter provides a survey of recent literature that relates closely to the three basic topics of the dissertation: (a) linkages between international trade and environmental effects, (b) interdependence between trade policies and environment policies in the presence of politics, and (c) FDI and environment.

2.1 International Trade in Goods and Environmental Issues

There is huge body of literature on this general topic. Our review in this chapter is selective.

Whilst several aspects of the trade and environment link remain elusive, a consensus seems to be emerging in respect of a few. One major issue amongst them is the effect of freer trade on the environment and welfare of countries. In this respect, the analytical works of C-T (1994, 1995) and Chichilinsky (1995), all of which utilize a North-South division of the world economy, are central in the literature. Bhagwati and Srinivasan (1996), Chandar and Khan (1999) and Das (2001) are the more recent theoretical papers on this issue.

C-T (1994) analyzes local pollution. Pollution is modelled as a variable input (with perfectly elastic supply) in the production process. (Equivalently, it is a by-product of the production process). Their model has two sets of countries, North (developed) and South (developing), and a continuum of goods inherently different in pollution intensities. North and South are distinguished by endowments of human capital (which is the only primary factor of production): North is relatively human capital abundant. National governments control pollution by pollution taxes, with North's choosing to set a higher tax rate because of higher incomes (this is on account of higher stock of human capital). Trade brings into play three effects in each country: (i) change in the industrial composition of output, whereby polluting industries contract in the North and expand in the South, (ii) expansion of economic activity, which is bad for the environment in both countries, and (iii) income growth that brings a higher willingness to pay for pollution abatement and lowers pollution in both the countries. The paper concludes that the composition effect is dominant and trade leads to higher pollution in the South and lower pollution in the North. Moreover, from autarky to a free trade regime, both North and South experience an improvement in the commodity terms-of-trade, and an increase in welfare.

C-T (1995) builds on this framework but analyzes transnational pollution (instead of local pollution). It assumes a large number of Northern and Southern countries. Countries control emissions through self-imposed national quotas. As trade is liberalized, the usual composition effect arises, with clean industries expanding in the North and polluting ones in the South. When countries are relatively similar in their human resource endowments and trade causes FPE, the pollution by each Southern country rises, by each Northern country falls, but the world pollution is unaffected as compared to autarky. More interestingly, in the FPE equilibrium, Southern countries gain and Northern countries lose in terms of welfare. However, if countries differ in their human capital stocks sufficiently, and factor prices do not equalize with trade, then, whilst the direction of change of pollution in each group of countries is similar to that under FPE, global pollution is higher in free trade than in autarky.

The related paper by Chichilinsky (1995) is interesting in that it characterizes the North and South by the underlying institutional structure: property rights over natural resources are ill-defined in the South (developing countries) in comparison with the North (developed countries). A simple model is used to show how trade between the North and South pronounces the "tragedy of commons", the driving factor being South's apparent (as opposed to real) comparative advantage in natural resource extraction due to its ill-defined property rights. South, therefore, produces a larger relative output of the resource-intensive good than if it had well-defined property rights. Consequently, trade leads to outcomes similar to C-T (1994).

In terms of more recent work on the subject, Chandar and Khan (1999) also uses a North-South model of trade in goods and transboundary pollution and shows that free trade may not lead to rise in world pollution even if the income effects on the demand for environmental are absent; in fact, global pollution would be less than that under autarky. This happens when trade in goods is accompanied by international trade in emissions, which induces a shift in the production of the polluting good from the country using higher pollution intensity of output (e.g. the South) to the less pollution-intensive country (e.g. the North), whilst the world output of the private good may not fall. Similar to C-T (1994), Chandar and Khan (1999) ignores the commodity terms-of-trade effect of environmental policy.

Addressing the concerns relating to demand for harmonization of cross-country intra-industry (CCII) environmental policies, Bhagwati and Srinivasan (1996) argues in favor of diverse environmental standards across countries. In the specific context of local pollution an important result derived is that "...the optimal pollution taxes (in a globally Pareto optimal solution) will not be equal across the countries...", and that the diversity in taxes is not only natural but also legitimate. In the case of global pollution as well, pollution taxes would vary across countries, except when there is factor price equalization.

A related paper, Das (2001) carries out a more detailed analysis of CCII environmental diversity. Again, it examines this in the context of both local as well as global pollution. It characterizes optimal pollution standard when the terms-of-trade effects of environment policy are internalized. He uses a partial-equilibrium two-country, one-commodity model of goods trade. The countries differ in terms of marginal costs of production (e.g. labor costs), which form the basis for "true or real" comparative advantage; these costs are distinct from pollution abatement costs. This has implications for choice of pollution standards by the country, thus dictating the costs of pollution abatement, which determines a country's "apparent" comparative advantage. (The notion of true versus apparent comparative advantage is somewhat similar to Chichilinsky (1995).) The predictions differ according to the type of pollution: local or global. When pollution is local in nature, at the autarky equilibrium the country with "true" cost advantage (and hence the exporter) imposes a higher pollution standard and has an "apparent" cost disadvantage as compared to the country with "true" cost disadvantage (the importer). The true cost advantage (disadvantage) is, thus, partly (not fully) offset by the apparent cost disadvantage (advantage). A move to free trade causes the exporting country to tighten its pollution standard, whilst the importing country may tighten or relax its standard; however, at the free trade (non-cooperative) equilibrium the former is always more stringent than the latter. By comparison, when pollution is transnational, the autarky equilibrium entails lower (higher) environmental standard for the low- (high-) cost country, implying that the two reinforce each other. A move to free trade entails changes in national environmental standards similar to when pollution is local, and the low-cost (exporting) country may continue to have pollution standards lower than the high-cost country.

A number of empirical studies such as Tobey (1990), Low and Yeats (1992), Lucas, Wheeler and Hettige (1992), Grossman and Krueger (1993), Sorsa (1994), Mani and Wheeler (1999), Strutt and Anderson (1999), Dean (1999) and most recently Antweiler, Copeland and Taylor (2000) have also addressed the question of the effect of trade liberalization and growth on environment. The results are, however, mixed. Some studies find no significant relationship between trade liberalization and environment. Some find a significant and negative relationship, whilst in others there is a significant positive link. Some studies also point toward factors other than international differences in pollution policies as the underlying motive for relocation of industries, such as differences in resource endowments, labor and so on.

Tobey (1990) and Grossman and Krueger (1993) test the impact of environmental regulation on trade flows by taking a Hecksher-Ohlin-Vanek (HOV) model, and focus on the composition effect alone. Both treat environment as a factor of production, which, along with labor, capital, and natural resources affects the pattern of trade. Tobey (1990) uses a multi-factor, multi-commodity model of 23 countries. He regresses the net exports of 5 aggregated industry groups (that are pollution-intensive) over endowments of productive factors, where the stringency of environmental regulation is used as the proxy for the stock of environmental resource. In none of the regressions is the environmental stringency variable found to be significant. Grossman and Krueger (1993) relates the 1987 United States (US) imports from Mexico (in comparison with aggregate US shipments) in 135 industrial sectors to factor shares as independent variables. Accordingly, factor shares in their model represent factor intensity of a sector, and environmental intensity is reflected in the ratio of pollution abatement costs to total value added by the industry. The paper finds that although US imports from Mexico are lower in industries that are highly capital-intensive (either physical or human), the pollution abatement costs have no significant impact on US imports from Mexico.

The statistical evidence found by Low and Yeats (1992) for pollution intensity of trade in developed and developing country (between the years 1965-88) suggests that developing countries had increased their share of world trade in all environmentally dirty goods (originating in the region) from 22 to 26 per cent, with a rising share of pollution-intensive exports in subregions of Eastern Europe, Latin America and West Asia, and a falling share (since the mid-1980s) in South-East Asia. Concomitantly, the share of industrialized countries in world trade reduced from 78 per cent to 74 per cent along with a similar percentage point fall in share in total exports from the region. The polluting industries refer to those incurring high levels of pollution abatement and control costs in the US, namely chemicals, non-ferrous metals, iron and steel, pulp and paper, petroleum products, and raw material processing. Whilst these estimates indicate growing comparative advantage of developing countries in pollution-intensive goods, the significance of the role of environmental regulation in causing this pattern remains unclear. For selected industries alternative reasons such as labor abundance, natural resource endowments etc., are cited as the other important factors underlying these trends. The authors also noted that many of the polluting industries were those associated with the early stages of industrialization, which would have grown irrespective of the 1-2 per cent cost advantage arising out of laxer environment regulation.

Lucas, Wheeler and Hettige (1992) focuses on the emissions intensity of output (measured by GDP). For the period 1960 to 1980 they regress the aggregate pollution intensity of output on initial per capita incomes, GDP growth and a measure of trade restriction. The paper finds that countries with faster growth of GDP experienced lower rates of increase in pollution intensity over the study period. For the faster growing low- and middle-income countries, which had lesser trade distortion, the toxic intensity was further lowered. On the other hand, higher trade distortion appeared to have accelerated the growth of toxic intensity of output. Thus, it concludes that openness to trade contributes to cleaner growth by changing the composition of output toward cleaner sectors.

Analyzing the trends in international trade between 1970 and 1990 in a cross-country model, Sorsa (1994) finds industrialized countries' share of manufacturing exports in the world to have declined from 91 per cent to 81 per cent. However, most of this decline was found in labor-intensive sectors such as textiles, apparel, footwear, and other light manufacturing, in which comparative advantage was in favor of developing countries (having lower labor costs). In contrast, developed countries' share of world trade in polluting products, which are by nature capital-intensive, remained essentially stable at 81.3 per cent in 1970 to 81.1 per cent in 1990.

Against the backdrop of tightening environmental regulation in industrialized countries (in the 1960s and 70s), and growing international gap in stringency in comparison with developing countries Mani and Wheeler's (1999) cross-country analysis initially seems to confirm the 'pollution haven' hypothesis: fraction of pollution-intensive output in total manufacturing output having fallen consistently in the Organization for Economic Cooperation and Development (OECD) countries and increased in the developing countries, and periods of spurts in net exports of pollution-intensive products from developing countries overlapping with time-periods when the OECD experienced rapid increases in pollution abatement costs. The paper, however, goes on to point out that the pollution haven effect may not be significant for three reasons: consumption to production ratios for polluting commodities in the developing world remained fairly close to unity through the period of study, indicating that production had largely been for domestic and not world markets; a majority of the increase in dirty-sector's share in developing countries had arisen out of high income-elasticity of demand for basic industrial goods, and as incomes rose the income-elasticity depicted a declining trend; growing stringency of environmental regulation associated with rising incomes had tended to bring about a shift toward cleaner and away from dirty sectors. Therefore, the paper concludes that the tendency to generation of pollution havens appears to be "self-limiting".

In contrast to the econometric approach used by others, Strutt and Anderson (1999) uses a computable general equilibrium (CGE) model to predict the incremental environmental impacts of trade liberalization in Indonesia in the future; the focus is on the technique effect. It analyzes marginal environmental damage caused by trade liberalization, specifically in the context of the impact of new technologies on emissions. In a static CGE model it is derived that, in respect of air and water quality, trade policy reforms would improve the environment or at worst cause only small environmental deterioration. However, if the dynamic effects of trade liberalization on economic growth are taken into account, there is greater worsening of air and water quality. The paper concludes that economic gains from trade reforms be used toward reducing environmental damage and social welfare.

Dean (1999) tests the effect of trade liberalization on the environment in the context of water pollution in China. She takes into account the effects of openness to trade on income growth and of income growth on environmental damage. This allows for trade to have both direct and indirect effects on emissions growth, both being opposite in sign. Dean finds that China has a comparative advantage in pollution-intensive goods, so that freer trade directly aggravates environmental damage by inducing specialization in these sectors – the composition effect. On the other hand, as trade enhances income levels, higher incomes have a negative effect on emissions growth, reducing pollution levels. This happens on account of increase in the demand for environmental quality - the technique effect.

The panel data analysis of Antweiler, Copeland and Taylor (2000) suggests that total emissions could fall with trade. The empirical evidence is based on the relationship between trade and ground level concentrations of sulphur dioxide derived for over 40 developed and developing countries with data spanning the period 1971-96. The model allows both - income and factor abundance differences – to conjointly determine the trade patterns. Decomposing the impact of trade into familiar scale, technique (or income) and composition of output effects, evidently trade would alter the composition of national output toward greater pollution intensity for capital-abundant (usually high-income) countries. Thus, the benefits that might flow out of lenient environmental regulation in the low-income economies may well get fully offset by their capital-scarcity implying that further openness to trade would have small effect on the pollution intensity of output of low-income economies. Simultaneously, the technique/income effect would dominate the scale effect. With specific reference to sulphur dioxide concentrations, a 1 per cent increase in the scale of economic activity would raise pollution concentrations by 0.25-0.5 per cent, but the accompanying increase in incomes would tend to drive concentrations down by 1.25-1.5 per cent through the technique effect. In the final analysis, if trade raises GDP per capita by 1 per cent, pollution concentrations would tend to fall by 1 per cent. Thus, for an average country trade may reduce emissions, although capital-abundant or poor countries may suffer increased concentrations on this account.

2.2 Political Economy of Trade and Environment Policies

The concerns about how environment and industry interests might influence trade or domestic policies have led to the emergence of analytical models that view trade and environment policies as an outgrowth of a political process.

There is a huge literature on the political economy issues of trade policy, most of which uses one or the other of the following two analytical approaches. The first approach, adopted by Hillman (1989) and Magee et.al. (1989), attempts to explain the outcome of a political process when there is political competition amongst rival candidates. Hillman and Ursprung (1992) uses this approach to investigate how environmental lobbying influences trade policy when environmental damage arises in production or consumption activities. According to this approach, competing parties make announcements on the policy proposals they plan to implement upon being elected. In response, organized lobbies evaluate their members' prospects under alternative policy packages and make contributions to the party that offers it the highest pay-off. The underlying intention is to impact the election outcome through financial contributions.

The alternative, more recent, approach for the analysis of political economy aspects of trade policy is due to G-H (1994, 1995). They use a many-principals-single-agent model. The incumbent government is perceived as the agent, whereas the organized lobbies in different industrial sectors of the economy are the principals. Industry or environmental groups seek political favors from the government by making contributions to sway policy outcomes in their favor. The political contributions are linked to the specific policy stance of the government. The government is not a benevolent maximizer of social welfare. It sets policies to maximize "political support" taken to be a weighted average of pure social welfare and the welfare of the lobbies.

Chapter 4, which addresses political economy of trade and environment policies, uses the G-H approach. Therefore, the focus of our review here is on the second strand of literature. Before moving to the discussion of this literature in the context of environment, a brief review of G-H (1994, 1995) – both in the context of trade policy alone – is in order.

G-H (1994) characterizes the trade policy in a representative democracy. It derives an explicit expression to characterize the structure of trade protection under the political influence of industrial lobbies. The level of protection to an industry is related to the state of its political organization, the ratio of domestic output in the industry to net trade and the elasticity of import demand or export supply. Industries having high import demand or export supply elasticity are found to have smaller deviations from free trade. The authors also discuss the determinants of size of political contributions that the various lobbies must make to support the equilibrium policy choice. G-H (1995) is the companion paper, where the authors use a similar framework to capture both – the strategic interaction between special interest groups and politicians in the domestic arena and strategic interaction between the national governments in the international arena. They derive the structure of trade protection in both non-cooperative and cooperative policy equilibria. Under non-cooperation, each political party ignores the impact of its policies on factor owners and political groups in the other country. Then similar to G-H (1994), the incumbent government is induced to offer import tariffs for industries that are politically organized. The rates of tariff are positively correlated with the stake of the specific factor in trade policy, and inversely to the sizes of elasticities of foreign export supply and home import demand. The authors go on to discuss the outcomes when the incumbent governments of trading countries enter into a cooperative trade negotiation with each other. With international bargaining, rates of protection reflect the political strength of the interest group at home and in the partner country. In the event that these are equally strong, a politically negotiated trade policy outcome is the same as free trade.

In the specific context of environment policy, the works of Fredriksson (1997a, 1997b), Aidt (1998, 2000), Schleich (1999) and Schleich and Orden (2000) are important; all of them utilize the G-H approach.

Fredriksson (1997a, 1997b) characterizes environmental regulation in the presence of lobbying by industrial and environmental special interest groups in the context of a small open economy. Fredriksson (1997a) finds the politically determined pollution tax to be different from the Pigouvian tax rate. It is a function of the lobby membership, government's politicization parameter (the weight accorded to political contributions vis-a-vis social welfare), and tax elasticity of pollution. Comparative statics find equilibrium pollution tax to be decreasing in the world price (if some groups in the economy are not organized into lobbies), and aggregate pollution to be increasing in it. As the environment lobby gets larger, three effects are found to emerge: total pollution increases, aggregate welfare is more adversely affected by pollution and environmental lobby's share of pollution tax revenue increases. The final outcome in terms of environment policy change remains unclear. As the government gets more political, pollution tax is even more distorted away from the Pigouvian level. Further, and strikingly, when the polluting industry can invest in abatement technology, pollution is increasing in the abatement subsidy rate if subsidy leads to a large enough increase in the output due to altered political effects on equilibrium output tax. Fredriksson (1997b), a related paper, focuses on pollution abatement subsidy and pollution tax. A benevolent government imposes a Pigouvian tax and zero subsidy, implying that subsidy is not efficient for pollution regulation. On the other hand, a politically inclined government sets a pollution tax to gain support of the environmental lobby, and compensates the industrial lobby by providing a subsidy on pollution abatement. A positive subsidy arises on account of the following. If pollution is decreasing in the abatement subsidy, the subsidy benefits both the environmentalists and industrialists. Alternatively, if pollution is increasing in pollution abatement (also in Fredriksson (1997a)), the environmentalists may still benefit if the pollution tax is high enough to lead to a reduction in overall pollution. Further, if the entire population organizes itself into lobby groups, or if government's concern for social welfare increases, the equilibrium pollution tax and abatement subsidy approach their socially optimum levels.

In a similar model, Aidt (1998) analyzes the issue of targeting the environmental externality. If two policy instruments, namely, production taxes-cum-subsidies and input taxes-cum-subsidies, are available, then whilst the former is used to satisfy the demands of lobby groups, the latter is used to regulate pollution. Under certain conditions the resulting pollution tax may exceed the Pigouvian tax. The paper analyzes two cases: one where the environmental lobby reflects both - environmental and economic - interests, and the other where lobby groups advocate only one goal - environmental or economic. In case of pure welfare maximization input taxes (and not production taxes), equivalent to the respective Pigouvian taxes, prevail across sectors. At the political equilibrium as well, only input taxes are used to correct for the external effects - i.e., the competitive process entails targeting the most efficient economic instrument for internalizing the external environmental effects, as in Fredriksson (1997b). Given proportional transfer of tax revenues, the environmental tax corresponds to the full Pigouvian adjustment. However, given the income distributional considerations, the political equilibrium does not imitate the social optimum unless all the sectors are organized into lobby groups. Under certain plausible conditions, the organized lobby groups manage to redistribute incomes in their favor (as in G-H (1994)) through a production subsidy and a raw material tax lower than the Pigouvian tax. Simultaneously, an electorally motivated government taxes the unorganized sectors at an inefficiently high rate to produce the extra tax revenue (as lobby groups have desire for monetary transfers from the government), a part of which is distributed back to the organized lobby groups. If the lobbies are functionally specialized the environmental tax on the polluting input is larger than the corresponding Pigouvian tax, since the government and the environmental group suffer from environmental damage, while only the government has the concern for loss in welfare resulting from the distorted pollution tax. The producer lobby accepts the environmental adjustment proposed by the environmental lobby in exchange for a production subsidy and an environmental discount. In the unorganized sectors the only policy adjustment takes place in respect of environmental tax, as firms in these sectors do not have industrial lobbies to bid for subsidies, whilst, simultaneously, the organized producer lobbies do not have stakes in the government revenue. This leads to environmental adjustment being always larger than the Pigouvian level.

Schleich (1999) and Schleich and Orden (2000) also use the G-H (1994) framework for examining the impact of alternative policy regimes on environmental quality, separately for small and large open economies separately for small and large open economies and for consumption and production externality. The policy instruments considered are domestic taxes and subsidies and trade taxes and subsidies. In general, both the papers emphasize how different policy tools of (environment or trade) regulation would target achievement of various environmental and economic goals.

The analysis in Schleich (1999) is in the context of a small open economy where the government could choose either both domestic and trade policies, or else, only one of the two. In the case of production externality, it is shown that at the political equilibrium when both (trade and environment) policies are available, the government chooses production policies over trade policies, which is similar to Aidt (1998). Also, lobbying by polluting industry generally worsens the environment, but may improve it if the pollution damage is decreasing in pollution. Moreover, trade policy alone may lead to a better environment than production policy alone. By comparison, for the consumption externality, both domestic and trade policies are required to deal with pollution and to satisfy the lobbies: whilst consumption taxes/subsidies are used to take care of consumption externality (always done at the socially optimal level), trade policy is used as protection for domestic industry.

Schleich and Orden (2000) is the companion paper that examines at the large open economy case and strategic interaction between the home and foreign country, similar to G-H (1995). It shows that, since lobbies prefer less to more efficient policies, neither the use of efficient policies (e.g., domestic environmental policies) alone nor cooperation by the government will lead to improved environment, in comparison with less efficient (e.g. trade) policies (from the view point of environment) or non-cooperation. In case of production externality and non-cooperation, equilibrium production policy alone entails a lower tax than the Pigouvian tax, whilst trade policy alone leads to better environment, as in Schleich (1999). With cooperation, the governments are able to give in to any lobby's demands at lower costs to other lobbies and total welfare. However, environment quality might be lower under cooperation than with non-cooperation. Moreover, in contrast with G-H (1995), where cooperation leads only one country's production sector to get protection, it is shown here that the organized production sector in both the home and foreign country may get protection in the political equilibrium. If the environmental effects arise in consumption, governments act non-cooperatively, (and both consumption and trade policies are available) then, like in Schleich (1999), the domestic policy addresses the environmental externality and distortions from trade intervention, the trade policy is used to satisfy the lobbies. However, unlike the case of small country (in Schleich (1999)), environment and domestic consumption will not be socially optimal, whether cooperation occurs or not. In case of limited policy choice, domestic protection via a consumption subsidy alone increases with the political power of the industry in the partner country. Moreover, when only trade policy is available, industry protection is harmonized between countries if the environmental effects have transnational spillover effects and countries cooperate.

As compared to Fredriksson (1997a, 1997b), Schleich (1999) and Schleich and Orden (2000), the Chapter 4 of the thesis carries out a more detailed analysis of the interactions between trade and environment policies in the context of a small import-competing industry. Further, unlike the above papers that have the underlying assumption of government not having any bargaining power vis-a-vis the industry lobbies, in Chapter 4 we improve upon this by assuming that both the government and the lobby possess positive bargain power against each other.

2.3 Foreign Direct Investment and Environment

"Tariff jumping" is commonly cited as the motivation for FDI, providing foreign private firms a means to enter the protected markets. In recent years, additional issues about environmental degradation have arisen, which voice concerns that environmentally less-conscious (mostly developing) nations have become "pollution havens" for foreign private investment flows, providing another explanation for international capital relocation.

Although there is a large volume of literature on the effect of North-South goods trade and environment, relatively less attention has been focused on the effect of FDI (the most important component of private capital flows) on environment. A review of theoretical and empirical studies points toward much less consensus on basic issues – such as environmental effects of FDI, FDI as a conduit for transfer of environmentally superior technologies, environmental effects of international competition for FDI etc. Amongst the important works, those of McGuire (1982), Merrifield (1988), Rauscher (1992, 1997), Schneider and Wellisch (1997), C-T (1997), Beladi, Chau and Khan (2000), Killinger (2000), and Chao and Yu (2001) span a fairly large set of issues under the FDI-environment debate.

McGuire (1982) develops a two-country, two-sector factor endowment model that examines the effect of unilateral environmental regulation in the presence of capital mobility. It is shown that unilateral action, together with mobility of capital (at given commodity prices), will drive out the regulated industry completely from more to less regulated economy. This is because, given constant world prices, to maintain the corresponding factor proportions requires that the composition of output must change in a manner that one sector is completely driven out of one country and the country specializes in the unregulated good alone.

Rauscher (1992) analyzes the effect of international capital mobility on environment in a two-country, two-factor (sector-specific capital and pollution) model, where countries are distinguished by capital endowments. It is shown that pollution in the capital importing country is always raised and in the capital exporting it is lowered, irrespective of whether pollution taxes are adjusted optimally or not. If the government is not entirely benevolent and pursues other politically-laden objectives, it may attempt to restrict the outflow of private capital. In this case, international competition for capital may induce the capital-rich country to relax its pollution policy and the capital-scarce country to tighten it, and will not lead to unacceptably low level of environmental regulation, or the "race to the bottom" as is commonly feared. An international convergence of environmental policies might occur.

In a related work, Rauscher (1997) does an extensive analysis of the links between FDI and environment. Most of the analysis utilizes comparative statics framework. A range of possible outcomes – for environment, FDI flows and welfare – under assumptions of small- and large-open economies, optimal and non-optimal pollution policies, and non-cooperative versus cooperative policy setting are considered. At least two kinds of environmental externalities are considered: first, environmental pollution directly impacts welfare in a negative fashion, and second, emissions impact production negatively. The key results follow. If the two countries are small (so that FDI does not affect the market rate of interest) openness to trade leads the capital-poor country to increase and the capital-rich country to reduce its emissions. In general the effects on welfare are ambiguous, whilst with optimal environment policies these are positive for both countries. If countries are large, so that capital movement affects the factor terms-of-trade, welfare losses for countries cannot be ruled out even when the environmental policies are set optimally, largely on account of an increase in national or global pollution. Further, if the negative environmental effects on production are relatively weak, an increase in the emissions by the importing country will lead to larger capital inflows into it; the opposite will hold if the capital exporting country increases its emissions. This is because the marginal product of capital (and, therefore, the return on it) is increasing in the level of utilization of other (complementary) input, emissions. If countries cooperate on environmental policies, welfare gains accrue on account of full internalization of the transboundary pollution effects, and environment policy (now) not getting influenced by the factor terms-of-trade effects (which cancel out between the two countries) as global welfare is maximized.

As Rauscher (1992), C-T (1997) also uses a two-factor, two-good model of North-South trade (in goods and capital), where only one sector – that uses sector-specific capital – generates pollution. It analyzes the impact of FDI on local pollution. It is shown that, when factor-abundance determines the trade patterns, then allowing free capital mobility will cause world pollution to rise (from free trade levels), as the pollution-intensive production shifts to the South which has laxer environment policy. If instead income differences lead to goods trade, capital mobility leads to a fall in world pollution.

Schneider and Wellisch (1997) takes up issues of ecological dumping in the context of a small open economy with two – traded- and non-traded goods – sectors, each using three factors, labor, capital and emissions. They find that if the factors are immobile, the environmental tax coincides with the Pigouvian tax, and countries do not attempt ecological dumping.[1] When capital is mobile and pollution permits are used as the means of environmental regulation, then under certain technological configuration, more generous pollution allowances may be granted to the non-traded sector as compared to the traded sector just the opposite of ecological dumping. This is because, by indulging in ecological dumping, whilst the rents on pollution flow out to foreign capital owners, the cost of pollution is fully borne by the residents of the country. The result is due to the price of the traded-good being constant, whilst that of the non-traded good remaining flexible. Following the release of emission permits to the traded sector, the non-traded goods sector experiences capital outflows, which are not fully offset by the capital inflows into the traded sector; this enhances the overall outflow of emission rents to capital owners outside the country.

In a North-South model of trade with partial specialization (where capital abundant North specializes in manufacturing and capital-scarce South produces both agricultural and manufacturing goods), Beladi, Chau and Khan (2000) look at investment flows with and without the commodity terms-of-trade changes. The key factor in their model is the sensitivity of agricultural productivity to pollution in the South. They show that unrestricted FDI may force the South to completely abandon the agricultural activity by lowering its productivity and, hence, returns to labor in agriculture. This drives out labor to seek employment in the manufacturing sector. This provides even greater incentive for capital to move into the South due to increasing marginal productivity of capital. Optimal investment policy in the absence of commodity terms-of-trade is a capital export subsidy by the North, which brings factor terms-of-trade gains. Correspondingly, it is optimal to tax capital imports in the South, at a level higher than the Pigouvian tax, which takes care of pollution damage and corrects for distortions arising out of over-investment. When the commodity

[1]Ecological dumping implies imposing relatively lax environmental policy in the traded sector as compared to the non-traded sector, to avoid loss of international competitiveness of the former.

terms-of-trade are endogenous, the choice of investment policies remains qualitatively the same for both countries, but in addition, both countries try to manipulate the commodity terms-of-trade to their advantage. This is done by imposing a consumption subsidy (tax) on manufacturing by the North (South).

Similar to Rauscher (1997), Killinger (2000) uses a two-country, one sector model; countries are linked on account of capital mobility and transnational pollution spillovers. The analysis focuses on welfare effects of unilateral policy changes – in respect of pollution tax and capital tax. Three policy goals are aimed at: strategic manipulation of return on capital, addressing domestic environmental externality and pollution spillover from partner country. Assuming lumpsum taxes, use of pollution taxes alone entails that these are not the first-best instruments. This is because whilst maximizing national welfare, each country ignores the effect of its pollution on the partner country, and also strategically exploits the market power to alter the rent on capital in its favor. The use of capital tax alone also yields a second-best (optimal) tax, that too purely from a national viewpoint. The international capital allocation is manipulated by each country to generate favorable interest rate changes, and environmental damages imposed on the other country are neglected. Combined use of the two policies leads pollution tax to assume its first-best character, although again from a purely national viewpoint. The capital tax now takes care of the negative effects imposed by the pollution tax on the environment of the partner country as well as the cost of capital. By comparison, cooperation and joint welfare maximization entail that Pigouvian tax (alone), equivalent to global marginal damage caused by any country, would attain global efficiency.

Chao and Yu (2001) considers capital mobility in the case of a small open economy, with two producing sectors: a polluting importable sector that uses labor and capital (domestic and foreign), and another non-polluting exportable sector that uses only labor and land as inputs. Pollution is a by-product of production and is controlled through a pollution tax. The model considers the effect of change in foreign investment requirements and environment policies on aggregate welfare, under alternative regimes of trade intervention through import tariffs and quantitative restrictions. When import tariffs are in place, it is optimal to have a pollution tax higher than the Pigouvian tax and to put in place a 100 per cent export share requirement for the foreign firms investing in the economy. This is because, FDI in the importable sector leads to sub-optimal expansion of this sector. The full export requirement works toward offsetting this production distortion whilst a high pollution tax corrects for the consumption distortion created by the import tariff. Correspondingly, in the presence of quantitative restrictions on imports, the market clearing price is distorted above its optimal level. A pollution tax higher than the Pigouvian tax exacerbates the price distortion by raising it even higher. A lower than the socially optimal pollution tax is, therefore, optimal for the economy. Simultaneously, a less than 100 per cent export requirement reduces the outflow of rents to the foreigners.

The findings of empirical studies on FDI location and stringency of environmental regulation are almost as inconclusive as those propounded by the theoretical studies. Friedman, Gerlowski and Silberman (1992) analyze data on foreign multinational location decisions in the US (from 1977-88) in relation to state-specific factors such as access to foreign markets, size of domestic market, port facilities, incomes, and finally a measure of stringency of pollution regulation, by using a conditional logit model. It concludes that pollution regulation does not significantly influence the location decisions of private investment firms. This prediction, however, holds at the aggregate level and may hide the effects for specific industries. Levinson (1996) uses a set of six measures of environmental stringency to assess new domestic firm location decisions spanning the period 1982-87, using a similar econometric approach. In most instances, the paper finds that the probability of choosing a state declines with the increase in the strictness of environmental regulation. It also points out that outcomes predicted are weak in terms of economic intuition and do not tend to vary logically with the pollution intensity of the industry. Taking the state-level data from 1986-93, a recent paper by List and Co (2000) also tests whether inflows of FDI into US are sensitive to state environmental regulations. It finds that the FDI flows into a state are deterred by the stringency of environmental regulation, and the magnitudes of these effects are rather large.

Chapter 3

North-South Trade and Pollution Migration: the Debate Revisited

3.1 Introduction

Globalization and growing environmental consciousness have generated a heated debate on how international trade and environment are linked, especially in the context of goods' trade between developed "Northern" and developing "Southern" countries. The debate centers around the familiar scale, composition and income effects of trade on both - level and geographical distribution - of pollution. The environmentalists blame freer trade for accentuating environmental problems - trade causes expansion in the *scale* of economic (production and consumption) activity that damages the environment. They also point toward the change in the *composition* of output stemming from relocation of pollution-intensive industries from countries having stricter environmental regulation (typically, the North) to where it is relatively lax (as in the South). In contrast, the pro-trade community argues that standard income gains entailed by trade lead to greater clamor for environmental quality by all countries, thus inducing a switch to cleaner technologies, the so-called *income* or *technique* effect.

The recent literature on this issue points toward a series of definitive results on how trade impacts environmental quality and welfare of developed (North) and developing (South) and of the world at large. As discussed in Chapter 2, C-T (1994, 1995) are the central theoretical papers on the subject. Several empirical studies, already discussed in Chapter 2, also address the question of effect of trade liberalization on environment but derive less conclusive results.

C-T (1994) analyzes the effect of trade on local pollution in case of countries being small open economies. The two countries, North and South, are distinguished by endowments of human capital. They find that trade leads to higher pollution in the South and lower pollution in the North, both North and South have an improvement in the terms-of-trade, and free trade is welfare improving for both countries. C-T (1995) is the companion paper where the earlier model is extended to transnational pollution and presence of large number of Northern and Southern countries. For a discussion on these, see Chapter 2.

The focus of this chapter is on re-examination of C-T (1994). Whilst C-T (1994) constitutes one of the first theoretical enquiries into effects of freer trade on environment their model suffers from an important limitation: it completely ignores the *commodity* terms-of-trade effect of environment policy.[1] The authors justify the 'small-country' assumption on the premise that governments do not manipulate the terms-of-trade through environment policy due to two factors: there is poor coordination of environment and trade policy in most countries, and further, GATT's Article XX bars countries from using environmental regulations as barriers to trade. Perhaps implicit in their assumption is also the existence of a large number of "Northern" and "Southern" countries, each too small to have any market influence. However, none of these assumptions hold strong ground. Environmental restrictions have been frequently used as non-tariff barriers to trade: the "tuna-dolphin" or

[1] However their subsequent paper, C-T (1995), does relax the small-country assumption and allows trading countries to take note of the terms-of-trade effects when choosing their pollution quotas. The analysis of these is, however, restricted to the FPE case alone.

the "shrimp-turtle" cases are widely quoted examples of use of environmental regulation as barriers to free trade. Moreover, for specific product groups some countries or a group of them may be large suppliers relative to the world market, e.g. Brazil for coffee, India and Sri Lanka for tea, Gulf countries for crude oil and petroleum products, and could potentially exercise market power to influence the terms-of-trade. Therefore, it is relevant to take into account the *commodity terms-of-trade effect* of environment policy.

This chapter builds on C-T (1994) by internalizing the *commodity terms-of-trade effects* of environment policy. It is demonstrated that a number of the C-T (1994) conclusions cannot be generalized when the small-country assumption is relaxed.

Whilst C-T (1994) examines a multi-good, 2-factor and 2-country model, the chapter develops a 2x2x2 factor endowment model of trade. The 2-good framework makes the internalization of the terms-of-trade effects of pollution policies analytically feasible. The two factors are skill-embodied labor and a pollution causing natural resource. The two production sectors vary in their pollution intensity. North and South are distinguished by their relative endowments of the two factor inputs: South is relatively more natural resource abundant and North relatively human skill abundant.[2] The respective governments own the stock of the natural resource and optimally choose the national environment policy in terms of the quantity of the resource to be released to the economy. This is different from C-T (1994) where pollution charge is the policy variable. The pollution effects are local (not global) in nature.[3]

Policy choices by the national governments can be seen in terms of a two-stage game. In the first, the respective governments in the North and South optimally decide on the supply of the natural resource, by trading-off the real income gains from its use against the marginal disutility from pollution caused by it. Governments make their choices in a non-cooperative

[2]We do not characterize North and South as high- and low-income respectively. Instead, they are distinguished by relative endowments of productive factors.

[3]The examples of local pollution are oxides of sulfur or nitrogen and particulate matter from petroleum or coal combustion in industries, or discharge of hazardous wastes from chemical processes in industries.

Nash fashion. In the second stage, the resource is auctioned-off competitively in the factor market, and production and consumption takes place. Relative endowment differences cause countries to choose differing pollution standards in the first stage. This forms the basis for differences in comparative advantage in the second.

The chapter adopts the following sequence of analysis. The autarky equilibrium is characterized first, followed by free trade. The outcomes under autarky form the benchmark.

The autarky equilibrium is defined by six equilibrium equations: the two zero-profit equations, one for each sector, two factor employment conditions, one market clearing condition, and finally the government's decision rule for optimal release of the resource input. The last condition governs the optimal choice of environment policy. Thus, our model is a variant of the standard factor-endowment model, with supply of one factor (natural resource) determined endogenously. At the autarky equilibrium North is shown to have comparative advantage in the production of the "cleaner" good and South in the "dirtier" good.

In the free trade regime, different equilibria could emerge – (a) both North and South remain incompletely specialized, (b) North specializes (in the cleaner good) whilst South produces both the goods, (c) North continues to produce both the goods whilst South becomes completely specialized (in the polluting good), and (d) both North and South specialize in the good they have comparative advantage in. Our analysis is restricted to two extreme cases: incomplete specialization (as in (a)) and complete specialization (as in (d)) in both countries. (Characterization of the two partial specialization cases does not seem analytically tractable.) Compared to autarky, free trade regime is distinct in two respects: first, there is global, rather than domestic, market clearing, and second, the national environmental policies of the two countries are strategically linked with each other. Non-cooperative Nash concept is used throughout.

We first study the case of diversification in production in both countries, which leads to FPE. This is based on the assumption that the relative endowments of North and South are not too apart. In this case, all the results derived in the chapter are qualitatively similar to C-T (1994), barring one, that relates to the change in the commodity terms-of-trade. Whilst C-T (1994) predicts that both countries experience a terms-of-trade improvement, it is derived here that the impacts on the terms-of-trade of only one of, North and South, is unambiguous whilst the other country may lose or gain. This is because, apart from the standard gains, each country's terms-of-trade are now affected by the changes in (own and other country's) pollution policy. The two effects – standard effect and the effect of environment policy change on the commodity terms-of-trade – may work counter to each other, leaving the overall change in the commodity terms-of-trade unclear. For instance, in moving toward the FPE equilibrium, if countries reset their pollution policies such that there is higher release of the polluting input at the global level (as compared to autarky), this would lead to a larger relative output and, hence, a lower relative price of the pollution-intensive good in the world market. The equilibrium relative price may even be less than the autarky relative price in the South and this would mean a terms-of-trade decline for the South. North would, of course, face an improvement in its terms-of-trade.

We next examine the case where the factor endowments of two countries are sufficiently apart and trade leads North to specialize in the "cleaner" good and South in the "dirtier" good. In this case, more interesting results emerge. Not only does pollution fall in the North in moving from autarky to free trade, but this happens in the South as well. It is interesting and paradoxical that South also reduces its pollution, despite specializing in the pollution-intensive good. This result is again due to the commodity terms-of-trade effect of environment policy. As discussed, the terms-of-trade effect works through changes in the regional environment policies impacting the production decision of firms and, hence, the international commodity prices. The effect arises when countries begin to trade, irrespective of whether they are incompletely or completely specialized in production. However, when countries specialize completely in the production of their exportable good, it turns out to be the dominant one and leads to outcomes very different from C-T (1994). As said earlier, it is found that South may be also be induced to reduce its pollution along with the North, inspite of specializing in the pollution-intensive good. This is just the opposite of C-T (1994) for the South.

Moreover, under the complete specialization regime, contrary to C-T (1994) free trade may entail a terms-of-trade loss for the North, whilst South will always have a positive change in the terms-of-trade. Finally, inspite of a better environment, free trade may cause both the countries to gain or lose in aggregate welfare. In the terminology of Newbery and Stiglitz (1984), this is yet another illustration of *Pareto inferior trade*.

Thus, as long as complete specialization occurs in the free trade equilibrium, our results differ significantly from C-T. It is also noteworthy that a majority of these differences can be directly or indirectly ascribed to the commodity terms-of-trade effect of environment policies of the countries. Most strikingly, we find that freer trade may *not* be bad for the environment of either country.

We now begin with the formal analysis.

3.2 Model structure

The world economy consists of two regions - North and South. Each region produces and consumes two goods, X and Y.[4] The inputs for production are labor, L, (taken to be skill-embodied or effective labor) and a natural resource, T. The use of the resource generates pollution proportional to its use and pollution is a local bad, as also assumed by C-T.

Let factor endowments be represented by a bar on top and countries, North and South, by superscript N and S. Then, $\bar{T}^N$ and $\bar{T}^S$ denote the resource stocks of North and South, and $\bar{L}^N$ and $\bar{L}^S$ the respective labor endowments. Observe that variables with a bar on top

[4] For simplicity, unlike C-T (1994) the composition effects are not endogenous in our model.

represent the stocks and those without it the actual utilization levels of the factor inputs. South is assumed to be relatively natural resource abundant as compared to the North, that is, $\bar{T}^S/\bar{L}^S > \bar{T}^N/\bar{L}^N$.[5] This difference could arise on account of absolute or relative endowment differences of individual factor inputs. In each country, government owns the stock of the natural resource, $\bar{T}$, and chooses its optimal supply (release), $T^N(\equiv T_x^N + T_y^N)$ or $T^S(\equiv T_x^S + T_y^S)$.

The production technology in each sector i $(i = x, y)$ is assumed to be Cobb-Douglas in form and exhibit constant returns to scale, i.e.

$$Q_i = L_i^{\alpha_i} T_i^{1-\alpha_i}, \tag{3.1}$$

where L_i and T_i are the inputs of labor and "polluting resource" in sector i and α_i is the factor intensity parameter. There is no joint production of goods. The technology embodied in (3.1) is identical between the two regions but differs between the two production sectors in pollution intensity. We assume $\alpha_x > \alpha_y$ such that the production of good Y is more pollution- (resource-) intensive than good X. Let good X be the numeraire good, and let p denote the relative price of good Y.

If τ is the rent (or price) per unit of the resource and w is the wage rate, the relative factor price ratio τ/w is represented by ρ. Taking τ and w as given, firms minimize production costs. Cobb-Douglas production function yields the unit cost function of firm i as $c_i = \kappa_i \tau^{1-\alpha_i} w^{\alpha_i}$ where $\kappa_i = \alpha_i^{-\alpha_i}(1-\alpha_i)^{-(1-\alpha_i)}$. The resource input is allocated to the two production sectors in a competitive market that determines its "price or rent", τ. The wage rate is also determined in the competitive market. The aggregate revenues from the sale of the natural resource, $\tau(T_x + T_y)$, are transferred back to the households as a lumpsum transfer.[6]

[5] In C-T (1994), what distinguishes between North and South is the aggregate human capital endowments, that is, $\bar{L}^N$ and $\bar{L}^S$, whilst pollution is essentially a by-product of production. In our model too, in relative terms, North is the human capital abundant country.

[6] C-T take the supply of the resource to the economy as infinitely elastic. Also, in their model, environment is regulated through a pollution tax, τ, and pollution revenues are transferred to households in lumpsum.

The analytical framework is similar to the Heckscher-Ohlin-Samuelson (HOS) model, except that the supply of one input, natural resource T ($< \bar{T}$), to the production sectors is determined endogenously. Apart from the determination of T, the supply side of the economy is represented by the familiar zero-profit equations, one for each production sector, and two factor-employment conditions. Eqs. (3.2) and (3.3) represent these for country j, $j = N, S$:

$$c_x(\tau^j, w^j) = 1, \quad c_y(\tau^j, w^j) = p^j, \tag{3.2}$$

$$a_{lx}(\tau^j, w^j)Q_x^j + a_{ly}(\tau^j, w^j)Q_y^j = \bar{L}^j, \quad a_{tx}(\tau^j, w^j)Q_x^j + a_{ty}(\tau^j, w^j)Q_y^j = T^j. \tag{3.3}$$

The unit factor coefficients, denoted by a_{mi} ($m = l, t$; $i = x, y$), are the partials of c_i with respect to input prices.

On the demand side, consumers in each country have identical and homothetic preferences defined over the two goods X and Y and the environmental "good" $(\bar{T} - T)$ or its residual resource stock.[7] The utility function for country j ($j = N, S$), is given by:

$$U^j = a \ln D_x^j + (1 - a) \ln D_y^j + \gamma \ln(\bar{T}^j - T^j), \quad 0 < a < 1, \quad \gamma > 0 \tag{3.4}$$

where D_i^j is the aggregate demand for good i, a is the budget share of good X and $\gamma(\bar{T}^j - T^j)$ represents sub-utility from the environmental good. The log-linear form of the function offers mathematical tractability, especially since our model involves endogenous environment policy setting by the national governments and comparisons across discrete trading equilibria.[8] Moreover, log-linearity ensures that demand for environment is directly related to income.

Relative endowment differences cause countries to choose differing pollution policies. In setting the pollution policy governments are assumed to act non-cooperatively throughout the analysis.

We begin with autarky.

[7] Use of the pollution "damage" function of the kind in C-T (1994), where utility is negatively related to the level of pollution, does not impact our results.

[8] Other papers, such as C-T (1995), Brander and Taylor (1998), also assume a similar utility function.

3.3 Autarky

Suppose that initially both North and South are in complete isolation and there is no trade in goods between them.

Our assumption of Cobb-Douglas preferences, as in eq. (3.4), implies that each country will have to produce both the goods. Similar to the standard two-sector model, the familiar production-side relations, as those defined by eqs. (3.2) and (3.3), would yield the following solutions in implicit form:

$$w^j = w^j(\underset{(-)}{p^j}); \quad \tau^j = \tau^j(\underset{(+)}{p^j}); \quad \rho^j = \rho^j(\underset{(+)}{p^j}) \tag{3.5}$$

$$Q_i^j = Q_i^j(p^j, \bar{L}^j, T^j); \quad Q_x^j/Q_y^j = g(p^j, \underset{(-)}{T^j/\bar{L}^j}), \tag{3.6}$$

where $T^j(< \bar{T}^j)$ is policy determined. The signs in (3.5) follow from the Stopler-Samuelson theorem and in (3.6) from the Rybzcinski theorem.

From homotheticity, relative demands, equal to the ratio of outputs in autarky, are a function of relative prices alone, that is,

$$\frac{D_x^j}{D_y^j} \equiv \frac{Q_x^j}{Q_y^j} = \frac{a}{1-a} p^j \Rightarrow p^j = \frac{(1-a)Q_x^j}{aQ_y^j}. \tag{3.7}$$

This, together with function $g(\cdot)$, yields $p^j = p^j(T^j/\bar{L}^j)$. Substituting it into (3.5) and (3.6) gives all input prices and outputs as functions of the policy variable, T^j. These are

$$\begin{aligned}
&\tau^j(T^j) = \frac{1}{\kappa_x}\left(\lambda\frac{T^j}{\bar{L}^j}\right)^{-\alpha_x}, \; w^j = \frac{1}{\kappa_x}\left(\lambda\frac{T^j}{\bar{L}^j}\right)^{1-\alpha_x}, \; p^j = \frac{\kappa_y}{\kappa_x}\left(\lambda\frac{T^j}{\bar{L}^j}\right)^{-(\alpha_x-\alpha_y)}, \\
&Q_x(T^j) = \frac{1}{\kappa_x(\alpha_x-\alpha_y)}\left[(1-\alpha_y)\bar{L}^j\left(\lambda\frac{T^j}{\bar{L}^j}\right)^{1-\alpha_x} - \alpha_y T^j\left(\lambda\frac{T^j}{\bar{L}^j}\right)^{-\alpha_x}\right], \\
&Q_y(T^j) = \frac{1}{\kappa_y(\alpha_x-\alpha_y)}\left[\alpha_x T^j\left(\lambda\frac{T^j}{\bar{L}^j}\right)^{-\alpha_y} - (1-\alpha_x)\bar{L}^j\left(\lambda\frac{T^j}{\bar{L}^j}\right)^{1-\alpha_y}\right],
\end{aligned} \tag{3.8}$$

where $\lambda \equiv (a\alpha_x + (1-a)\alpha_y)/(a(1-\alpha_x) + (1-a)(1-\alpha_y))$.

Marshallian demands aggregated over the entire population of country j yield $D_x^j = aI^j$ and $D_y^j = [(1-a)/p^j]I^j$, where $I^j = Q_x^j + pQ_y^j$ is the GDP of country j, which has the envelope property, $\partial I^j/\partial T^j = \tau^j$. Substitution of these demands in (3.4) yields welfare in indirect form:

$$U^{j^{at}}(T^j) = a\ln a + (1-a)\ln(1-a) + \ln I^j(T^j) - (1-a)\ln p^j(T^j) + \gamma\ln(\bar{T}^j - T^j), \quad (3.9)$$

where superscript "at" denotes autarky. This is maximized with respect to T^j,and the resulting first-order condition is

$$\frac{\tau^j}{I^j} = \frac{\gamma}{\bar{T}^j - T^j}. \quad (3.10)$$

The l.h.s. represents the marginal benefit from T^j. The addition to aggregate income from a unit increase in pollution is equal to its marginal product, τ^j. This can be called as the *output effect.* The marginal valuation of aggregate income toward aggregate welfare equals $1/I^j$, which can be called as the *income effect.* Thus, the marginal benefit from pollution is given by τ^j/I^j. We call this the *adjusted output effect.* The r.h.s. of (3.10) is its marginal cost.

A couple of remarks are in order.

1. There are no terms-of-trade implications of a change in T^j, since $D_y^j = Q_y^j$ in autarky.
2. Pollution level in one country is chosen independently of that in the other, i.e., there is no strategic interaction between T^N and T^S.

By utilizing (3.8), τ^j and I^j can be expressed in terms of T^j, and, (3.10) can be specified as

$$\frac{\xi}{T^j} = \frac{\gamma}{\bar{T}^j - T^j} \quad (3.11)$$

where $\xi \equiv a(1-\alpha_x) + (1-a)(1-\alpha_y)$. Thus, the marginal benefits from and marginal costs of pollution are respectively decreasing and increasing in pollution. In turn, this implies that the second-order condition of welfare maximization is met.

Indeed, T^j can be explicitly solved from (3.11):

$$T^{j^{at}} = \frac{\xi}{\gamma + \xi}\bar{T}^j. \tag{3.12}$$

Observe that for any country j, $T^{j^{at}}$ or the proportion of the use of resource input to its endowment is independent of the labor endowments. Initially, this appears to be somewhat puzzling, especially since from the eq. (3.10) the equilibrium pollution policy is a function of I^j which, in turn, depends on $\bar{L}^j$. However, recall that a similar result is also derived by C-T (1994, 1995) where they find autarky pollution to be independent of human capital. C-T (1995) provides the intuition that "...a larger production capacity created by higher human capital levels increases the demand for pollution permits (a scale effect), but the ensuing higher income reduces the amount of pollution the population is willing to supply, leading to higher pollution permit price and cleaner techniques of production (a technique effect)." These scale and technique effects exactly offset each other, entailing equilibrium pollution to be independent of the level of human capital.

Analogous effects are at work here as well. In this model, both the output effect, τ^j (the counterpart of C-T's scale effect) and the income effect, $1/I^j$ (the counterpart of technique effect in C-T) are a function of labor to natural resource ratio, $\bar{L}^j/T^j$ (see expressions in eq. (3.8) for the functional forms). As in C-T, in this case also the proportionate increase in the output effect on account of higher labor endowments is exactly offset by the associated increase in income such that equilibrium pollution level, T^j, is independent of the labor endowment, $\bar{L}^j$.

Given that the marginal cost in the r.h.s. of (3.10) is also independent of the labor endowment, the equilibrium pollution turns out to be a function of natural resource endowment alone.

Eq. (3.12) implies that

$$\frac{T^{N^{at}}}{\bar{L}^N} < \frac{T^{S^{at}}}{\bar{L}^S}, \tag{3.13}$$

Using the expression for τ^j $(j = N, S)$ in (3.5) together with the above ranking we have $\tau^{Nat} > \tau^{Sat}$.

This is our first result.

Proposition 1: *In autarky, South has a higher resource-use/labor ratio than the North. Also, natural resource is priced higher in the North than in the South.*

It is now easy to show that South has a comparative advantage in the production of the pollution-intensive good, Y, and North in good X. With relative resource use being higher, the ratio of production of good Y to good X is higher in the South than in the North. Mathematically, by defining $q^j = Q_x^j/Q_y^j$, comparative statics with respect to T^j gives $\hat{q}^j/\widehat{(T^j/\bar{L}^j)} = -(\alpha_x - \alpha_y) < 0$, since $\alpha_x > \alpha_y$ from our assumption on relative pollution intensity of the two goods.[9] This yields a lower price for good Y in the South, giving it a competitive edge over the North in its production. Graphically this is shown in Figure 3.1.

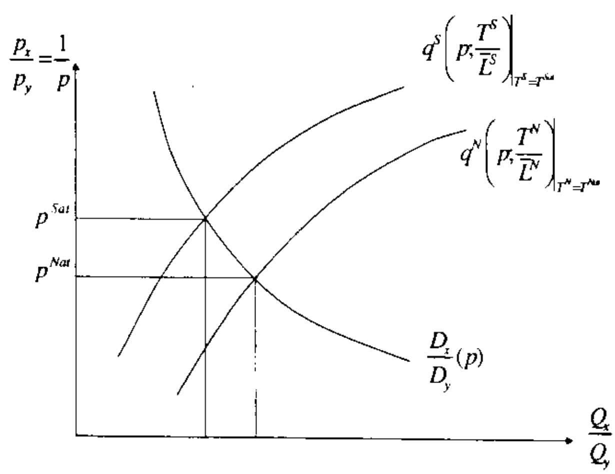

Figure 3.1: Supply and demand under autarky

It can be seen that for any given commodity price ratio, p, the relative supply curve, for the North, $q^N(p; T^N/\bar{L}^N)$, lies below or to the right of that for the South, $q^S(p; T^S/\bar{L}^S)$.

[9]The symbol "$\hat{x}$" refers to the rate of change of the variable, x, i.e. dx/x.

Moreover, identical and homothetic preferences imply a common relative demand curve for the two countries, shown as $D_x/D_y(p)$. Thus, the autarky relative price of good Y in the North will be higher than in the South, that is, $p^{S^{at}} < p^{N^{at}}$, implying that South has a comparative advantage in the production of the pollution-intensive good Y and North in good X. This pattern of comparative advantage indicates that South exports good Y to the North and imports good X from it.

However, unlike in the standard factor endowment model, the free trade price ratio may lie outside the interval $(p^{S^{at}},\ p^{N^{at}})$ since the $T^j/\bar{L}^j$ ratio changes as the economies move from autarky to free trade.

3.4 Free trade

Let the two countries - North and South - allow unrestricted trade in goods. In general, as trade opens up, a country may or may not specialize in the production of its exportable good. As said in the introduction, the focus is on the analysis of two alternative cases: (a) both North and South remain incompletely specialized, and (b) both countries completely specialize in the production of the good they have comparative advantage in. (In Appendices A and D respectively we formally characterize the conditions that would ensure incomplete or complete specialization to occur in both economies.) Further, in either case, the resource use T^j $(< \bar{T}^j)$ is determined endogenously. What remains to be determined is whether, at the free trade equilibrium, $T^N/\bar{L}^N < T^S/\bar{L}^S$, such that the ranking between the factor utilization ratios replicates the pattern underlying the standard factor abundance model even when factor utilization levels are endogenous. It is shown that this is satisfied in the model; the proofs are included in Appendix C for incomplete specialization case and in Section 3.4.2 of the text for the complete specialization case.

The two free trade equilibria are now characterized.

3.4.1 Incomplete specialization

When endowment differences between countries are sufficiently small, free trade leads both North and South to remain incompletely specialized in production and there will be FPE (see Appendix A for details on the parametric conditions under which this would happen). Also, for the immediate analysis we assume that $T^{N^{is}}/\bar{L}^N < T^{S^{is}}/\bar{L}^S$ (where superscript "is" denotes incomplete specialization); as mentioned earlier, it is shown in Appendix C that this ranking holds at the free trade incomplete specialization equilibrium.

At the FPE equilibrium most results are similar to those obtained by C-T (1994).

Production being diversified, the following equations characterize the supply and demand sides of the economies of North and South. There are four zero-profit equations, two for each country, that is

$$c_x(\tau^N, w^N) = 1, \quad c_y(\tau^N, w^N) = p^w, \tag{3.14}$$

$$c_x(\tau^S, w^S) = 1, \quad c_y(\tau^S, w^S) = p^w, \tag{3.15}$$

where p^w denotes the world market clearing price in the FPE regime.

Further, with unit factor coefficients denoted by a_{mi} $(m = l, t; i = x, y)$, the factor employment conditions for North and South will be:

$$a_{lx}(\rho)Q_x^N + a_{ly}(\rho)Q_y^N = \bar{L}^N, \quad a_{tx}(\rho)Q_x^N + a_{ty}(\rho)Q_y^N = T^N, \tag{3.16}$$

$$a_{lx}(\rho)Q_x^S + a_{ly}(\rho)Q_y^S = \bar{L}^S, \quad a_{tx}(\rho)Q_x^S + a_{ty}(\rho)Q_y^S = T^S, \tag{3.17}$$

where ρ is the common pollution charge/wage ratio between North and South.

Global trade balance implies

$$p^w = \frac{1-a}{a}\left(\frac{Q_x^N + Q_x^S}{Q_y^N + Q_y^S}\right), \tag{3.18}$$

which is the analog of (3.7).

Observe that, with FPE the trading world economy replicates the integrated world economy. For the latter, one could solve for relative factor price ratio as:

$$\rho = \frac{\bar{L}^W}{\lambda T^W}, \tag{3.19}$$

where $T^W = T^N + T^S$, $\bar{L}^W = \bar{L}^N + \bar{L}^S$ and λ is as defined earlier. Given the expression for ρ in (3.19), we can solve for $\tau^N = \tau^S$, $w^N = w^S$, p^w and the sectoral outputs. These are

$$\begin{aligned}
\tau^N(T^N, T^S) &= \tau^S(T^N, T^S) = \frac{1}{\kappa_x}\left(\lambda\frac{T^W}{\bar{L}^W}\right)^{-\alpha_x}, \\
w^N(T^N, T^S) &= w^S(T^N, T^S) = \frac{1}{\kappa_x}\left(\lambda\frac{T^W}{\bar{L}^W}\right)^{1-\alpha_x}, \\
p^w(T^N, T^S) &= \frac{\kappa_y}{\kappa_x}\left(\frac{\lambda T^W}{\bar{L}^W}\right)^{-(\alpha_x-\alpha_y)}, \\
Q_x^j(T^N, T^S) &= \frac{1}{\kappa_x(\alpha_x-\alpha_y)}\left[(1-\alpha_y)\bar{L}^j\left(\lambda\frac{T^W}{\bar{L}^W}\right)^{1-\alpha_x} - \alpha_y T^j\left(\lambda\frac{T^W}{\bar{L}^W}\right)^{-\alpha_x}\right], \\
Q_y^j(T^N, T^S) &= \frac{1}{\kappa_y(\alpha_x-\alpha_y)}\left[\alpha_x T^j\left(\lambda\frac{T^W}{\bar{L}^W}\right)^{-\alpha_y} - (1-\alpha_x)\bar{L}^j\left(\lambda\frac{T^W}{\bar{L}^W}\right)^{1-\alpha_y}\right].
\end{aligned} \tag{3.20}$$

From (3.20) observe that in the FPE regime the world market clearing price p^w is a function of the global resource-use/labor ratio, $T^W/\bar{L}^W$. This has implications for the change in commodity terms-of-trade due to the change in the regional environment policies. Specifically, a marginal increase in resource use, T^j, by either country j leads to a fall in p^w. That is, $\partial p^w/\partial T^j$ $(j = N, S) = \partial p^w/\partial T^W < 0$. Since North (South) is a net importer (exporter) of good Y, the fall in p^w implies a terms-of-trade improvement (decline) for it. Further, it is also easy to see that $\hat{p^w}/\hat{T^N} = \hat{p^w}/\hat{T^S} = -(\alpha_x - \alpha_y)$. These constitute our next set of results.

Proposition 2: *Under the FPE regime,*

(i) a marginal increase in resource use entails a terms-of-trade gain for the North and a terms-of-trade loss for the South, and

(ii) the magnitude of the elasticity of commodity terms-of-trade with respect to change in the environment policy of either country is the same.

Next, utilizing the expressions for Marshallian demands (similar to those under autarky) in the direct utility function (3.4) yields the welfare expressions for country j in indirect form as:

$$U^{j^{is}}(T^N, T^S) = K + \ln I^j(T^N, T^S) - (1-a)\ln p^w(T^N, T^S) + \gamma \ln(\bar{T}^j - T^j), \qquad (3.21)$$

where recall that superscript "is" denotes incomplete specialization and $K \equiv a \ln a + (1-a)\ln(1-a)$ is the constant. Maximizing $U^{j^{is}}$ with respect to the corresponding T^j, the first-order condition for country j takes the form:

$$\frac{1}{I^j(T^N, T^S)} \frac{\partial I^j(T^N, T^S)}{\partial T^j} - \frac{(1-a)}{p^w(T^N, T^S)} \frac{\partial p^w(T^N, T^S)}{\partial T^j} = \frac{\gamma}{\bar{T}^j - T^j} \qquad (3.22)$$

$$\Rightarrow \frac{\tau^j}{I^j} - \frac{(D_y^j - Q_y^j)}{I^j} \frac{\partial p^w}{\partial T^j} = \frac{\gamma}{\bar{T}^j - T^j}. \qquad (3.23)$$

The last equation is obtained by substituting for $\partial I^j / \partial T^j = \tau^j$, and the Roy's identity. In the l.h.s. of (3.23), which denotes the marginal benefit of pollution, besides the *adjusted output effect*, τ^j / I^j (notably, with trade, the adjusted output effect includes in it not just the income effect but also the composition effect associated with change in country's production mix), an additional effect represented by the second term now appears. This is the *commodity terms-of-trade effect* of environment policy, which is non-zero under the free trade regime, since $D_y^j \neq {Q_y}^j$. The terms-of-trade effect creates a wedge between the output effect on the marginal benefit side and the marginal costs of pollution, $\gamma/(\bar{T}^j - T^j)$. Further, observe that optimal T^N and T^S are now strategically linked on account of the commodity terms-of-trade effect.

Making substitution for the partials, the respective first-order conditions in (3.23) reduce to

$$R^N(T^N, T^S) \equiv \frac{T^S}{T^N + \lambda\mu_L T^W} + \xi - \frac{\gamma T^W}{\bar{T}^N - T^N} \quad = \quad 0 \tag{3.24}$$

$$R^S(T^N, T^S) \equiv \frac{T^N}{T^S + \lambda(1-\mu_L) T^W} + \xi - \frac{\gamma T^W}{\bar{T}^S - T^S} \quad = \quad 0, \tag{3.25}$$

where we had defined $\xi \equiv a(1-\alpha_x) + (1-a)(1-\alpha_y)(= 1/(1+\lambda))$ and $\mu_L \equiv \bar{L}^N/\bar{L}^W$. These two equations determine equilibrium T^N and T^S, which we denote as $T^{N^{is}}$ and $T^{S^{is}}$ respectively. Given our model specifications, the second-order conditions are met; these are derived in Appendix B.

We now examine how countries adjust their pollution policies in moving from autarky to the FPE equilibrium.

Pollution levels

The changes in regional pollution levels would depend on the changes in the marginal benefits and marginal costs of pollution induced by the move to free trade.

There is, however, no change in the marginal cost schedule of pollution. The l.h.s. of the first-order condition (3.23), which is the marginal benefit under free trade, can be compared with the corresponding l.h.s. of (3.10) in autarky. The following two effects are observed:

1. The first relates to the adjusted output effect of pollution, τ^j/I^j. At the initial level of pollution a move to free trade (with FPE) entails that the marginal product of resource input, τ^j now depends on the global resource-use/labor ratio, $T^W/\bar{L}^W$, instead of domestic resource/labor ratio $T^j/\bar{L}^j$ in autarky. Moreover, the global resource-use/labor ratio lies between the individual country factor ratios, i.e.

$$\frac{T^N}{\bar{L}^N} < \frac{T^W}{\bar{L}^W} < \frac{T^S}{\bar{L}^S}. \tag{3.26}$$

This combined with the fact that the adjusted output effect, τ^j/I^j, is decreasing in $T^j/\bar{L}^j$, implies that $\frac{\tau_N}{I^N}\left(\frac{T^N}{\bar{L}^N}\right) < \frac{\tau_N}{I^N}\left(\frac{T^W}{\bar{L}^W}\right)$ in the North. Likewise, in the South

$\frac{\tau_S}{I^S}\left(\frac{T^S}{L^S}\right) > \frac{\tau_S}{I^S}\left(\frac{T^W}{L^W}\right)$.[10] That is, on account of the adjusted output effect alone, North (South) would tend to lower (increase) their pollution.

2. Second, apart from the adjusted output effect we also have the commodity terms-of-trade effect of pollution coming into play. This also leads to shifts in the marginal benefits. North (South) being a net importer (exporter) of good Y, $D_y^N - Q_y^N > 0$ and $D_y^S - Q_y^S < 0$. These, together with $\partial p^w/\partial T^j < 0$, would raise (lower) the marginal benefits for the North (South). Hence, on account of the commodity terms-of-trade effect, North (South) would tend to increase (decrease) pollution.

In sum, the adjusted output and commodity terms-of-trade effects of pollution policy tend to have opposing effects on the marginal benefits of any country. Thus, *a priori* it is difficult to ascertain whether a country would relax or tighten its pollution policy at the free trade equilibrium as compared to autarky.

Proposition 3: *In moving to free trade and incomplete specialization, pollution in the North falls and that in the South rises.*

That is, both for North and South the respective adjusted output effects dominate the terms-of-trade effects. Proposition 3 is similar to C-T (1994) in terms of change in regional pollution levels. This result is derived in Appendix C.

The dominance of the adjusted output effect could be explained as follows. When there is

[10]In view of (3.26) for any T^N the autarky solution to $\tau^N/I^N(\cdot)$ for the North will be

$$\begin{aligned}
\frac{\tau_N}{I^N}\left(\frac{T^N}{\bar{L}^N}\right) &= \frac{\frac{1}{\kappa_z}\left(\frac{\lambda T^N}{\bar{L}^N}\right)^{-\alpha_z}}{\frac{1}{\kappa_z}\left(\frac{\lambda T^N}{\bar{L}^N}\right)^{-\alpha_z} T^N(1+\lambda)} \\
< \frac{\tau_N}{I^N}\left(\frac{T^W}{\bar{L}^W}\right) &= \frac{\frac{1}{\kappa_z}\left(\frac{\lambda T^N}{\bar{L}^N}\right)^{-\alpha_z}}{\frac{1}{\kappa_z}\left(\frac{\lambda T^N}{\bar{L}^N}\right)^{-\alpha_z} T^N\left(1+\lambda\frac{T^W}{\bar{L}^W}\frac{\bar{L}^N}{T^N}\right)}
\end{aligned}$$

that pertains to the free trade regime. The opposite order of ranking holds for the South.

diversification in production, changes in environment policies cause intersectoral shifts in the utilization of the natural resource. These shifts tend to offset the first-round impact of change in pollution policies on the commodity terms-of-trade and weaken the terms-of-trade effect. For example, in the South a marginal increase in the release of the resource entails a first-round terms-of-trade loss (see Proposition 2). This induces producers to shift resources away from the polluting sector, Y, into the cleaner sector X, thus partly offsetting the first-round losses in the terms-of-trade. Correspondingly, in the North, the first-round terms-of-trade losses on account of more restricted natural resource use (since good Y is North's importable) gets partly offset by resource reallocation toward this sector, which lowers the relative price of North's importable. Hence, the presence of a smaller commodity terms-of-trade effects (in relation to the output effect) explain the changes in regional pollution effects in Proposition 3.

Next, turn to the implications for the overall change in the commodity terms-of-trade.[11]

Commodity terms-of-trade

Strikingly, a move from autarky to free trade may not ensure that a country enjoys a commodity terms-of-trade gain. This is because a change in the regime entails a change in the pollution policy. The overall change in the commodity terms-of-trade is due to two effects: (a) a move from autarky to FPE equilibrium *whilst there is no change in the pollution policies of the countries*, and (b) change in the pollution policies *when countries are in the free trade regime.*

The effect due to (a) is the standard effect and entails a commodity terms-of-trade gain for both North and South. In addition, in our model (b) also arises as trade leads to endogenous change in own and partner country's pollution policies, which also affect the terms-of-trade. Suppose now the countries have moved to the free trade regime and there is a change in

[11] Note that these effects are distinct from the commodity terms-of-trade effects of environment policy discussed in the last section.

their pollution policies. Then, the effect (b) on the terms-of-trade is given by:

$$dp^w = \underbrace{\frac{\partial p^w}{\partial T^N}}_{(-)} \underbrace{dT^N}_{(-)} + \underbrace{\frac{\partial p^w}{\partial T^S}}_{(-)} \underbrace{dT^S}_{(-)} = \underbrace{\frac{\partial p^w}{\partial T^W}}_{(-)} \underbrace{dT^W}_{(+/-)} \gtrless 0 \qquad (3.27)$$

(Since good Y is North's (South's) importable (exportable), a rise its relative price, p^w, implies a terms-of-trade loss (gain) for the North (South).)

Note that $\partial p^w/\partial T^N = \partial p^w/\partial T^S = \partial p^w/\partial T^W$ (from (3.20)). Suppose T^W decreases from its autarky level. Then, $dT^W < 0$ and, hence, $dp^w > 0$. This means a terms-of-trade decline (improvement) for the North (South). Hence, the overall ((a)+(b)) effect of trade on North's terms-of-trade is ambiguous, whilst on the South's terms-of-trade is positive. The opposite is true when $dT^W > 0$, that is, North will experience terms-of-trade improvement whilst South may or may not.

Thus,

Proposition 4: *A move to free trade (with incomplete specialization) entails an improvement in the commodity terms-of-trade of one country, whilst the other may have an improvement or a decline in its terms-of-trade.*

This result differs from C-T (1994) who predict a positive change in the commodity terms-of-trade for both North and South.

However, a deterioration in the commodity terms-of-trade does *not* necessarily imply that countries will lose in terms of welfare. In what follows the change in the welfare levels of North and South is examined.

Welfare implications

Similar to changes in the commodity terms-of-trade, there are two effects of trade on the country's welfare. They are (a) from a discrete change in the regime from autarky to FPE equilibrium without any adjustment in T^j, and (b) from change T^N and T^S. Analogous to the standard fixed-endowment model, the welfare changes on account of (a) are the standard gain from trade, which are positive. In what follows we examine the welfare change from (b) assuming that economies are in the FPE regime.

Algebraically, from (3.21) the total changes in the welfares of North and South due to change in T^N and T^S are given by

$$\begin{aligned}
dU^{N^{is}} &= \frac{\tau^N}{I^N}dT^N + \frac{Q_y^N}{I^N}\left(\frac{\partial p^w}{\partial T^N}dT^N + \frac{\partial p^w}{\partial T^S}dT^S\right) - \frac{\gamma}{\bar{T}^N - T^N}dT^N \\
&\quad -\frac{(1-a)}{p^w}\left(\frac{\partial p^w}{\partial T^N}dT^N + \frac{\partial p^w}{\partial T^S}dT^S\right); \\
dU^{S^{is}} &= \frac{\tau^S}{I^S}dT^S + \frac{Q_y^S}{I^S}\left(\frac{\partial p^w}{\partial T^N}dT^N + \frac{\partial p^w}{\partial T^S}dT^S\right) - \frac{\gamma}{\bar{T}^S - T^S}dT^S \\
&\quad -\frac{(1-a)}{p^w}\left(\frac{\partial p^w}{\partial T^N}dT^N + \frac{\partial p^w}{\partial T^S}dT^S\right).
\end{aligned}$$

Using Roy's identity and gathering terms, the above two equations reduce to

$$dU^{N^{is}} = \left(\frac{\tau^N}{I^N} - \frac{(D_y^N - Q_y^N)}{I^N}\frac{\partial p^w}{\partial T^N} - \frac{\gamma}{\bar{T}^N - T^N}\right)dT^N - \frac{(D_y^N - Q_y^N)}{I^N}\frac{\partial p^w}{\partial T^S}dT^S \quad (3.28)$$

$$= -\underbrace{\frac{(D_y^N - Q_y^N)}{I^N}}_{(+)}\underset{(-)}{\frac{\partial p^w}{\partial T^S}}\underset{(+)}{dT^S} > 0, \quad (3.29)$$

$$dU^{S^{is}} = \left(\frac{\tau^S}{I^S} - \frac{(D_y^S - Q_y^S)}{I^S}\frac{\partial p^w}{\partial T^S} - \frac{\gamma}{\bar{T}^S - T^S}\right)dT^S - \frac{(D_y^S - Q_y^S)}{I^S}\frac{\partial p^w}{\partial T^N}dT^N \quad (3.30)$$

$$= -\underbrace{\frac{(D_y^S - Q_y^S)}{I^S}}_{(-)}\underset{(-)}{\frac{\partial p^w}{\partial T^N}}\underset{(-)}{dT^N} > 0. \quad (3.31)$$

Note that the first term in the r.h.s. of each of (3.28) or (3.30) denotes the effect on welfare due to change in the *own* pollution policy. Since T^j, $j = N, S$ is set individually optimally, both under autarky and free trade, the effect of a change in own pollution toward welfare is zero.[12] The second term represents the "spillover" effect of a change in the other country's pollution policy via the change in the terms-of-trade. This is positive for both the countries. For example, everything else the same, an increase in T^S will lead to a higher relative output

[12]Mathematically, from the first-order condition (3.23), the bracketed portion of the second term in (3.28) and (3.30) vanishes.

of the pollution-intensive (importable) good Y, and lower its price in the world market. These positive welfare effects are indicated in (3.29) and (3.31), and have implications for overall welfare change once the countries are in the free trade regime.

Therefore, combining (a) and (b),

Proposition 5: *A movement from autarky to trade with FPE leads to an unambiguous increase in the welfare of both North and South.*

Proposition 5 generalizes the C-T results. But it is interesting that South also has overall welfare gains even though, with trade, it increases its pollution level and may also experience a deterioration in its commodity terms-of-trade.

The predictions of the model begin to differ significantly from C-T when one considers the other extreme case, where free trade leads countries to completely specialize in production. Henceforth, "*cs*" denotes complete specialization.

3.4.2 Complete specialization

Complete specialization entails that each country would now allocate all its productive inputs to one sector alone whilst the consumption of the other good is totally imported. This derives from large enough differences in factor endowments between North and South. The necessary and sufficient conditions which ensure that complete specialization occurs are formally characterized in Appendix D. The analysis of complete specialization is relevant from the viewpoint of studying environmental policy to the extent that it implies, at the free trade equilibrium, a higher pollution charge/wage ratio in the North than in the South at the free trade equilibrium, which is an empirical fact.

Further, given endogenous determination of T^N and T^S, it remains to be shown that at the free trade equilibrium the relative resource-use/labor endowment ratio is as predicted by the standard HOS model. That is, $T^{N^{cs}}/\bar{L}^N < T^{S^{cs}}/\bar{L}^S$. This is shown later in this section, in the course of examining the regional pollution changes. In what follows immediately, it is presumed that this inequality holds.

When both countries specialize at the free trade equilibrium, there are two zero-profit equations, one for each production sector in the North and South respectively. The four factor employment conditions, two for each country, now depict all of the labor endowment and natural resource being allocated to the production of one good, i.e., good X in the North and good Y in the South. The trade balance condition is also changed accordingly.

The factor employment conditions solve for the respective resource price/wage ratios, ρ^j, $j = N, S$ and the outputs, Q_x^N and Q_y^S for both countries. These, together with the standard profit maximizing conditions determine w^j and τ^j. Given Cobb-Douglas technology, these solutions are:

$$\begin{aligned} \tau^N &= \frac{1}{\kappa_x}\left(\frac{\alpha_x}{1-\alpha_x}\frac{T^N}{\bar{L}^N}\right)^{-\alpha_x}, & \tau^S &= \frac{(1-a)(1-\alpha_y)}{a}\frac{\bar{L}^N}{T^S}\left(\frac{T^N}{\bar{L}^N}\right)^{1-\alpha_x}; \\ w^N &= \frac{1}{\kappa_x}\left(\frac{\alpha_x}{1-\alpha_x}\frac{T^N}{\bar{L}^N}\right)^{1-\alpha_x}, & w^S &= \frac{(1-a)\alpha_y}{a}\frac{\bar{L}^N}{\bar{L}^S}\left(\frac{T^N}{\bar{L}^N}\right)^{1-\alpha_x}; \\ Q_x^N &= \bar{L}^N\left(\frac{T^N}{\bar{L}^N}\right)^{1-\alpha_x}, & Q_y^S &= \bar{L}^S\left(\frac{T^S}{\bar{L}^S}\right)^{1-\alpha_y}. \end{aligned} \tag{3.32}$$

Denoting the market clearing price by p^o, the world market equilibrium is given by $Q_x^N/Q_y^S = ap^o/(1-a)$. Substituting the expressions for Q_x^N and Q_y^S, we get

$$p^o(T^N, T^S) = \frac{1-a}{a}\left(\frac{\bar{L}^S}{\bar{L}^N}\right)^{-1}\left(\frac{T^N}{\bar{L}^N}\right)^{1-\alpha_x}\left(\frac{T^S}{\bar{L}^S}\right)^{-(1-\alpha_y)}. \tag{3.33}$$

In respect of the free trade commodity terms-of-trade, p^o, two observations are in order.

First, the equilibrium price p^o is increasing in T^N and decreasing in T^S. This differs from the FPE regime, where the equilibrium price p^w was declining in T^j for any j (see Proposition 2). More specifically, under the FPE regime, in the North an increase in T^N would increase the relative output of the dirtier good (good Y), and hence lower its relative price. In contrast, when it specializes in producing the cleaner good (good X), an increase in T^N increases the relative output of the cleaner good, which tends to increase the price of the dirtier good. For the South, however, an increase in T^S leads to an increase in the output of the dirtier good whether it specializes incompletely or completely, and thus unambiguously lowers its price. The impacts of changes in T^N and T^S on p^o mean that an increase in T^j worsens country j's terms-of-trade (and improves the other country's terms-of-trade).

Second, the elasticity of p^o with respect T^S is higher than that with respect to T^N. Algebraically,

$$\left|\frac{\hat{p^o}}{\hat{T^S}}\right| = (1-\alpha_y) > \left|\frac{\hat{p^o}}{\hat{T^N}}\right| = (1-\alpha_x) \quad \text{since } \alpha_x > \alpha_y.$$

This asymmetry in elasticities arises because good Y is relatively more resource/pollution intensive than good X and, hence, the elasticity of output of good Y due to marginal increase in resource use. This is different from the FPE case where the magnitude of elasticity of p^w was the same with respect to T^N and T^S. This asymmetry is used to explain later the overall change in the commodity terms-of-trade due to the move from autarky to free trade.

Hence,

Proposition 6: *At the free trade equilibrium,*

(i) a marginal increase in the release of natural resource by North or South implies a commodity terms-of-trade loss for it,

(ii) the magnitude of the elasticity of terms-of-trade with respect to T^S is higher than that due to change in T^N.

Corollary to Proposition 6 (i): *For either country, a marginal increase in resource use by the partner country is a source of terms-of-trade improvement.*

Returning to the model solutions, finally, the aggregate income of the two countries could be written as

$$I^N = Q_x^N = \bar{L}^N \left(\frac{T^N}{\bar{L}^N} \right)^{1-\alpha_x} \equiv I^N(T^N); \tag{3.34}$$

$$\begin{aligned} I^S = p^o Q_y^S &= \left(\frac{1-a}{a} \left(\frac{\bar{L}^S}{\bar{L}^N} \right)^{-1} \left(\frac{T^N}{\bar{L}^N} \right)^{1-\alpha_x} \left(\frac{T^S}{\bar{L}^S} \right)^{(1-\alpha_y)} \right) \bar{L}^S \left(\frac{T^S}{\bar{L}^S} \right)^{1-\alpha_y} \\ &\equiv I^S(T^N, T^S). \end{aligned} \tag{3.35}$$

In view of (3.34)-(3.35) and Cobb-Douglas preferences, the expressions for demands are $D_x^N = aI^N = aQ_x^N$, $D_x^S = aI^S = ap^oQ_y^S$, $D_y^N = (1-a)I^N/p^o = (1-a)Q_x^N/p^o$, $D_y^S = (1-a)I^S/p^o = (1-a)Q_y^S$.

We can now express each country's welfare function in indirect form as:

$$U^{N^{cs}}(T^N, T^S) = K + \ln I^N(T^N) - (1-a)\ln p^o(T^N, T^S) + \gamma \ln(\bar{T}^N - T^N); \tag{3.36}$$

$$U^{S^{cs}}(T^N, T^S) = K + \ln I^S(T^N, T^S) - (1-a)\ln p^o(T^N, T^S) + \gamma \ln(\bar{T}^S - T^S), \tag{3.37}$$

where constant K is as defined earlier.

Under Nash non-cooperative behavior, $U^{N^{cs}}$ and $U^{S^{cs}}$ are maximized with respect to T^N and T^S respectively. The respective first-order conditions are

$$\begin{aligned} \frac{1}{I^N}\frac{\partial I^N(\cdot)}{\partial T^N} - \frac{(1-a)}{p^o}\frac{\partial p^o(\cdot)}{\partial T^N} &= \frac{\gamma}{\bar{T}^N - T^N} \\ \Leftrightarrow \frac{\tau^N}{I^N} - \frac{D_y^N}{I^N}\frac{\partial p^o(\cdot)}{\partial T^N} &= \frac{\gamma}{\bar{T}^N - T^N}; \end{aligned} \tag{3.38}$$

$$\begin{aligned} \frac{1}{I^S}\frac{\partial I^S(\cdot)}{\partial T^S} - \frac{(1-a)}{p^o}\frac{\partial p^o(\cdot)}{\partial T^S} &= \frac{\gamma}{\bar{T}^S - T^S} \\ \Leftrightarrow \frac{\tau^S}{I^S} - \frac{(D_y^S - Q_y^S)}{I^S}\frac{\partial p^o(\cdot)}{\partial T^S} &= \frac{\gamma}{\bar{T}^S - T^S}. \end{aligned} \tag{3.39}$$

The eqs. (3.38)-(3.39) follow from using Roy's identity in the respective previous equations.

As in the FPE regime, in the l.h.s. or the marginal benefit side of (3.38)-(3.39), both the *adjusted output* and the *commodity terms-of-trade effects* of pollution policy come into play. The terms-of-trade effect is represented by the second term and it drives a wedge between the output effect and the marginal cost of pollution (in the r.h.s.).

Substituting for the partials from the expressions in (3.32) and (3.33), the conditions (3.38) and (3.39) reduce to:

$$\frac{(1-\alpha_x)}{T^N} - \frac{(1-a)(1-\alpha_x)}{T^N} \equiv \frac{a(1-\alpha_x)}{T^N} = \frac{\gamma}{\bar{T}^N - T^N}; \qquad (3.40)$$

$$\frac{(1-\alpha_y)}{T^S} - \frac{[(1-\alpha_y)-(1-a)(1-\alpha_y)]}{T^S} \equiv \frac{(1-a)(1-\alpha_y)}{T^S} = \frac{\gamma}{\bar{T}^S - T^S}. \qquad (3.41)$$

In general, the strategic interaction between T^N and T^S works through the commodity terms-of-trade as North and South open up free trade. Observe, however, in (3.40) and (3.41) there is no strategic complementarity or substitutability between T^N and T^S. This is because, under complete specialization the impacts on marginal benefits via the commodity terms-of-trade (represented by the second terms in the extreme l.h.s. of each equation), are a function of each country's *own* policy alone, and not that of the partner country's.

Further, it is straightforward that $\partial^2 U^N/\partial {T^N}^2 = -a(1-\alpha_x)/{T^N}^2 - \gamma/(\bar{T}^N - T^N)^2 < 0$ and $\partial^2 U^S/\partial {T^S}^2 = -(1-a)(1-\alpha_y)/{T^S}^2 - \gamma/(\bar{T}^S - T^S)^2 < 0$ and the second-order conditions are met. Also, the first-order conditions (3.38) and (3.39) being linear in T^N and T^S, the equilibrium is unique.

Pollution levels

Solving the eqs. (3.40) and (3.41) we get the levels of optimum pollution as:

$$T^{N^{cs}} = \frac{a(1-\alpha_x)}{\gamma + a(1-\alpha_x)}\bar{T}^N; \quad T^{S^{cs}} = \frac{(1-a)(1-\alpha_y)}{\gamma + (1-a)(1-\alpha_y)}\bar{T}^S, \qquad (3.42)$$

A comparison with the autarky solution in eq. (3.12) is immediate. Since both $a(1-\alpha_x)$ and $(1-a)(1-\alpha_y)$ are less than $a(1-\alpha_x) + (1-a)(1-\alpha_y)$, we would have $T^{N^{cs}} < T^{N^{at}}$ and $T^{S^{cs}} < T^{S^{at}}$. That is,

Proposition 7: *A movement from autarky to free trade with complete specialization in production implies a reduction in pollution in both North and South.*

This is the key result of this chapter. That pollution falls in the South is just the converse of C-T and is 'surprising'. Moreover, this happens whist South completely specializes in the production of the pollution-intensive good.

Proposition 7 could be seen as an interplay of the following effects. As compared to autarky, where the marginal benefit from pollution consisted of two effects, (a) the output effect and (b) the income effect, here, in the presence of international trade, there are two additional effects coming into play, namely (c) the composition effect and (d) the commodity terms-of-trade effect. The composition effect refers to the change in sectoral output mix. Since North (South) completely specializes in the production of the cleaner (dirtier) good, the composition effect induces a decrease (an increase) in pollution in the North (South). As each country is completely specialized, an increase in polluting input raises the supply of the country's exportable good, causing a worsening of its terms-of-trade. This is the terms-of-trade effect, which lowers the marginal benefit from pollution.

As countries move from autarky to free trade, on account (a), (b) and (c), there is a net decrease in the marginal benefit from pollution in the North and a net increase of it in the South. On account of (d) alone, there is a decrease in the marginal benefit from pollution in both North and South.

Mathematically, in view of (3.38), (3.39) and (3.10), the change in the marginal benefit from pollution for country j is given by

$$\underbrace{\left.\frac{\tau^j}{I^j}\right|_{\text{free trade}} - \left.\frac{\tau^j}{I^j}\right|_{\text{autarky}}}_{(a)+(b)+(c)} + \underbrace{\frac{(Q_y^j - D_y^j)}{I^j}\frac{\partial p^o(\cdot)}{\partial T^j}}_{(d)}.$$

For North and South these terms respectively boil down to

$$\text{North}: \quad \underbrace{\left[\frac{1-\alpha_x}{T^N} - \frac{a(1-\alpha_x)+(1-a)(1-\alpha_y)}{T^N}\right]}_{(a)+(b)+(c)} + \underbrace{\left[-\frac{(1-a)(1-\alpha_x)}{T^N}\right]}_{(d)}$$
$$= \underbrace{-\frac{(1-a)(\alpha_x-\alpha_y)}{T^N}}_{(a)+(b)+(c)} - \underbrace{\frac{(1-a)(1-\alpha_x)}{T^N}}_{(d)} < 0;$$

$$\text{South}: \quad \underbrace{\left[\frac{1-\alpha_y}{T^S} - \frac{a(1-\alpha_x)+(1-a)(1-\alpha_y)}{T^S}\right]}_{(a)+(b)+(c)} + \underbrace{\left[\frac{a(1-\alpha_y)}{T^S}\right]}_{(d)}$$
$$= \underbrace{\frac{a(\alpha_x-\alpha_y)}{T^S}}_{(a)+(b)+(c)} - \underbrace{\frac{a(1-\alpha_y)}{T^S}}_{(d)} = -\frac{a(1-\alpha_x)}{T^S} < 0.$$

Thus, in case of the North, effect (d) supplements the combined (a)+(b)+(c) effects on the marginal benefit of pollution, such that North is induced to reduce its use of the natural resource (and hence pollution) as it moves to free trade. On the other hand, in case of the South, the effect (d) not only moves opposite to the combined (a)+(b)+(c) effects, but it outweighs them.[13] Hence South *also* reduces its resource use or pollution under free trade as compared to autarky. This is where out result differs from C-T (1994) who derive that it is always the composition effect that pre-dominates and, hence, trade causes North (South) to reduce (increase) pollution. It is the terms of trade effects, which distinguishes our analysis from that of C-T.

Pollution charge to wage ratios and resource-use to labor-endowment ratios

Internalization of terms-of-trade effects of pollution policy changes also entails important implications for the overall changes in terms-of-trade and welfare as the countries move from

[13]Unlike the case of incomplete specialization, under complete specialization, if a country restricts its resource supply, there are no intersectoral shifts in the use of the resource input to counter the first-round terms-of-trade effect of environment policy. Therefore, reducing resource use (or pollution) brings larger terms-of-trade improvement under complete specialization than under incomplete specialization. This is why the terms of trade effect outweighs the other effects in the South.

autarky to free trade. Moreover, these are different from the case where both countries incompletely specialize in the free trade equilibrium. However, before we analyze them, by using the solutions just obtained for the pollution levels at the trading equilibrium, we will derive two results. First, it will be shown that the pollution charge to wage ratio in the North exceeds that in the South. Unlike FPE, it is consistent with the observed fact relating to differences in stringency of environmental standards between developed and developing countries. Thus, the complete specialization case has an empirical relevance and, therefore, its predictions should not be judged as merely theoretical inquiries. Second, note that thus far we have assumed that $T^{N^{cs}}/\bar{L}^N < T^{S^{cs}}/\bar{T}^S$. But this needs to be proven since T^N and T^S are endogenous, and we do it by using the first result.

We first show that $\rho^N > \rho^S$. Using (3.32), the resource price to wage ratio for North and South, are expressed as

$$\rho^N = \frac{\tau^S}{w^N} = \frac{(1-\alpha_x)}{\alpha_x}\frac{\bar{L}^N}{T^N}; \quad \rho^S = \frac{\tau^N}{w^N} = \frac{(1-\alpha_y)}{\alpha_y}\frac{\bar{L}^S}{T^S} \tag{3.43}$$

$$\Rightarrow \frac{\rho^N}{\rho^S} = \frac{(1-\alpha_x)\alpha_y}{\alpha_x(1-\alpha_y)}\frac{\bar{L}^N}{T^N}\frac{T^S}{\bar{L}^S}. \tag{3.44}$$

Substituting into it the closed form solutions for $T^{N^{cs}}$ and $T^{S^{cs}}$ from (3.42)

$$\frac{\rho^N}{\rho^S} = \frac{((1-a)\alpha_y)\cdot(\gamma+a(1-\alpha_x))}{a\alpha_x\cdot(\gamma+(1-a)(1-\alpha_y))}\frac{\bar{T}^S/\bar{L}^S}{\bar{T}^N/\bar{L}^N} > 1. \tag{3.45}$$

The necessary and sufficient conditions for complete specialization derived in Appendix D imply that the r.h.s of (3.45) exceeds one (see condition (D7) in Appendix D). Hence, $\rho^N > \rho^S$.

Following on from the above result, it can be shown that $T^{N^{cs}}/\bar{L}^N < T^{S^{cs}}/\bar{L}^S$. Given the expressions for ρ^N and ρ^S in (3.43), $\rho^N > \rho^S$ is equivalent to

$$\frac{(1-\alpha_x)}{\alpha_x}\frac{\bar{L}^N}{T^{N^{cs}}} > \frac{(1-\alpha_y)}{\alpha_y}\frac{\bar{L}^S}{T^{S^{cs}}} \Rightarrow \frac{T^{N^{cs}}}{\bar{L}^N} < \frac{T^{S^{cs}}}{\bar{L}^S},$$

since $\alpha_x > \alpha_y$. This replicates the relative resource/labor use pattern in the standard fixed-endowment model.

Commodity terms-of-trade

As under the FPE regime, pollution policies being endogenous imply that free trade may not lead to an improvement of the terms-of-trade of a country. Recall that in the FPE case, it was determined that one country always has a commodity terms-of-trade improvement whilst the other may or may not. But whether North or South would gain could not be ascertained. However, when both countries completely specialize, it turns out that South will have an unambiguous improvement in its terms-of-trade whilst North's terms-of-trade may improve or deteriorate. We begin by providing an intuition for this assertion.

We have already seen that as countries move from autarky to free trade, both T^N and T^S fall. From the Corollary to Proposition 6 (i), a decrease in T^N tends to lower (raise) South's (North's) terms-of-trade, whilst a decrease in T^S implies the opposite. However, in view of Proposition 6 (ii) the terms-of-trade are more elastic with respect to a change in T^S than to a change in T^N (since good Y is more pollution-intensive than good X and North and South respectively specialize in good X and good Y). Therefore, the effect of the change in T^S dominates. As a result, South's (North's) terms-of-trade improve (deteriorate) because of adjustments in T^N and T^S. Coupled with the standard effect due to trade (without adjustments in T^N or T^S), it follows that the South's terms-of-trade improve unambiguously, whilst North's terms-of-trade may improve or deteriorate.

Furthermore, it turns out that for the North the terms-of-trade will decline when consumers attach a high enough weight, γ, on environmental quality. This is synonymous with higher disutility from pollution. By itself, a higher γ implies that either country has lower tolerance for pollution and is induced to adopt a stricter pollution policy as compared to when γ is smaller. Therefore, at high enough γ, the effect of decrease in T^S on the terms-of-trade is very large. For the North, in particular, this (negative effect on the terms-of-trade) would outweigh the sum of the standard positive effect of trade as well as the effect of decrease in T^N, which is also positive.

Hence,

Proposition 8: *A movement from autarky to trade with complete specialization leads to an unambiguous improvement in the terms-of-trade for the South, whilst North may gain or lose.*

A formal proof of this result as well as a sufficient condition on the magnitude of γ under which North "suffers" a terms-of-trade loss are given in Appendix E.

In sum, there are two non-standard implications. First, a country may face a worsening of its commodity terms-of-trade as it moves from autarky to free trade. Second, in the free trade equilibrium, a country may specialize in the production of the good whose terms-of-trade have declined. These results stem from the fact that pollution policies are endogenous and strategically linked via the terms-of-trade movements.

Next, turn to the welfare implications of trade.

Welfare effects

In a standard competitive fixed-endowment model countries always obtain a favorable terms-of-trade and a welfare improvement as they move from autarky to free trade. This is not true in our model. Both countries reduce their pollution, which, *per se*, improves welfare. But, interestingly, one or *both* countries may *lose* from free trade.

This can be seen in terms of the Prisoner's Dilemma paradigm. Suppose that both countries move from autarky to free trade, but they do not adjust their pollution policies. There are then standard gains from trade for each country. Given this situation, let us now consider the incentive of one of the countries, say the South, to adjust its pollution policy whilst the other, the North, maintains its original policy. The optimal response of the South will be to reduce its pollution-causing resource use. It is driven by the terms-of-trade improvement motive. As T^S falls, it causes the world supply of good Y (the only good produced and exported by the South) to fall, and hence raises its relative world price. This inflicts an equivalent terms-of-trade loss for the North to the extent that its welfare may be lower than that in autarky. Of course, North would do the same. Hence, in the Nash equilibrium, it is possible that both countries lose.[14]

Algebraically, turn to eq. (3.33). Let $T^N = T^{Nat}$. Eq. (3.39) gives optimal T^S in the trading regime, which is independent of T^N. This is given in (3.42). Substituting it into (3.33), the free trade market clearing price is given by

$$p^o\Big|_{T^N=T^{Nat},T^S=T^{Scs}} = \frac{(1-a)}{a}\frac{\bar{L}^N}{\bar{L}^S}\left(\frac{a(1-\alpha_x)+(1-a)(1-\alpha_y)}{\gamma+a(1-\alpha_x)+(1-a)(1-\alpha_y)}\frac{\bar{T}^N}{\bar{L}^N}\right)^{1-\alpha_x} \cdot \left(\frac{(1-a)(1-\alpha_y)}{\gamma+(1-a)(1-\alpha_y)}\frac{\bar{T}^S}{\bar{L}^S}\right)^{-(1-\alpha_y)} . \quad (3.46)$$

The relative price in the North in autarky is given in the expressions in (3.8). Substituting (3.12) into it yields the reduced-form expression for this relative price:

$$p^{Nat} = \frac{\kappa_y}{\kappa_x}\left(\lambda\cdot\frac{a(1-\alpha_x)+(1-a)(1-\alpha_y)}{\gamma+a(1-\alpha_x)+(1-a)(1-\alpha_y)}\frac{\bar{T}^N}{\bar{L}^N}\right)^{-(\alpha_x-\alpha_y)} . \quad (3.47)$$

Recall that λ is as defined in Section 3.3.

Comparing (3.46) and (3.47),

$$p^o\Big|_{T^N=T^{Nat},T^S=T^{Scs}} > p^{Nat}$$
$$\Leftrightarrow \frac{(1-a)}{a}\frac{\bar{L}^N}{\bar{L}^S}\frac{\kappa_x}{\kappa_y}\lambda^{\alpha_x-\alpha_y} > \left(\frac{\frac{(1-a)(1-\alpha_y)}{\gamma+(1-a)(1-\alpha_y)}\cdot\frac{\bar{T}^S}{\bar{L}^S}}{\frac{a(1-\alpha_x)+(1-a)(1-\alpha_y)}{\gamma+a(1-\alpha_x)+(1-a)(1-\alpha_y)}\cdot\frac{\bar{T}^N}{\bar{L}^N}}\right)^{1-\alpha_y} . \quad (3.48)$$

It turns out that (3.48) is not inconsistent with the necessary and sufficient conditions for complete specialization, characterized by (D5) and (D6) in Appendix D, for the North and South respectively.

Hence, as long as (3.48) is satisfied, South's unilateral adjustment of pollution policy makes the North worse off as compared to autarky.

[14] We acknowledge the useful comment of a referee, enquiring the basis of welfare loss for a country. This led to these observations.

Let us now turn to the analysis of welfare change when both countries optimally adjust their pollution policy in response to free trade. For any country, a *net* welfare change would arise on account of two broad effects: (a) the standard commodity terms-of-trade effect, which is due to change in the trade regime *alone* while there is no change in T^N and T^S, and (b) effect due to changes in T^N and T^S as countries reset their pollution policies in the trading regime. (b), in turn, comprises three effects for each country: (i) shift in the production possibility frontier, (ii) change in the terms-of-trade, and (iii) direct impact on welfare due to change in national environmental quality.

As both countries reduce their pollution in moving from autarky to free trade equilibrium, it is possible that the production possibility shifts and the terms-of-trade losses (mainly inflicted by the partner country's change in the pollution policy) counter the standard terms-of-trade gains or direct welfare gains on account of improved environmental quality. Hence, in general, the overall change in welfare remains ambiguous for both countries. This is our first point.

Our second point is that, it is possible that *both* countries lose in terms of welfare.[15]

To see these implications formally, we first decompose the net welfare change for country j as:

$$U^{j^{cs}} - U^{j^{at}} = \underbrace{\left(U^{N^{cs}}\Big|_{T^N=T^{N^{at}}} - U^{N^{at}}\Big|_{T^N=T^{N^{at}}}\right)}_{(a)} + \underbrace{\left(U^{N^{cs}}\Big|_{T^N=T^{N^{cs}}} - U^{N^{cs}}\Big|_{T^N=T^{N^{at}}}\right)}_{(b)}, \quad (3.49)$$

where superscripts "at" and "cs" respectively refer to variables at the autarky and free trade equilibrium (with complete specialization).

The first term in (3.49) is the standard welfare change when pollution policies are unchanged at their autarky solution levels. The second term represents the welfare change as pollution policies adjust in the trading regime.

As shown in Appendix F, the first term is positive (as it should). As said earlier, the effect (b)

[15]These welfare implications differ sharply from the incomplete specialization case in which both countries unambiguously gain in terms of welfare.

comprises three distinct effects – (i), (ii) and (iii) – for each country.

Hence, the overall change in welfare for country j given in the r.h.s. of (3.49) can be decomposed as:

$$= \underbrace{\left(U^{N^{cs}}\Big|_{T^N=T^{N^{at}}} - U^{N^{at}}\Big|_{T^N=T^{N^{at}}}\right)}_{\text{Effect (a): } > 0}$$
$$+ \underbrace{\left[\xi^N\left[\ln\left(\frac{\xi^N}{\gamma+\xi^N}\right) - \ln\left(\frac{\xi}{\gamma+\xi}\right)\right] + \xi^S\left[\ln\left(\frac{\xi^S}{\gamma+\xi^S}\right) - \ln\left(\frac{\xi}{\gamma+\xi}\right)\right]\right]}_{\text{Effects (b)(i) + (b)(ii): } < 0}$$
$$+ \underbrace{\gamma\left[\ln\left(\frac{\gamma}{\gamma+\xi^j}\right) - \ln\left(\frac{\gamma}{\gamma+\xi}\right)\right]}_{\text{Effect (b)(iii): } > 0} \lesseqgtr 0, \tag{3.50}$$

where $\xi^N = a(1-\alpha_x)$, $\xi^S = (1-a)(1-\alpha_y)$, and hence, $\xi = \xi^N + \xi^S$.

Notice that the combined effect of the *shrinking of the production possibility frontier*, (b)(i), and *change in the terms-of-trade*, (b)(ii), induced by lowering of both T^N and T^S, is negative.[16] The last term in (3.50) captures the *direct environmental effect* on welfare, (b)(iii), which is positive as each country gains due to improved environmental quality. The overall effect on welfare thus remains ambiguous, in general.

In the absence of any conclusive analytical results on aggregate welfare of countries, numerical simulations were resorted to. Specific numerical values were assigned to the parameters of the model, namely, a, α_x, α_y, $\bar{L}^N$, $\bar{L}^S$, $\bar{T}^N$, $\bar{T}^S$ and γ. The values of a, α_x and α_y were varied in the range from 0.01 to 0.99, ensuring that $\alpha_x > \alpha_y$ and γ was varied from 0.1 to 1000. The absolute values of $\bar{L}^N$, $\bar{L}^S$, $\bar{T}^N$, and $\bar{T}^S$ were allowed to vary from 10 to 1000000, whilst the ratio $(\bar{T}^S/\bar{L}^S)/(\bar{T}^N/\bar{L}^N)$ was varied from 1 to 5050.

Next, using the closed form solutions in (3.12) and (3.42) the expression for welfare change in (3.50) was assessed for both North and South. Table 3.1 illustrates the results of the simulation exercise for selected values of parameters. In case of each of the simulations presented, the parameters chosen are consistent with the existence of a specialized

[16] This is because both ξ^N and $\xi^S < \xi$.

equilibrium for each country, meaning that both the necessary and sufficient conditions for complete specialization (conditions (D5) and (D6) in Appendix D) are satisfied.

As can be seen, the effect of free trade (with complete specialization) on the welfare of *either* country may be positive or negative, that is, (i) both North and South may gain (as shown in Runs 2a, 2b, 4a, 4b, 7a and 9a), (ii) North loses whilst South gains (as in case of Runs 1a, 1b, 3a, 3b, 5a, 5b, 6a, 6b, 7b, 8a and 8b), (iii) South loses and North gains (as corroborated by Runs 9b, 10c, 11a and 11b), and (iv) both countries may lose (as indicated by Runs 10a, 10b, 12a and 12b).

Table 3.1: Results of numerical simulations (for chosen parameter values)

	a	α_x	α_y	$\bar{L}^N$	$\bar{L}^S$	$\bar{T}^N$	$\bar{T}^S$	γ	$dU^{N^{cs}}$	$dU^{S^{cs}}$	$dU^{W^{cs}}$
Run 1a	0.10	0.15	0.10	1000	100	1000	6000	0.20	-0.566	0.016	-0.550
Run 1b								0.25	-0.541	0.006	-0.535
Run 2a	0.10	0.50	0.10	10000	1000	20000	200000	1.00	0.069	0.064	0.133
Run 2b								100.00	0.254	0.036	0.290
Run 3a	0.10	0.20	0.01	1000	10	1000	6000	0.50	-0.140	0.014	-0.126
Run 3b		0.99							-0.204	0.382	0.178
Run 4a	0.20	0.75	0.20	1000	500	1000	10000	5.00	0.576	0.036	0.612
Run 4b		0.90							0.593	0.113	0.706
Run 5a	0.10	0.31	0.10	2000	200	4000	40000	0.50	-0.031	0.004	-0.026
Run 5b		0.99							-0.030	0.253	0.222
Run 6a	0.10	0.70	0.22	1000	100	1000	6000	0.50	-0.882	0.211	-0.671
Run 6b			0.02						-0.181	0.106	-0.075
Run 7a	0.001	0.99	0.01	1000	100	1000	1000000	5.00	0.807	0.005	0.811
Run 7b			0.445						-3.569	0.008	-3.560
Run 8a	0.01	0.05	0.01	1000	100	1000	3000	0.50	-2.974	0.001	-2.972
Run 8b	0.03								-1.881	0.000	-1.881
Run 9a	0.01	0.60	0.10	1000	500	1000	100000	5.00	0.273	0.003	0.276
Run 9b	0.02								0.933	-0.002	0.932
Run 10a	0.50	0.50	0.45	1000	100	1000	7000	5.00	-0.067	-0.018	-0.085
Run 10b				1000	100	1000	8000		-0.030	-0.052	0.082
Run 10c				1000	100	1000	9000		0.002	-0.081	-0.079
Run 11a	0.50	0.50	0.40	500	50	500	3500		0.045	-0.037	0.008
Run 11b				500	50	500	4000		0.085	-0.070	0.015
Run 12a	0.5	0.25	0.20	1000	10	1000	3500	5.00	-0.085	-0.043	-0.128
Run 12b				1000	10	1000	4000		-0.032	-0.093	-0.125

The welfare implications of trade are summarized below.

Proposition 9: *If both North and South completely specialize in production in the free trade equilibrium then, compared to autarky, each country may experience a welfare gain or loss.*

The most striking welfare implication is that welfare losses for each country cannot be ruled out. This will happen when the reductions in T^N and T^S cause sufficient shrinkage of the production possibility frontier, which, coupled with its effect on the terms-of-trade, outweigh the standard real income gains from trade and improved environmental quality.

3.5 Conclusions

Extending the C-T (1994) analysis to incorporate the terms-of-trade effects of environment policy change, our analysis uncovers, compared to existing literature, some dramatically different implications of free international trade between North and South, i.e., between developed and developing countries. In particular, two key differences in results are observed. First, South reduces its pollution (compared to autarky), despite that it may specialize in the production of the "dirty" good. Second, it is possible that both North and South may lose from free trade, although both experience improved environment. A summary of the important findings follows.

If both countries incompletely specialize in the free trade equilibrium, most of the results derived by C-T (1994) hold. As trade opens up North is induced to reduce its pollution and South increases it. In terms of aggregate welfare, both countries are better off with free trade. The only notable difference is that one country (but not both) may experience a deterioration in its terms-of-trade, against C-T who predict that both countries will experience a terms-of-trade improvement.

However, major differences in predictions emerge when both North and South specialize in the production of their exportable good. It is found that with trade *both* North and South would *reduce* their pollution as compared to autarky. The surprising element is that South also reduces its pollution inspite of specializing in the production of the pollution-intensive good. Moreover, free trade may entail a terms-of-trade loss for the North, whilst South always experiences an improvement in its terms-of-trade. Finally, in spite of an improvement in the terms-of-trade and environment quality (due to lower pollution), losses in welfare of *both* North or South cannot be ruled out.

The key finding of this chapter is that free trade in goods may not harm the environment of either of the trading countries.

Appendix A

The parametric configurations that ensure both countries to have incomplete specialization in production in free trade equilibrium are derived. Incomplete specialization implies FPE, which replicates the integrated world equilibrium *a la* Dixit and Norman (1980).[17]

Suppose that at the free trade equilibrium, the amounts of the natural resource released by North and South are $T^{N^{is}}$ and $T^{S^{is}}$. Let $T^{N^{is}}/\bar{L}^N < T^{S^{is}}/\bar{L}^S$. Denote $T^{W^o} = T^{N^{is}} + T^{S^{is}}$. Now imagine an integrated world economy, as in Dixit and Norman (1980), that is endowed with T^{W^o} of the resource input and $\bar{L}^W = \bar{L}^N + \bar{L}^S$ of labor. Moreover, labor *as well as* the natural resource input (that is, all of T^{W^o}) are fully employed. Given technology and preferences, positive amounts of both good X and good Y will be produced in equilibrium. In Figure 3.2, O^N denotes the origin of the world economy in terms of factor use. Let $O^N X^N$ and $O^N Y^N$ denote the equilibrium factor intensity rays in sector X and sector Y respectively. Let O^S be the world resource endowment point with coordinates $(\bar{L}^W,\ T^{W^o})$. The lines $O^S X^S$ and $O^S Y^S$ are drawn parallel to the line $O^N X^N$ and $O^N Y^N$ respectively.

[17] For the necessary and sufficient conditions for both countries to have complete specialization see Appendix D.

The intersection points A and B determine the factor use in sector X and Y. Given constant returns to scale technology, the rays $O^N A$ and $O^N B$ measure the respective world outputs. Note that the slopes of $O^N X^N$ and $O^N Y^N$ are equal to

$$\frac{\alpha_x}{(1-\alpha_x)} \frac{\bar{L}^W}{\lambda T^{Wo}}; \text{ and } \frac{\alpha_y}{(1-\alpha_y)} \frac{\bar{L}^W}{\lambda T^{Wo}}, \tag{A1}$$

where recall that $\lambda \equiv [a\alpha_x + (1-a)\alpha_y)]/[a(1-\alpha_x) + (1-a)(1-\alpha_y)]$. These expressions are derived by solving explicitly for the resource price-wage ratio in the autarkic world economy.

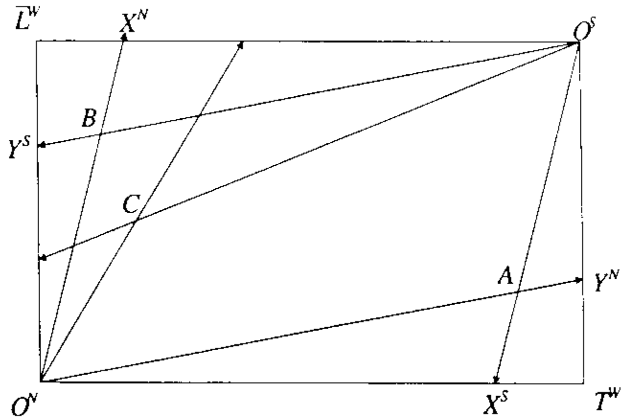

Figure 3.2: Regions characterizing alternative patterns of production specialization

Now return to the division of world into North and South with respective endowments $(\bar{L}^N,\ T^{N^{is}})$, $(\bar{L}^S,\ T^{S^{is}})$. Let O^N and O^S denote the origin of these countries respectively. Following the Dixit-Norman analysis, it follows that both countries incompletely specialize in production at the free trade equilibrium if and only if their factor allocations lie within the parallelogram $O^N A O^S B$. Let the point C, which has coordinates $(\bar{L}^N,\ T^{N^{is}})$ from the origin O^N and $(\bar{L}^S,\ T^{S^{is}})$ from the origin O^S, be such an endowment point. Therefore, the necessary and sufficient conditions for incomplete specialization in both countries (and FPE) are that the rays $O^N C$ and $O^S C$ lie in between the rays $O^N X^N$ and $O^N Y^N$. In view of (A1), this is equivalent to

$$\frac{\alpha_y}{(1-\alpha_y)}\,\frac{\bar{L}^W}{\lambda T^{W^o}} < \frac{\bar{L}^N}{T^{N^{is}}} < \frac{\alpha_x}{(1-\alpha_x)}\,\frac{\bar{L}^W}{\lambda T^{W^o}}; \tag{A2}$$

$$\frac{\alpha_y}{(1-\alpha_y)}\,\frac{\bar{L}^W}{\lambda T^{W^o}} < \frac{\bar{L}^S}{T^{S^{is}}} < \frac{\alpha_x}{(1-\alpha_x)}\,\frac{\bar{L}^W}{\lambda T^{W^o}}. \tag{A3}$$

Further, given our assumption that at the FPE equilibrium[18]

$$\frac{T^{N^{is}}}{\bar{L}^N} < \frac{T^{S^{is}}}{\bar{L}^S}. \tag{A4}$$

Also, note that $T^{N^{is}}$ and $T^{S^{is}}$ must be equal to the optimal choice of pollution levels at the free trade equilibrium, given incomplete specialization in both countries. In other words, these are the implicit solutions to eqs. (3.24) and (3.25). Let these be denoted by

$$T^{N^{is}} = \widetilde{T^N}^{is}(\bar{T}^N, T^S); \quad T^{S^{is}} = \widetilde{T^S}^{is}(\bar{T}^S, T^N) \tag{A5}$$

Combining the inequalities in (A2), (A3) and (A4), and using the expressions in (A5), we have

$$\frac{\alpha_y}{\lambda(1-\alpha_y)} < \frac{\left(\bar{L}^S/\widetilde{T^S}^{is}(\bar{T}^S, T^N)\right)}{\bar{L}^W/T^{W^o}} < \frac{\left(\bar{L}^N/\widetilde{T^N}^{is}(\bar{T}^N, T^S)\right)}{\bar{L}^W/T^{W^o}} < \frac{\alpha_x}{\lambda(1-\alpha_x)} \tag{A6}$$

which constitute the necessary and sufficient conditions for incomplete specialization by both North and South.

Appendix B

When there is FPE, it is shown here that the second-order conditions corresponding to the first-order conditions (3.24) and (3.25) are met.

[18] That this ranking of natural resource use to labor endowment ratio holds is proven in Appendix C.

The first-order conditions could be expressed as:

$$\begin{aligned}\frac{\partial R^N(T^N,T^S)}{\partial T^N} &= \frac{T^S}{T^W\left(T^N+\lambda\frac{\bar{L}^N}{\bar{L}^W}T^W\right)}+\frac{\xi}{T^W}-\frac{\gamma}{\bar{T}^N-T^N};\\ \frac{\partial R^S(T^N,T^S)}{\partial T^S} &= \frac{T^N}{T^W\left(T^S+\lambda\frac{\bar{L}^S}{\bar{L}^W}T^W\right)}+\frac{\xi}{T^W}-\frac{\gamma}{\bar{T}^S-T^S}.\end{aligned} \tag{B1}$$

Then

$$\begin{aligned}\frac{\partial^2 R^N}{\partial T^{N2}} &= -\frac{T^S}{T^W}\frac{1+\lambda(\bar{L}^N/\bar{L}^W)}{\left(T^N+\lambda(\bar{L}^N/\bar{L}^W)T^W\right)^2}-\frac{T^S}{T^{W2}}\frac{1}{T^N+\lambda(\bar{L}^N/\bar{L}^W)T^W}\\ &\quad -\frac{\xi}{T^{W2}}-\frac{\gamma}{\left(\bar{T}^N-T^N\right)^2}<0;\\ \frac{\partial^2 R^S}{\partial T^{S2}} &= -\frac{T^N}{T^W}\frac{1+\lambda(\bar{L}^S/\bar{L}^W)}{\left(T^S+\lambda(\bar{L}^S/\bar{L}^W)T^W\right)^2}-\frac{T^N}{T^{W2}}\frac{1}{T^S+\lambda(\bar{L}^S/\bar{L}^W)T^W}\\ &\quad -\frac{\xi}{T^{W2}}-\frac{\gamma}{\left(\bar{T}^S-T^S\right)^2}<0.\end{aligned} \tag{B2}$$

Hence, the second-order conditions are met.

Appendix C

It is shown that in moving from autarky to free trade with FPE, (a) North reduces its pollution whilst that in the South goes up, i.e. Proposition 3 holds and (b) at the FPE equilibrium $T^{N^{is}}/\bar{L}^N < T^{S^{is}}/\bar{L}^S$.

We first prove (a). This is done in two steps.

Step 1: It is first shown that, with free trade, both countries do not change their pollution levels in the same direction. Observe that, for country j, $j = N, S$, the marginal cost of pollution, $\gamma T^j/(\bar{T}^j - T^j)$, is increasing in T^j. Then, in moving from autarky to free trade equilibrium, if it is assumed that North reduces its pollution, such that

$$\frac{\gamma T^{N^{is}}}{\bar{T}^N - T^{N^{is}}} < \xi \equiv \frac{\gamma T^{N^{at}}}{\bar{T}^N - T^{N^{at}}}, \tag{C1}$$

then South would increase its pollution

$$\frac{\gamma T^{S^{is}}}{\bar{T}^S - T^{S^{is}}} > \xi \equiv \frac{\gamma T^{S^{at}}}{\bar{T}^S - T^{S^{at}}}. \tag{C2}$$

This is proved by contradiction.

Let both North and South reduce their pollution in moving from autarky to FPE equilibrium such that

$$\frac{\gamma T^{N^{is}}}{\bar{T}^N - T^{N^{is}}} < \xi, \text{ and} \tag{C3}$$

$$\frac{\gamma T^{S^{is}}}{\bar{T}^S - T^{S^{is}}} < \xi. \tag{C4}$$

The inequality in (C3) together with the first-order condition (3.24) in the text implies

$$\xi - \frac{\gamma T^{N^{is}}}{\bar{T}^N - T^{N^{is}}} = \frac{\gamma T^{S^{is}}}{\bar{T}^N - T^{N^{is}}} - \frac{T^{S^{is}}}{T^{N^{is}} + \frac{1-\xi}{\xi}\mu_L T^{W^{is}}} > 0$$

(Recall that $\xi \equiv a(1-\alpha_x) + (1-a)(1-\alpha_y)$ and $\mu_L \equiv \bar{L}^N/\bar{L}^W$.) The r.h.s. is positive since, from (C3), the l.h.s. is positive. Next, by multiplying the r.h.s by T^N/T^S yields

$$\frac{\gamma T^{N^{is}}}{\bar{T}^N - T^{N^{is}}} - \frac{T^{N^{is}}}{T^{N^{is}} + \frac{1-\xi}{\xi}\mu_L T^{W^{is}}} > 0. \tag{C5}$$

The inequalities in (C3) and (C5) together imply

$$\xi > \frac{\xi T^{N^{is}}}{\xi T^{N^{is}} + (1-\xi)\mu_L T^W} \Leftrightarrow \frac{T^{S^{is}}}{1-\mu_L} > \frac{T^{N^{is}}}{\mu_L}. \tag{C6}$$

Likewise, combining (C4) with the other first-order condition, (3.25), yields

$$\xi > \frac{\xi T^{S^{is}}}{\xi T^{S^{is}} + (1-\xi)(1-\mu_L)T^{W^{is}}} \Leftrightarrow \frac{T^{N^{is}}}{\mu_L} > \frac{T^{S^{is}}}{1-\mu_L}. \tag{C7}$$

This contradicts (C6). Hence, in moving to free trade both, North and South, will not be induced to reduce their pollution levels simultaneously. Following the same steps it could be shown that trade and incomplete specialization will also not lead to a simultaneous increase in pollution in both the countries.

Hence, as countries move from autarky to free trade, if pollution rises in one country, it would fall in the other.

Step 2: It is now shown that, indeed, pollution in the South rises and that in the North falls as countries move to the free trade regime (with FPE), i.e., the inequalities in both (C1) and (C2) hold. From Step 1 it is clear that (C6) is necessary for this to be true. In what follows it is proven that (C6) is also sufficient for this to be true.

This result is also derived by contradiction. Let us suppose that (C6) holds. Next, also suppose that pollution in the North rises and that in the South falls as countries move from autarky to free trade. The latter is implied by

$$\frac{\gamma T^{N^{is}}}{\bar{T}^N - T^{N^{is}}} > \xi > \frac{\gamma T^{S^{is}}}{\bar{T}^S - T^{S^{is}}}.$$

Then, from the first-order condition (3.24) for the North

$$\xi - \frac{\gamma T^{N^{is}}}{\bar{T}^N - T^{N^{is}}} = \frac{\gamma T^{S^{is}}}{\bar{T}^N - T^{N^{is}}} - \frac{\xi T^{S^{is}}}{\xi T^{N^{is}} + (1-\xi)\mu_L T^{W^{is}}} < 0. \tag{C8}$$

Similar to the manipulations done earlier, multiply the numerator of the r.h.s. by T^N/T^S which yields that

$$\begin{aligned} \frac{\gamma T^{N^{is}}}{\bar{T}^N - T^{N^{is}}} &< \frac{\xi T^{N^{is}}}{\xi T^{N^{is}} + (1-\xi)\mu_L T^{W^{is}}} \\ \Rightarrow \xi < \frac{\xi T^{N^{is}}}{\xi T^{N^{is}} + (1-\xi)\mu_L T^{W^{is}}} &\Leftrightarrow \frac{T^{S^{is}}}{1-\mu_L} < \frac{T^{N^{is}}}{\mu_L}. \end{aligned} \tag{C9}$$

This contradicts (C6).

Similarly, for the South, from (3.25) one gets

$$\frac{\gamma T^{S^{is}}}{\bar{T}^S - T^{S^{is}}} > \frac{\xi T^{S^{is}}}{\xi T^{S^{is}} + (1-\xi)(1-\mu_L)T^{W^{is}}} \Rightarrow \frac{T^{N^{is}}}{\mu_L} > \frac{T^{S^{is}}}{1-\mu_L}. \tag{C10}$$

This also contradicts (C6). Thus, (C6) is both necessary and sufficient for both (C1) and (C2) to hold.

It now remains to be shown that (C6) does, in fact, hold at the FPE equilibrium. Note that FPE implies $\tau^N = \tau^S$. Moreover, from (3.20) in the text it follows that $\partial p^w/\partial T^N = \partial p^w/\partial T^S$. With North (South) being a net importer (exporter) of good Y, $(D_y^N - Q_y^N) > 0$ and $(Q_y^S - D_y^S) > 0$. From these relationships, it is easy to see that

$$\tau^N - (D_y^N - Q_y^N)\frac{\partial p^w}{\partial T^N} > \tau^S + (Q_y^S - D_y^S)\frac{\partial p^w}{\partial T^S},$$

which can be expressed as a function of the policy variables to yield the condition

$$\begin{aligned} T^S + \xi\left(T^N + \lambda\frac{\bar{L}^N}{\bar{L}^W}T^W\right) &> T^N + \xi\left(T^S + \lambda\frac{\bar{L}^S}{\bar{L}^W}T^W\right) \\ \Leftrightarrow 2\mu_L T^{S^{is}} &> 2(1-\mu_L)T^{N^{is}} \\ \Leftrightarrow \frac{T^{S^{is}}}{1-\mu_L} &> \frac{T^{N^{is}}}{\mu_L}. \end{aligned}$$

Thus, the results in Step 1 and Step 2 imply that (a) is proven. Moreover, from the last inequality (b) is also proven.

Appendix D

In this appendix the necessary and sufficient conditions for both North and South to have complete specialization as they open up free trade are derived.

To derive these conditions we introduce the variable π^{j^o} $(j = N, S)$, which is the terms-of-trade facing country j at the borderline between the diversification and complete specialization (in production) regimes. Then, for country j, $\pi^{j^o} = \pi^{j^o}((\rho^o(T^j/\bar{L}^j))$, where ρ^{j^o} is the solution to equilibrium pollution charge/wage ratio at the complete specialization equilibrium. Utilizing the closed-form solutions for $T^{N^{cs}}$ and $T^{S^{cs}}$ at complete specialization equilibrium (given in (3.42)), we have

$$\pi^{N^o} = \frac{\kappa_y}{\kappa_x}\left(\frac{(1-\alpha_x)}{\alpha_x}\frac{\bar{L}^S}{\delta^N \bar{T}^N}\right)^{\alpha_x - \alpha_y}, \quad \text{(D1)}$$

$$\pi^{S^o} = \frac{\kappa_y}{\kappa_x}\left(\frac{(1-\alpha_y)}{\alpha_y}\frac{\bar{L}^S}{\delta^S \bar{T}^S}\right)^{\alpha_x - \alpha_y}, \quad \text{(D2)}$$

where $\delta^N \equiv a(1-\alpha_x)/(\gamma + a(1-\alpha_x))$ and $\delta^S \equiv (1-a)(1-\alpha_y)/(\gamma + (1-a)(1-\alpha_y))$ and δ^S. The above expressions, together with the fact that good X (Y) is North's (South's) exportable, the ranking of the commodity terms-of-trade which will imply that both countries experience terms-of-trade gains and, hence, move to complete specialization are:

$$p^o < \pi^{N^o}(\cdot); \tag{D3}$$

$$p^o > \pi^{S^o}(\cdot). \tag{D4}$$

Utilizing the expressions for $p^o(\cdot)$ in (3.33), for π^{N^o} and π^{S^o} in (D1) and (D2) and substituting for the closed-form solutions for $T^{N^{cs}}$ and $T^{S^{cs}}$ from (3.42)), (D3) and (D4) respectively imply,

$$\begin{aligned}
\frac{(1-a)}{a}\frac{\bar{L}^N}{\bar{L}^S}\left(\delta^N\frac{\bar{T}^N}{\bar{L}^N}\right)^{1-\alpha_x}\left(\delta^S\frac{\bar{T}^S}{\bar{L}^S}\right)^{-(1-\alpha_y)} &< \frac{\kappa_y}{\kappa_x}\left(\frac{1-\alpha_x}{\alpha_x}\right)^{\alpha_x-\alpha_y}\left(\delta^N\frac{\bar{T}^N}{\bar{L}^N}\right)^{-(\alpha_x-\alpha_y)} \\
\Leftrightarrow \frac{(1-a)}{a}\frac{\bar{L}^N}{\bar{L}^S}\frac{\kappa_x}{\kappa_y}\left(\frac{\alpha_x}{1-\alpha_x}\right)^{\alpha_x-\alpha_y} &< \left(\frac{\delta^S}{\delta^N}\right)^{1-\alpha_y}\left(\frac{\bar{T}^S/\bar{L}^S}{\bar{T}^N/\bar{L}^N}\right)^{1-\alpha_y}; \qquad \text{(D5)} \\
\frac{(1-a)}{a}\frac{\bar{L}^N}{\bar{L}^S}\left(\delta^N\frac{\bar{T}^N}{\bar{L}^N}\right)^{1-\alpha_x}\left(\delta^S\frac{\bar{T}^S}{\bar{L}^S}\right)^{-(1-\alpha_y)} &> \frac{\kappa_y}{\kappa_x}\left(\frac{1-\alpha_y}{\alpha_y}\right)^{\alpha_x-\alpha_y}\left(\delta^S\frac{\bar{T}^S}{\bar{L}^S}\right)^{-(\alpha_x-\alpha_y)} \\
\Leftrightarrow \frac{(1-a)}{a}\frac{\bar{L}^N}{\bar{L}^S}\frac{\kappa_x}{\kappa_y}\left(\frac{\alpha_y}{1-\alpha_y}\right)^{\alpha_x-\alpha_y} &> \left(\frac{\delta^S}{\delta^N}\right)^{1-\alpha_x}\left(\frac{\bar{T}^S/\bar{L}^S}{\bar{T}^N/\bar{L}^N}\right)^{1-\alpha_x}. \qquad \text{(D6)}
\end{aligned}$$

The conditions in (D5) and (D6) together constitute both necessary and sufficient conditions for complete specialization. Further, together the two yield that

$$\frac{\alpha_y(1-\alpha_x)}{(1-\alpha_y)\alpha_x}\frac{\delta^S}{\delta^N}\frac{\bar{T}^S/\bar{L}^S}{\bar{T}^N/\bar{L}^N} > 1, \tag{D7}$$

which is used in drawing a comparison of relative resource price/wage ratio between North and South at the free trade equilibrium in section 3.4.2 of the text.

In the next appendix both (D5) and (D6) are used in comparing the autarky and free trade equilibrium commodity terms-of-trade of both North and South.

Appendix E

Given the necessary and sufficient condition for complete specialization in (D5)-(D6), it is shown that a move to the free trade regime implies that South will always have a commodity terms-of-trade gain, whilst North may gain or lose. For this, recall that $p^{Nat} = p^{Nat}(\bar{T}^N/\bar{L}^N)$ and $p^{Sat} = p^{Sat}(\bar{T}^S/\bar{L}^S)$ in (3.8) denote autarky equilibrium prices for North and South, and $p^o = p^o(\bar{T}^N/\bar{L}^N, \bar{T}^S/\bar{L}^S)$ from (3.33) is the commodity terms-of-trade at the free trade (specialized) equilibrium. Moreover, given $\alpha_x > \alpha_y$ and $a \in (0,1)$, the following inequality follows

$$\begin{aligned} \frac{\alpha_x}{1-\alpha_x} > \frac{a\alpha_x + (1-a)\alpha_y}{a(1-\alpha_x)+(1-a)(1-\alpha_y)} (\equiv \lambda) > \frac{\alpha_y}{1-\alpha_y} \\ \Rightarrow \frac{(1-\alpha_y)\lambda}{\alpha_y} > \frac{(1-\alpha_x)\lambda}{\alpha_x}, \end{aligned} \tag{E1}$$

which is also used in deriving the various proofs below.

In what follows the case of the South is exposed first.

That the movement from autarky to free trade will entail a commodity terms-of-trade gain for the South is implied by

$$p^o(\cdot) > p^{Sat}$$

$$\Leftrightarrow \frac{(1-a)}{a}\frac{\bar{L}^N}{\bar{L}^S}\left(\delta^N\frac{\bar{T}^N}{\bar{L}^N}\right)^{1-\alpha_x}\left(\delta^S\frac{\bar{T}^S}{\bar{L}^S}\right)^{-(1-\alpha_y)} > \frac{\kappa_y}{\kappa_x}\lambda^{\alpha_x-\alpha_y}\left(\delta\frac{\bar{T}^S}{\bar{L}^S}\right)^{-(\alpha_x-\alpha_y)} \tag{E2}$$

$$\Leftrightarrow \frac{(1-a)}{a}\frac{\bar{L}^N}{\bar{L}^S}\left(\frac{\delta^N}{\delta^S}\right)^{1-\alpha_x}\frac{\kappa_x}{\kappa_y}\lambda^{\alpha_x-\alpha_y}\left(\frac{\delta}{\delta^S}\right)^{\alpha_x-\alpha_y} > \left(\frac{\bar{T}^S/\bar{L}^S}{\bar{T}^N/\bar{L}^N}\right)^{1-\alpha_x}. \tag{E3}$$

The expression in (E2) follows by substituting the closed-form solutions for T^{Ncs} and T^{Scs} from (3.42) and denoting $a(1-\alpha_x)/(\gamma+a(1-\alpha_x)) \equiv \delta^N$, $((1-a)(1-\alpha_y))/(\gamma+(1-a)(1-\alpha_y)) \equiv \delta^S$. Also, let $(a(1-\alpha_x)+(1-a)(1-\alpha_y))/((\gamma+a(1-\alpha_x)+(1-a)(1-\alpha_y))) \equiv \delta$, and λ is as defined already in Appendix A. We now show that the inequality in (E3) is satisfied.

From the definitions of δ^S and δ, it follows that $\delta/\delta^S > 1$. Moreover, the inequality in (E1) implies that $\lambda > \alpha_y/(1-\alpha_y)$. In view of these relations the l.h.s. of (E3) is greater than

$$\frac{(1-a)}{a}\frac{\bar{L}^N}{\bar{L}^S}\left(\frac{\delta^N}{\delta^S}\right)^{1-\alpha_x}\frac{\kappa_x}{\kappa_y}\left(\frac{\alpha_y}{1-\alpha_y}\right)^{\alpha_x-\alpha_y} > \left(\frac{\bar{T}^S/\bar{L}^S}{\bar{T}^N/\bar{L}^N}\right)^{1-\alpha_x}. \tag{E4}$$

in view of (D6). Hence, (E3) holds and $p^o > p^{Sat}$.

Analogously, North will have an unambiguous terms-of-trade improvement if

$$p^o < p^{Nat}$$

$$\Leftrightarrow \frac{(1-a)}{a}\frac{\bar{L}^N}{\bar{L}^S}\left(\delta^N\frac{\bar{T}^N}{\bar{L}^N}\right)^{1-\alpha_x}\left(\delta^S\frac{\bar{T}^S}{\bar{L}^S}\right)^{-(1-\alpha_y)} < \frac{\kappa_y}{\kappa_x}\lambda^{\alpha_x-\alpha_y}\left(\delta\frac{\bar{T}^N}{\bar{L}^S}\right)^{-(\alpha_x-\alpha_y)} \tag{E5}$$

$$\Leftrightarrow \frac{(1-a)}{a}\frac{\bar{L}^N}{\bar{L}^S}\left(\frac{\delta^N}{\delta^S}\right)^{1-\alpha_y}\frac{\kappa_x}{\kappa_y}\lambda^{\alpha_x-\alpha_y}\left(\frac{\delta}{\delta^N}\right)^{\alpha_x-\alpha_y} < \left(\frac{\bar{T}^S/\bar{L}^S}{\bar{T}^N/\bar{L}^N}\right)^{1-\alpha_y}. \tag{E6}$$

This ranking may or may not hold, since from (E1) and the definitions of δ^N and δ, $\alpha_x/(1-\alpha_x) > \lambda$ and $\delta/\delta^N < 1$. In view of these relations, the l.h.s. of (E6) may be less or greater than

$$\frac{(1-a)}{a}\frac{\bar{L}^N}{\bar{L}^S}\left(\frac{\delta^N}{\delta^S}\right)^{1-\alpha_y}\frac{\kappa_x}{\kappa_y}\left(\frac{\alpha_x}{1-\alpha_x}\right)^{\alpha_x-\alpha_y}\left(\frac{\delta}{\delta^N}\right)^{\alpha_x-\alpha_y} < \left(\frac{\bar{T}^S/\bar{L}^S}{\bar{T}^N/\bar{L}^N}\right)^{1-\alpha_y}. \tag{E7}$$

The last inequality follows from (D5). Thus, in general $p^o \lesseqgtr p^{Nat}$.

In particular, it follows from the inequalities in (E6)-(E7) that $p^o \lesseqgtr p^{Nat}$ as

$$\left(\lambda\frac{\delta}{\delta^N}\right)^{\alpha_x-\alpha_y} \lesseqgtr \left(\frac{\alpha_x}{1-\alpha_x}\right)^{\alpha_x-\alpha_y}$$

$$\Leftrightarrow \frac{[a\alpha_x+(1-a)\alpha_y][\gamma+a(1-\alpha_x)]}{[\gamma+a(1-\alpha_x)+(1-a)(1-\alpha_y)][a(1-\alpha_x)]} \lesseqgtr \frac{\alpha_x}{1-\alpha_x}$$

$$\Leftrightarrow (1-a)\gamma\alpha_y \lesseqgtr a(1-a)\left(\alpha_x(1-\alpha_y)-\alpha_y(1-\alpha_x)\right) \Leftrightarrow \gamma \lesseqgtr a\left(\frac{\alpha_x-\alpha_y}{\alpha_y}\right). \tag{E8}$$

Thus, only when $\gamma < a\left(\frac{\alpha_x-\alpha_y}{\alpha_y}\right)$, it follows that $p^o < p^{Nat}$ and North has clear terms-of-trade gains. Otherwise, may lose or gain in its terms-of-trade.

Appendix F

It is shown here that the standard commodity terms-of-trade effect entails welfare gains for both North and South.

We take up the case for the North first. From the indirect welfare functions in (3.9) and (3.36),

$$U^{Ncs}\Big|_{T^N=T^{Nat}} - U^{Nat}\Big|_{T^N=T^{Nat}} = \Big[a\ln a + (1-a)\ln(1-a) + \ln I^{Ncs}(\cdot) - (1-a)\ln p^o(\cdot)$$
$$+\gamma\ln(\bar{T}^N - T^{Nat})\Big] - \Big[a\ln a + (1-a)\ln(1-a) + \ln I^{Nat}(\cdot)$$
$$-(1-a)\ln p^{Nat}(\cdot) + \gamma\ln(\bar{T}^N - T^{Nat})\Big]. \qquad \text{(F1)}$$

Utilizing the expressions for p^{Nat} in (3.8) and p^o in (3.33), making substitution for $T^N = T^{Nat}$ from (3.12), using the definition of ξ and, finally, adding and subtracting $(1-a)\ln\left(\frac{\alpha_x}{1-\alpha_x}\right)^{\alpha_x-\alpha_y}$, the r.h.s. reduces to

$$-(1-a)\ln\left(\frac{(1-a)}{a}\frac{\bar{L}^N}{\bar{L}^S}\frac{\kappa_x}{\kappa_y}\left(\frac{\alpha_x}{1-\alpha_x}\right)^{\alpha_x-\alpha_y}\right) + (1-a)\ln\left(\frac{\frac{a(1-\alpha_x)+(1-a)(1-\alpha_y)}{\gamma+a(1-\alpha_x)+(1-a)(1-\alpha_y)}\cdot\frac{\bar{T}^S}{\bar{L}^S}}{\frac{a(1-\alpha_x)+(1-a)(1-\alpha_y)}{\gamma+a(1-\alpha_x)+(1-a)(1-\alpha_y)}\cdot\frac{\bar{T}^N}{\bar{L}^N}}\right)$$
$$-[a\alpha_x + (1-a)\alpha_y]\ln\left(\frac{\alpha_x}{a\alpha_x+(1-a)\alpha_y}\right) + [a(1-\alpha_x)+(1-a)(1-\alpha_y)]\cdot$$
$$\ln\left(\frac{a(1-\alpha_x)+(1-a)(1-\alpha_y)}{1-\alpha_x}\right). \qquad \text{(F2)}$$

In view of the necessary and sufficient condition for complete specialization by the North, that is, (D5) in Appendix D, the sum of the first two terms in (F2) is positive. What remains to be shown is that the sum of the remaining terms is also positive. To prove this, let

$$-[a\alpha_x + (1-a)\alpha_y]\cdot\ln\left(\frac{\alpha_x}{a\alpha_x+(1-a)\alpha_y}\right)$$
$$+[a(1-\alpha_x)+(1-a)(1-\alpha_y)]\cdot\ln\left(\frac{a(1-\alpha_x)+(1-a)(1-\alpha_y)}{1-\alpha_x}\right) \equiv h^N,$$

then, for any given α_x, $h^N(\cdot)$ could be re-expressed as

$$= \; -h_1^N\ln\left(\frac{\alpha_x}{a\alpha_x+(1-a)\alpha_y}\right) + h_2^N\ln\left(\frac{a(1-\alpha_x)+(1-a)(1-\alpha_y)}{1-\alpha_x}\right),$$

where $h_1^N = a\alpha_x + (1-a)\alpha_y$ and $h_2^N = a(1-\alpha_x) + (1-a)(1-\alpha_y)$.

Next, it is shown that $dh^N/d\alpha_x > 0$. We get

$$\begin{aligned}\frac{dh^N}{d\alpha_x} &= -h_1^N\left(\frac{a\alpha_x+(1-a)\alpha_y}{\alpha_x}\right)\left(\frac{a\alpha_x+(1-a)\alpha_y-a\alpha_x}{(a\alpha_x+(1-a)\alpha_y)^2}\right)\\&+h_2^N\left(\frac{1-\alpha_x}{a(1-\alpha_x)+(1-a)(1-\alpha_y)}\right)\left(\frac{(1-a)(1-\alpha_y)}{(1-\alpha_x)^2}\right).\end{aligned} \tag{F3}$$

whose r.h.s. reduces to

$$(1-a)\left[\frac{(1-\alpha_y)}{(1-\alpha_x)}-\frac{\alpha_y}{\alpha_x}\right]>0 \quad \text{in view of } \alpha_x-\alpha_y>0. \tag{F4}$$

Since the minimum value that α_x can take in the limit is α_y, it follows that

$$\begin{aligned}\text{Min } h^N\Big|_{\alpha_x=\alpha_y} &= 0\\ \Rightarrow h^N > \text{Min } h^N &= 0.\end{aligned} \tag{F5}$$

The result in (F5) together with the sum of the first two terms in (F2) positive implies that $U^{Ncs}\Big|_{T^N=T^{Nat}} - U^{Nat}\Big|_{T^N=T^{Nat}} > 0$.

Similarly, for the South,

$$\begin{aligned}U^{Scs}\Big|_{T^S=T^{Sat}} - U^{Sat}\Big|_{T^S=T^{Sat}} &= \left[a\ln a+(1-a)\ln(1-a)+\ln I^{Scs}(\cdot)-(1-a)\ln p^o(\cdot)\right.\\&\left.+\gamma\ln(\bar{T}^S-T^{Sat})\right]-\left[a\ln a+(1-a)\ln(1-a)+\ln I^{Sat}(\cdot)\right.\\&\left.-(1-a)\ln p^{Sat}(\cdot)+\gamma\ln(\bar{T}^S-T^{Sat})\right],\end{aligned} \tag{F6}$$

from (3.9) and (3.37). This reduces to

$$\begin{aligned}&a\ln\left(\frac{(1-a)}{a}\frac{\bar{L}^N}{\bar{L}^S}\frac{\kappa_x}{\kappa_y}\left(\frac{\alpha_y}{1-\alpha_y}\right)^{\alpha_x-\alpha_y}\right)-a\ln\left(\frac{\frac{a(1-\alpha_x)+(1-a)(1-\alpha_y)}{\gamma+a(1-\alpha_x)+(1-a)(1-\alpha_y)}\cdot\frac{\bar{T}^S}{\bar{L}^S}}{\frac{a(1-\alpha_x)+(1-a)(1-\alpha_y)}{\gamma+a(1-\alpha_x)+(1-a)(1-\alpha_y)}\cdot\frac{\bar{T}^N}{\bar{L}^N}}\right)\\&-[a(1-\alpha_x)+(1-a)(1-\alpha_y)]\ln\left(\frac{1-\alpha_y}{a(1-\alpha_x)+(1-a)(1-\alpha_y)}\right)+[a\alpha_x+(1-a)\alpha_y]\cdot\\&\ln\left(\frac{a\alpha_x+(1-a)\alpha_y}{\alpha_y}\right)\end{aligned} \tag{F7}$$

by making similar substitutions as in (F1) and adding and subtracting $a\ln\left(\frac{\alpha_y}{1-\alpha_y}\right)^{\alpha_x-\alpha_y}$ in the r.h.s..

From (D6) in Appendix D, it is straightforward that the sum of the first two terms in (F7) is positive. As for the sum of the remaining two terms, like in case of the North, let

$$-[a(1-\alpha_x)+(1-a)(1-\alpha_y)]\cdot\ln\left(\frac{1-\alpha_y}{a(1-\alpha_x)+(1-a)(1-\alpha_y)}\right)$$
$$+[a\alpha_x+(1-a)\alpha_y]\cdot\ln\left(\frac{a\alpha_x+(1-a)\alpha_y}{\alpha_y}\right)\equiv h^S.$$

Next, express

$$h^S=-h_1^S\ln\left(\frac{1-\alpha_y}{a(1-\alpha_x)+(1-a)(1-\alpha_y)}\right)+h_2^S\ln\left(\frac{a\alpha_x+(1-a)\alpha_y}{\alpha_y}\right),$$

where $h_1^S=[a(1-\alpha_x)+(1-a)(1-\alpha_y)]$ and $h_2^S=[a\alpha_x+(1-a)\alpha_y]$.

It is now easy to show that

$$\frac{dh^S}{d\alpha_y} = a\left[\frac{1-\alpha_x}{1-\alpha_y}-\frac{\alpha_x}{\alpha_y}\right]<0.$$

This implies that

$$h^S > \text{Min } h^S\Big|_{\alpha_y=\alpha_x} = 0. \tag{F8}$$

(F8), together with the sum of first two terms in (F7) positive, proves that $U^{Scs}\Big|_{T^S=T^{Sat}} - U^{Sat}\Big|_{T^S=T^{Sat}} > 0.$

Chapter 4

Interaction between Trade and Environment Policies with Special Interest Politics

4.1 Introduction

The basic tenets of economics view that an effective rule based system of multilateral trade and investment is welfare improving, because it achieves economic integration by utilizing the principles of competitiveness and comparative advantage. However, in its present form, the efficacy of international trade to accomplish higher welfare for all and sustainable development is a topic of debate worldwide. There is adequate evidence to indicate that, in both international and domestic policy circles, the mobilization of pressure group politics around the economic themes is just as important as the need for analytically legitimate economic claims or rationale.[1] Observably, incumbent governments in representative democracies set

[1] A look at the events of the last few years, e.g. the third World Trade Organization (WTO) Ministerial Conference in Seattle in December 1999, and the United Nations Conference on Trade and Development (UNCTAD) X in Bangkok in February 2000, shows that the debates have not been driven by economic principles alone, but have been mainstreamed (involving non-governmental organizations) and politicized to

policies to maximize "political support" rather than the welfare of its citizenry.

This chapter attempts to examine the impact of political lobbying with reference to trade and environment policies. Specifically, it contains an analysis of *interdependencies* in the determination of trade and environment policies when they meet in the legislative arena, in the presence of special-interest politics.

In the theoretical literature, the concerns about how lobbying could distort policies have led to the development of models that view trade or environment policies as an outgrowth of a political process, and that do not lead to maximization of representative agent's welfare. As reviewed in Chapter 2, these models treat industry or environmental groups as lobbying for political favors from the incumbent government by offering contributions to it to sway the policy outcomes in their favor (see for example Grossman and Helpman (1994, 1995, 1996) (henceforth called G-H) in context of trade policy, and Fredriksson (1997a, 1997b), Aidt (1998. 2000) and Schleich (1999) and Schleich and Orden (2000) in the context of environment policy). The contributions are linked to specific policy stance of the government. On the other hand, the government is not a benevolent maximizer of social welfare. It sets policies to maximize political support, taken to be a weighted average of pure social welfare and the welfare of the lobbies. Hence, these models are said to follow a "political support" approach to incorporate political economy considerations. Typically, these do not explicitly model the process of election.[2] It is this approach that we adopt for our analysis.

gain attention at the larger WTO Agenda.

This holds true for domestic policy circles as well. In India and other developing countries, tariff protection offered to domestic import-competing industries (textiles, fertilizers, heavy machinery, metals and minerals), energy and input subsidies to agriculture, job quotas for specific social groups, all point toward an overwhelming influence of political economy on specific government policy stance.

News reports on the Indian aquaculture industry indicate how the 11 December, 1996 Supreme Court of India ruling banning aquaculture industries/shrimp culture, effective March 31, 1997, on environmental grounds has faced opposition from the shrimp-exporting industry, often culminating into anti-prawn culture agitation (WFF 1999). Subsequently, the provincial governments have been relenting and the deadline for the shrimp industry to begin dismantling shrimp ponds has been postponed twice. In spite of the severity of the Court's decision, India's powerful shrimp industry has tried to circumvent the Supreme Court ruling by lobbying with the government, challenging the Coastal Regulation Zone legislation (Quarto and Cissna (1997)).

[2]An alternative approach, adopted by Hillman (1989), Magee et.al. (1989) and Hillman and Ursprung

As mentioned earlier, in the specific context of environment, a volume of analytical work has recently emerged on how political-economy factors impinge on policies and impact the state of the environment. A majority of these have the focus on lobbying for either trade or environment policy, but *not both* (e.g. Hillman and Ursprung (1992), Fredriksson (1997a, 1997b, 1999), and Aidt (1998, 2000)).[3] The detailed survey of literature on the subject is included already in Chapter 2. Broadly speaking, these models analyze trade-environment linkages in terms of the effect of a politically determined trade policy on pollution or, alternatively, the impact of the politically chosen environmental regulation on trade, depending on whether lobbies choose to influence the trade *or* environment policy stance of the government.

Clearly, in real economies, lobbies have stakes in both the trade and environment policies and, therefore, it is more appropriate to postulate that they negotiate with the government over both. For example, organized industry groups in the import-competing sector stand to lose from stricter pollution regulation on account of higher costs of production, and benefit from enhanced import-protection. Accordingly, they have the incentive to press the government to reduce pollution taxes and raise tariffs on imports. Just the opposite holds true for environmentally motivated groups. A change in a basic parameter facing an economy may induce the politically motivated government to reduce/increase both trade protection and pollution tax or to reduce one and increase the other. Characterization of policy interdependencies is the focus of this chapter.

As discussed in Chapter 2, Schleich (1999) and Schleich and Orden (2000) utilize the G-

(1992), attempts to explain the outcome of a political process when there is "political competition" amongst rival candidates. Competing parties make pre-announcements on the policy proposals they plan to implement upon being elected. In response, organized lobbies evaluate their members' prospects under alternative policy packages and make financial contributions to the party (that offers it the highest pay-off) to enhance the probability that their favorite candidate wins the elections. The underlying intention is to impact the election outcome through financial contributions (see G-H (1994) for discussion on this).

[3]Some papers also extend the analysis to include strategic interaction between the governments of the countries over trade and environment policies, when both domestic and international special-interest groups are influential (e.g. G-H (1995) in the context of trade policy, and Fredriksson (1999) and Aidt (2000) for environment policy).

H's political economy model to analyze lobbying over both (or one of) – domestic (production and consumption) and trade policies, in the context of small- and large-open economies respectively. However, the focus there is on characterization of domestic and trade policies at the political equilibrium in terms of how these serve different objectives. The policy goals are – gaining political support of organized lobby groups, addressing environmental externalities at local and global levels and achieving more favorable terms-of-trade. The politically determined outcomes are compared with the benchmark case of socially optimum policies.

By adopting the same basic political-economy framework of G-H (1994) this chapter carries out a more focussed analysis of the interaction between the two policy instruments, in the context of a small import-competing industry as compared to Schleich (1999) or Schleich and Orden (2000).

Further, similar to G-H model, Fredriksson (1997a, 1997b), Schleich (1999) and Schleich and Orden (2000) assume that the government does not have any bargaining power vis-a-vis the lobbies. In other words, the lobbies are the 'principals' having all bargaining power and the government is the 'agent' having zero bargaining power. We improve upon this by assuming that both the government and the lobby possess positive bargain power vis-a-vis each other. The concept of Nash-bargaining is used to capture this.

Additionally, the chapter studies the impact on equilibrium trade and environmental policies (and interdependencies between them) of exogenous changes in basic parameters facing the economy.

In the absence of lobbying, free trade and a Pigouvian tax constitute the first-best policy package for a small-open economy. This is our benchmark. Present lobbying, interesting deviations emerge. In some instances they are apparently counter-intuitive. The major findings of the analysis of this chapter are as follows:

1. When only the environment policy is 'political' – i.e. politically manipulable by indus-

try lobby - the pollution tax is set at a level lower than that of the Pigouvian tax. If, instead, the lobby can influence trade policy only, the government provides a positive level of protection to the domestic import-competing sector.[4]

But, when both trade and environment policies are political, there is strategic interaction between the two instruments, and, it displays asymmetry. The pollution tax is a strategic complement of import tariff, i.e., government offsets a higher import tariff by raising the level of the pollution tax. However, tariff is a strategic substitute of pollution tax: an increase in the pollution tax induces the government to lower the level of import protection. (The reason behind this asymmetry will be discussed later).

2. Given that both policy instruments are political, compared to the benchmark case, the government "concedes" with respect to trade policy - i.e. it offers a positive tariff protection. But surprisingly it *may not* concede on environment policy, i.e. it may supplement a protectionist trade policy with a pollution tax *higher* than the Pigouvian level. However, there is an upper bound on the tariff protection. Similarly, when equilibrium pollution tax is higher than the Pigouvian tax, there is *cap* on the magnitude by which it could exceed the latter. The pollution at the political equilibrium is always higher than the socially optimal level, irrespective of environment policy being more or less stringent at the political equilibrium than at the social optimum.

3. Some of the comparative statics of the model are as follows. As long as there is only one organized lobby the relative bargaining strengths of the government and the lobby do not impact the equilibrium level of tax or tariff. They merely determine the division of the surplus between the two groups. Further, an exogenous increase in the preference for "cleaner" environment induces the government to raise the tax on pollution and lower the tariff protection. Clearly, the impact on the environment is positive.

[4]These implications are quite intuitive and straightforward to see.

The equilibrium level of import protection (measured as the difference between the domestic and world price of the importable good) is positively related to the world price of the importable good. The pollution tax may be inversely or positively related to the world price conditional on the price elasticity of output of the importable good. The effect of increase in the world price of the importable good on environment is negative, however.

In response to an exogenous increase in the relative weight on political contributions, the government raises the level of tariff protection. The effect on the environment policy is not clear, however. The level of pollution always increases.

4.2 The framework

Our analytical framework follows G-H (1994). Organized industrial lobbies offer contribution schedules to affect the policy stance of an electorally motivated government, and the government decides on its policies given these schedules. However, our model differs from theirs in three ways. First, instead of many industries at a time, we focus on one industry. Hence there is only one lobby. Second, we assume that the industrial lobby in the import-competing sector is capable of influencing more than one (related) policy at the same time. These are trade and environment policies. Third, the government is not simply at the "receiving end" but wields a bargaining power vis-a-vis the lobby. The analysis focuses on a small open economy trading at given world prices. We call it the "home country".

4.2.1 The economy

It has two production sectors. One produces a non-polluting numeraire good Y, which uses only labor as the input. The other produces good X using three inputs - labor, a sector-specific capital or land, and a sector-specific pollution-causing environmental/natural resource. Whilst labor is mobile between the two production sectors, sector-specific capital and natural resource are sectorally immobile. Perfect competition prevails in both sectors.

Good X is the home country's importable, with net imports represented by M_x. The price of good Y is normalized to one. The relative world price of good X is denoted by p^w. Denoting the import tariff rate by t, the domestic price of good X, by arbitrage, is $p = p^w(1+t) \equiv p(t)$.

Three groups inhabit the economy: workers (f), industrialists (i), and the government (g). Full employment of labor and specific capital is assumed. Let the total population of workers be $\bar{L}$. Only workers supply labor to the production sectors, with each offering one unit, implying $\bar{L} = L_x + L_y$, where L_x and L_y are the number of workers employed in sectors X and Y. The wage rate is denoted by w. Industrialists are the owners of the stock of sector-specific fixed factor, $\bar{K}_x$, and, therefore, have stakes in the reward/profit to the specific factor, represented by π. Moreover, workers are the only consumers of the two goods, X and Y, whilst industrialists consume only the numeraire good.[5]

Unlike in Chapter 3, the government does not regulate the physical quantity of the environmental resource, but, instead sets its charge (price), τ. (This is similar to C-T (1994, 1995).) The supply of the environmental resource is perfectly elastic. Hence the equilibrium quantity of environmental resource used, N_x, is demand-determined.

Tariff, t, is the other policy variable that government controls. The total revenues collected are equal to $\tau N_x + tp^w M_x$. These are transferred back to the economy in a lumpsum fashion. The government does not make any direct transfers to the firm. The pollution charge, the tariff or both are determined in the political-game.

Sector Y uses constant-returns production technology, and by choosing units appropriately the labor-output coefficient is assumed to be one. The supply of labor is sufficiently

[5]This is somewhat similar to the model of Roberts (1987) in a very different context, which assumes that a group of workers producing good i only consume goods produced by other workers. In the context of environment, this is the same as Aidt (1998) which considers the case of functionally specialized producers' and environmental lobbies.

large as to imply a positive output of the numeraire good in equilibrium. With perfect competition and free entry and exit, the equilibrium wage rate, w, is driven down to one in terms of the numeraire good Y. Sector X also uses a constant-returns technology in the three inputs, L_x, K_x, and N_x, and is Cobb-Douglas in form. With $\tilde{Q}_x$ denoting the output of good X, we have $\tilde{Q}_x = {L_x}^{\alpha}{N_x}^{\beta}\bar{K}_x^{1-\alpha-\beta}$. This could be re-expressed as

$$\frac{\tilde{Q}_x}{\bar{K}_x^{1-\alpha-\beta}} \equiv Q_x \quad = \quad {L_x}^{\alpha}{N_x}^{\beta}, \tag{4.1}$$

by normalizing $\bar{K}_x$ to one.

Profit maximization by firms yields the supply function $Q_x = Q_x(p(t), \tau)$, factor demand functions, $N_x = N_x(p(t), \tau)$ and $L_x = L_x(p(t), \tau)$, and the indirect profit function, $\pi = \pi(p(t), \tau)$. The specific analytical solutions are:

$$Q_x = \left(\frac{\alpha+\beta}{\kappa_x}\right)^{\frac{\alpha+\beta}{1-\alpha-\beta}} p(t)^{\frac{\alpha+\beta}{1-\alpha-\beta}} \tau^{-\frac{\beta}{1-\alpha-\beta}}; \tag{4.2}$$

$$N_x = \left(\frac{\alpha}{\beta}\tau\right)^{-\frac{\alpha}{\alpha+\beta}} Q_x^{\frac{1}{\alpha+\beta}} \equiv \beta\left(\frac{\alpha+\beta}{\kappa_x}\right)^{\frac{\alpha+\beta}{1-\alpha-\beta}} p(t)^{\frac{1}{1-\alpha-\beta}} \tau^{-\frac{1-\alpha}{1-\alpha-\beta}}; \tag{4.3}$$

$$L_x = \left(\frac{\alpha}{\beta}\tau\right)^{\frac{\beta}{\alpha+\beta}} Q_x^{\frac{1}{\alpha+\beta}} \equiv \alpha\left(\frac{\alpha+\beta}{\kappa_x}\right)^{\frac{\alpha+\beta}{1-\alpha-\beta}} p(t)^{\frac{1}{1-\alpha-\beta}} \tau^{-\frac{\beta}{1-\alpha-\beta}}; \quad \text{and} \tag{4.4}$$

$$\pi = (1-\alpha-\beta)\left(\frac{\alpha+\beta}{\kappa_x}\right)^{\frac{\alpha+\beta}{1-\alpha-\beta}} p(t)^{\frac{1}{1-\alpha-\beta}} \tau^{-\frac{\beta}{1-\alpha-\beta}}. \tag{4.5}$$

where $\kappa_x \equiv (\alpha/\beta)^{\frac{\beta}{\alpha+\beta}} + (\alpha/\beta)^{\frac{-\alpha}{\alpha+\beta}}$. Note that the amount of pollution is indicated by the magnitude of N_x. Also, the price elasticity of output exceeds or falls short of one as $\alpha + \beta \gtrless 1/2$. As will be seen, some results of our analysis are conditional on whether $\alpha + \beta \gtrless 1/2$.

By Hotelling's lemma,

$$\frac{\partial \pi}{\partial p(t)} = Q_x(\cdot), \quad \text{and} \quad \frac{\partial \pi}{\partial \tau} = -N_x(\cdot). \tag{4.6}$$

Moreover, given Cobb-Douglas technology, we have

$$\frac{\tau N_x}{p Q_x} = \beta, \tag{4.7}$$

the share of the natural resource. These relationships will be utilized later in the analysis.

The use of the natural resource in the import-competing sector X generates pollution that is proportional to its use. Hence, the magnitude of N_x measures the magnitude of pollution. Pollution is local.[6]

All workers have identical utility function. One part of it is quasi-linear with respect to goods X and Y. Further, it is quadratic with respect to the consumption of good X. Another part captures disutility from pollution. It is given by

$$U^f = c_y + \nu_x c_x - \frac{c_x^2}{2} - \tilde{\gamma} N_x, \quad \nu_x, \ \tilde{\gamma} > 0. \tag{4.8}$$

A consumer maximizes this subject to his budget constraint, $c_y + pc_x = I$, where I denotes consumer spending. Utility maximization problem yields a linear demand function for good X as $c_x = \nu_x - p$. The consumer surplus from the consumption of good X equals $u(c_x(p)) - pc_x(p) = c_x^2(p)/2$.

4.2.2 The political structure

Industrialists being the specific factor owners have a common interest in the reward to this factor, $\pi(\cdot)$. It is assumed that they are able to organize themselves for the purpose of lobbying. Call them lobby-x. One the other hand, the workers are not organized and they do not lobby. The industrial lobby is assumed to overcome the free-rider problem and coordinates campaign contributions for an incumbent government to implement a policy in its favor (Olson (1965)). As expected, the industrial lobby's welfare is increasing in import tariff and decreasing in pollution tax (see eq. (4.5)).

Our analysis does not model any explicit competition amongst politicians to gain office. Rather, the government is assumed to be facing an implicit opponent/challenger. It is assumed to maximize a weighted sum of social welfare and campaign contributions. On one

[6] Since our focus is on policy determination in the home country alone (rather than on policy interaction between countries), whether pollution is local or global does not have any qualitative bearing on the results.

hand, contributions from lobby-x are used toward campaign spending and to sway voters in its favor. On the other, an increase in social welfare increases the probability of re-election, given that the voters' population takes this into account in casting their vote for a candidate.

Unlike G-H (1994, 1995) in our model government wields bargaining power vis-a-vis the lobby, as does the lobby vis-a-vis the government. As in Binmore, Rubenstein and Wolinsky (1986) and Qiu (1999) we apply Nash-bargaining to characterize the interaction between the government and the lobby-x. Let $\lambda \in (0,1)$ and $(1-\lambda)$ represent the government's and lobby-x's bargaining power respectively.

In the absence of campaign contributions, the pay-offs of lobby-x and the government can be defined as

$$U^i = \pi(\tau, p(t)); \tag{4.9}$$

$$U^{sw} = \bar{L} + \bar{L}\frac{c_x(p(t))^2}{2} + \pi(\tau, p(t)) + tp^w M_x(\tau, p(t)) + \tau N_x(\tau, p(t)) - \gamma N_x(\tau, p(t)), \tag{4.10}$$

where "sw" stands for aggregate social welfare, $\bar{L}$ is the total wage income, $\bar{L}c_x^2(\cdot)/2$ and $\pi(\cdot)$ are aggregate consumer and producer surplus, $tp^w M_x(\cdot) + \tau N_x(\cdot)$ are the total tax/tariff revenues ploughed back to the economy, and $\gamma(\equiv \bar{L}\tilde{\gamma}) > 0$ is the economy-wide marginal pollution damage parameter.

In the presence of lobbying and campaign contributions, the pay-off function of the government is a weighted average of social welfare (as defined in (4.10)) and lobby-x's contributions, O_x:

$$U^g = U^{sw} + aO_x, \tag{4.11}$$

where $a > 0$ is the weight that government assigns to political contributions relative to that on social welfare. Define $\rho \equiv a/(1+a)$, which is the relative weight the politician attaches to the campaign contribution; ρ can be treated as the "politicization" parameter. The net payoff of lobby-x is given by $U^i - O_x$.

4.2.3 The stages of the game

There are three stages in the game played between the incumbent government and lobby-x. In the first stage the government and lobby jointly decide the contribution schedule, $O_x(p(t), \tau)$ through a process of Nash-bargaining.

In the second stage, the government chooses a pair (t^*, τ^*) on the contribution schedule $O_x(\cdot)$ that maximizes U^g. Having announced the policies, it receives from lobby-x the monetary contribution $O_x(t^*, \tau^*)$ associated with the chosen policy pair. Although the political game takes place in one-shot, it is assumed that the interest group does not renege on its promise to make monetary contributions in the second stage of the game.

In the third stage, production and consumption take place and the labor market clears.

4.3 The analysis

4.3.1 Social optimum

As a benchmark suppose that there is no politics and the government is a benevolent maximizer of aggregate social welfare. Then, clearly, a free trade policy ($t = 0$) and a Pigouvian tax on pollution input constitute the first-best policy package for this small open economy. The latter is the solution to the problem:

$$\underset{\tau}{\text{Max}} \quad U^{sw} \equiv \bar{L} + \bar{L}\frac{c_x^2(p^w)}{2} + \pi(\tau, p^w) + (\tau - \gamma)N_x(\tau, p^w),$$

which yields

$$\tau^o = \gamma, \tag{4.12}$$

where superscript "o" denotes socially optimal solutions.[7] Thus, in the absence of lobbying, pollution tax is set at the level of social marginal damage, γ, and there is full internalization of the environmental externality by the government.

We next bring in the presence of interest group politics. A description of the bargaining process follows.

4.3.2 The bargaining process

Nash-bargaining over $O_x(\tau, t)$ is represented by

$$\max_{O_x} \quad (\Delta U^{sw}(\tau,t) + aO_x)^{\lambda}(\Delta U^{i}(\tau,t) - O_x)^{1-\lambda}$$
$$\text{s.t.} \qquad O_x > 0, \tag{4.13}$$

where ΔU^{sw} and ΔU^{i} represent the change in the pay-off of the government and lobby-x respectively (excluding campaign offers from lobby to the government) in moving from the social optimum to a politically determined equilibrium. This yields

$$O_x = \lambda \Delta U^{i}(\cdot) - \frac{(1-\lambda)}{a}\Delta U^{sw}(\cdot) \tag{4.14}$$
$$= \lambda\left[\pi(\cdot) - \pi^{o}\right] - \frac{(1-\lambda)}{a}\left[\bar{L}\left(\frac{c_x^2(\cdot)}{2} - \frac{c_x^{o2}}{2}\right) + (\pi(\cdot) - \pi^{o}) + (\tau N_x(\cdot) - \tau^{o}N_x^{o}) + tp^{w}M_x(\cdot) - \gamma(N_x(\cdot) - N_x^{o})\right] \equiv O_x(\tau, t). \tag{4.15}$$

It is the solution to the first-stage bargaining game. As long as $\Delta U^{i} > 0$ and $\Delta U^{sw} < 0$ the contribution $O_x(\cdot) > 0$ for all λ and a.[8]

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[7] $\max_{\tau}|_{t=0} \quad U^{sw}$ yields the equilibrium condition

$$\frac{\partial \pi}{\partial \tau} + (\tau - \gamma)\frac{\partial N_x}{\partial \tau} + N_x = 0 \Leftrightarrow -N_x + (\tau - \gamma)\frac{\partial N_x}{\partial \tau} + N_x = 0 \quad \text{(from (4.6))},$$

which gives (4.12).

[8] We have $\Delta U^{sw} = U^{sw}(\tau, t) - U^{sw}(\gamma, 0) < 0$ since U^{sw} is maximized at $t = 0$ and $\tau = \gamma$. Moreover, it is easy to see that $\pi = \pi(\underset{(-)}{\tau}, \underset{(+)}{t})$. Thus, $\Delta U^{i}(\equiv \Delta\pi) = U^{i}(\tau, t) - U^{i}(\gamma, 0) > 0$ as long as $\tau \leq \gamma$ and $t > 0$. By continuity, it follows that $\Delta U^{i} > 0$ even when $\tau > \gamma$ as long as $|\tau - \gamma|$ is sufficiently small.

In (4.14) it is implicit that both τ and t are politically set. One could, however, consider special cases where only one policy instrument is political, either the pollution tax or the tariff rate, whilst the other is set to maximize social welfare. In such cases, the contribution functions will respectively be of the form: $O_x(\tau, 0)$ and $O_x(\gamma, t)$.

4.3.3 The political equilibria

We begin by considering situations where only one policy instrument - pollution tax or tariff - is political.[9]

Bargaining over environment policy

Let the government be committed to free trade (i.e. $t = 0$) whilst the pollution tax is political. It will be shown, as one would expect, that the pollution tax in the political equilibrium is always less than the Pigouvian tax.

Given $O_x = O_x(\tau, 0)$, the government solves the maximization problem:

$$\begin{aligned} \underset{\tau}{Max} \quad U^g &\equiv U^{sw}(\cdot) + aO_x(\cdot) \\ &= \bar{L} + \bar{L}\frac{c_x^2(\cdot)}{2} + \pi(\cdot) + (\tau - \gamma)N_x(\cdot) \\ &\quad + a\lambda[\pi(\cdot) - \pi^o] - (1 - \lambda)\left[\bar{L}\left(\frac{c_x^2(\cdot)}{2} - \frac{c_x^{o2}}{2}\right)\right. \\ &\quad \left. + \pi(\cdot) - \pi^o + (\tau - \gamma)N_x(\cdot) - (\tau^o - \gamma)N_x^o\right]. \end{aligned} \tag{4.16}$$

The first-order condition is:

$$a\frac{\partial \pi}{\partial \tau} + \left(\frac{\partial \pi}{\partial \tau} + (\tau - \gamma)\frac{\partial N_x}{\partial \tau} + N_x\right) = 0.$$

Notice that it is independent of λ. Using the Hotelling's lemma in (4.6) the above is equiv-

[9] However, the centerpiece of our analysis is the characterization of the full political equilibrium, where bargaining happens over both the policy instruments.

alent to

$$-\left(\frac{1-\alpha}{1-\alpha-\beta}\right)\left(\frac{\tau-\gamma}{\tau}\right)N_x - aN_x \quad = \quad 0. \tag{4.17}$$

This leads to the solution

$$\tau^e \quad = \quad \frac{(1-\alpha)\gamma}{1-\alpha+a(1-\alpha-\beta)} < \gamma, \tag{4.18}$$

where superscript "e" represents that there is bargaining over environment policy alone. Hence, the politically set environmental tax is below the socially optimal level. The second-order conditions are always met; for detailed derivation see Appendix A.

Bargaining over import tariffs

Suppose that the government is committed to optimally regulating the state of the environment, i.e., it sets $\tau = \tau^o \equiv \gamma$, the Pigouvian tax. But trade policy is "politically negotiable". It then solves

$$\begin{aligned} \underset{t}{\text{Max}} \quad U^g \quad &= \quad \bar{L} + \bar{L}\frac{c_x^2(\cdot)}{2} + \pi(\cdot) + tp^w M_x(\cdot) + a\lambda[\pi(\cdot) - \pi^o] \\ &\quad -(1-\lambda)\left[\bar{L}\left(\frac{c_x^2(\cdot)}{2} - \frac{c_x^{o\,2}}{2}\right) + \pi(\cdot) - \pi^o + tp^w M_x(\cdot)\right]. \end{aligned} \tag{4.19}$$

The first-order condition is:

$$\begin{aligned} aQ_x - t\left(\bar{L}p^w + \frac{\partial Q_x}{\partial t}\right) \quad &= \quad 0 \\ \Leftrightarrow aQ_x(\tau, t) - \frac{t}{1+t}\left[\bar{L}p(t) + \frac{\alpha+\beta}{1-\alpha-\beta}Q_x(\tau, t)\right] \quad &= \quad 0. \end{aligned} \tag{4.20}$$

Again, the bargaining power does not influence the choice of policy. The last expression is obtained by utilizing the Hotelling's lemma in (4.6), using definitions, $M_x = C_x - Q_x$, $C_x = \bar{L}c_x$, cancelling out terms and inserting value of the partial $\partial Q_x/\partial t$ from the solution in (4.2). Note that at $t = 0$, $\partial U^g/\partial t = aQ_x > 0$. This is because the deadweight loss from tariff is of second-order in magnitude whereas the marginal gain from campaign contributions is of first-order magnitude. This implies that $t > 0$ at the political equilibrium. (This is dealt with in greater detail later.)

By substituting for Q_x from (4.2) factoring out $((\alpha+\beta)/\kappa_x)^{\frac{\alpha+\beta}{1-\alpha-\beta}} \bar{L}p^{w\,\frac{\alpha+\beta}{1-\alpha-\beta}} \tau^{\frac{-\beta}{1-\alpha-\beta}} (1+t)^{\frac{\alpha+\beta}{1-\alpha-\beta}}$, the first-order condition in (4.20) can be restated as

$$m(t^f) \equiv -t^f \frac{\bar{L}p^{w\,\frac{1-2(\alpha+\beta)}{1-\alpha-\beta}} \gamma^{\frac{\beta}{1-\alpha-\beta}}}{\Gamma(1+t^f)^{\frac{\alpha+\beta}{1-\alpha-\beta}}} - \frac{\alpha+\beta}{1-\alpha-\beta} \frac{t^f}{1+t^f} + a \;=\; 0, \tag{4.21}$$

where "f" denotes the situation where lobbies influence trade policies alone, $\tau^f = \gamma$ by assumption and $\Gamma \equiv [(\alpha+\beta)/\kappa_x]^{\frac{\alpha+\beta}{1-\alpha-\beta}}$.

In view of (4.21), we get

Proposition 1:

$$\frac{t^f}{1+t^f} < \frac{a(1-\alpha-\beta)}{\alpha+\beta}.$$

That is, there is an upper bound on the tariff rate.

Appendix B proves that the solution to $t^f \in (0,1)$ exists, the "true" solution of t^f is unique and the second-order condition is met if

$$\text{either } (i)\ \alpha+\beta \le \frac{1}{2};\ \text{or } (ii)\ \rho \le \frac{1}{2}, \tag{R1}$$

where recall that $\rho \equiv a/(1+a)$ is the politician's weight on campaign contribution in its objective function. This condition may be viewed as a "regularity" condition. Intuitively, this says that the price elasticity of output of the importable good be less than one, or that the elasticity be high *and* the degree of politicization be *not* high enough. We assume that (R1) holds. Figure 4.1 illustrates it in the (α, β) space.

The equilibrium outcomes under the single-instrument cases are summed up in Proposition 2.

Proposition 2: *(i) When only the pollution tax is politically determined, the government sets it below the social optimum. Alternatively, if only the import tariff is political, a positive*

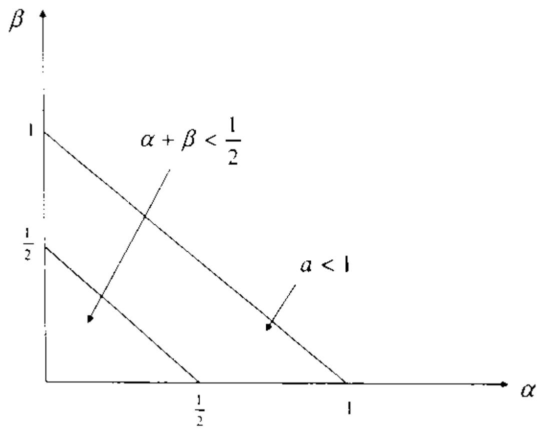

Figure 4.1: Regularity condition (R1)

level of protection is provided to the importable sector. (ii) The larger is the weight on campaign contributions, more distorted are environment and trade policies from the socially desirable one. On the other hand, larger is the worker population, closer is the pollution tax to the Pigouvian level and lower is the level of tariff protection.

It is intuitive that, since government cares for political contributions, the policy stance of the government reflects a compromise in terms of social welfare. If the lobby influences environment policy only, the government is induced to set an environmental standard that is lower than the socially desirable level. If there is bargaining over trade policy alone, the government concedes through providing a positive level of tariff protection.

Moreover, the higher is government's concern for contributions from the lobby, represented by a higher value of a, the more favorable are the equilibrium policies toward lobby-x, that is, $d\tau^e/da < 0$ and $dt^f/da > 0$.[10] These depict a larger deviation from the social

[10] Differentiating (4.18) and (4.21) respectively with respect to a, we get

$$\frac{d\tau^e}{da} = -\frac{(1-\alpha)(1-\alpha-\beta)\gamma}{[(1-\alpha)+a(1-\alpha-\beta)]^2} < 0; \quad \frac{dt^f}{da} = -\frac{\partial m/\partial a}{\partial m/\partial t^f} > 0,$$

where we recall that $m(\cdot)$ defines the l.h.s. of the first-order condition (4.21). The sign of dt^f/da follows optimum.

Besides political contributions, government also cares for consumers' welfare. We find that the effect of an increase in consumer (worker) population, $\bar{L}$, works in a manner which is just the opposite of change in the weight parameter, a. Since a larger population implies greater aggregate damage from exposure to pollution (from $\gamma \equiv \bar{L}\tilde{\gamma}$), the pollution tax is found to be increasing in it, that is, $d\tau^e/d\bar{L} > 0$. Similarly, tariffs lead to higher domestic price for the importable good, a source of loss in consumer surplus. Therefore, larger is the population of workers and, hence, the overall loss in consumer surplus, the lower is the equilibrium tariff rate, namely $dt^f/d\bar{L} < 0$.[11] Having made these points, we henceforth normalize $\bar{L}$ to one for ease of exposition of the results.

Trade and environment policies: both political

This is our central case. Let lobby-x bargain with the government over both policy instruments: pollution tax and import tariff. The government solves the maximization problem

$$\begin{aligned}\operatorname*{Max}_{\tau,t} U^g \;=\;& 1 + \frac{c_x^2(\cdot)}{2} + \pi(\cdot) + \tau N_x(\cdot) + tp^w M_x(\cdot) - \gamma N_x(\cdot) + a\lambda[\pi(\cdot) - \pi^o] \\ & -(1-\lambda)\left[\left(\frac{c_x^2(\cdot)}{2} - \frac{c_x^{o\,2}}{2}\right) + \pi(\cdot) - \pi^o + (\tau-\gamma)N_x(\cdot)\right. \\ & \left. -(\tau^o - \gamma)N_x^o + tp^w M_x(\cdot)\right], \end{aligned} \tag{4.22}$$

where $c_x = \bar{L}c_x = C_x$, the aggregate economy-wide demand for good X. (Recall that $\bar{L}$ is normalized to one.)

By collecting terms and utilizing the Hotelling's lemma (in (4.6)), the first-order condition

---

$\partial m/\partial t^f < 0$ from second-order conditions (see Appendix B) and $\partial m/\partial a > 0$.

[11] Taking the two equations again, differentiating with respect to $\bar{L}$ gives

$$\frac{d\tau^e}{d\bar{L}} = \frac{(1-\alpha)\tilde{\gamma}}{(1-\alpha) + a(1-\alpha-\beta)} > 0; \quad \frac{dt^f}{d\bar{L}} = -\frac{\partial m/\partial \bar{L}}{\partial m/\partial t^f} < 0.$$

Again, the sign $dt^f/d\bar{L}$ follows from the second-order conditions being met and $\partial m/\partial \bar{L} < 0$.

with respect to pollution tax is

$$\frac{\partial U^g}{\partial \tau} = 0 \quad \Leftrightarrow \quad (\tau - \gamma)\frac{\partial N_x}{\partial \tau} - tp^w \lambda \frac{\partial Q_x}{\partial \tau} - aN_x = 0.$$

Making substitutions for the partials from the expressions in (4.2) and (4.3) and using the relationship in (4.7) this is equivalent to

$$f(\tau^l, t^l) \equiv -(1-\alpha)\left(\frac{\tau^l - \gamma}{\tau^l}\right) + \frac{t^l}{1+t^l} - a(1-\alpha-\beta) \quad = \quad 0 \tag{4.23}$$

$$\Leftrightarrow \tau^l = \frac{(1-\alpha)\gamma}{1-\alpha+a(1-\alpha-\beta)-\frac{t^l}{1+t^l}}. \tag{4.24}$$

The superscript "l" stands for full-lobbying or full-political equilibrium. This is the extension of (4.18) where only the pollution tax is political.

With respect to import tariff the first-order condition is:

$$\frac{\partial U^g}{\partial t} = 0 \quad \Leftrightarrow \quad (\tau - \gamma)\frac{\partial N_x}{\partial t} + tp^w\left[\frac{\partial C_x}{\partial t} - \frac{\partial Q_x}{\partial t}\right] + ap^w Q_x = 0,$$

after utilizing Hotelling's lemma in (4.6), $C_x = c_x$ (with $\bar{L}$ is normalized to unity) and $M_x = C_x - Q_x$. Substituting for the partials from the solutions in (4.2) and (4.3), the above equation is equivalent to

$$g(\tau^l, t^l) \equiv \frac{\beta}{1-\alpha-\beta}\left(\frac{\tau^l-\gamma}{\tau^l}\right) - t^l\left[\frac{p^{w\,\frac{1-2(\alpha+\beta)}{1-\alpha-\beta}}\tau^{l\,\frac{\beta}{1-\alpha-\beta}}}{\Gamma(1+t^l)^{\frac{\alpha+\beta}{1-\alpha-\beta}}} + \frac{\alpha+\beta}{(1-\alpha-\beta)(1+t^l)}\right] + a = 0, \tag{4.25}$$

where recall $\Gamma \equiv [(\alpha+\beta)/\kappa_x]^{\frac{\alpha+\beta}{1-\alpha-\beta}}$. Note that this is an extension of (4.21) in the one-instrument case. In most of what follows, we use eqs. (4.23), and eq. (4.26) below.

$$h(\tau^l, t^l) \equiv a(1-\alpha-\beta) - \frac{\alpha t^l}{1+t^l} - \frac{(1-\alpha)t^l p^{w\,\frac{1-2(\alpha+\beta)}{1-\alpha-\beta}}\tau^{l\,\frac{\beta}{1-\alpha-\beta}}}{\Gamma(1+t^l)^{\frac{\alpha+\beta}{1-\alpha-\beta}}} = 0. \tag{4.26}$$

This is derived by substituting (4.23) into (4.25) and eliminating $(\tau^l - \gamma)/\tau^l$.

We first prove that a solution of $(\tau^l,\ t^l)$ in the positive quadrant exists. This is straightforward. Turning to (4.24), we see that it generates τ as a function of t as shown by the upward sloping U^g_τ curve in Figure 4.2. Consider now the first-order condition (4.26), which can be rewritten as:

$$\tau^l = (1+t^l)^{\frac{\alpha+\beta}{\beta}} \left[\frac{a(1-\alpha-\beta) - \alpha \frac{t^l}{1+t^l}}{(1-\alpha)t^l} \right]^{\frac{1-\alpha-\beta}{\beta}} \equiv n(t), \tag{4.27}$$

where, for notational simplicity, we have normalized $p^{w \frac{1-2(\alpha+\beta)}{1-\alpha-\beta}}/\Gamma = 1$. This function has the properties that as $t \to 0$, $n(t) \to \infty$ and as t is equal to that positive number such that $a(1-\alpha-\beta) - \alpha\frac{t^l}{1+t^l} = 0$, say $\bar{t}$, $n(\bar{t}) = 0$. Hence the U^g_τ curve the $n(t)$ function *must* intersect in the positive quadrant, proving that a solution of (τ, t) in this quadrant exists. In particular, $0 < t^l < \bar{t}$, i.e.,

Proposition 3:

$$\frac{t^l}{1+t^l} < \frac{a(1-\alpha-\beta)}{\alpha} \qquad \text{from (4.26).} \tag{4.28}$$

This is the upper limit on tariff rate. In Appendix C it is derived that the second-order

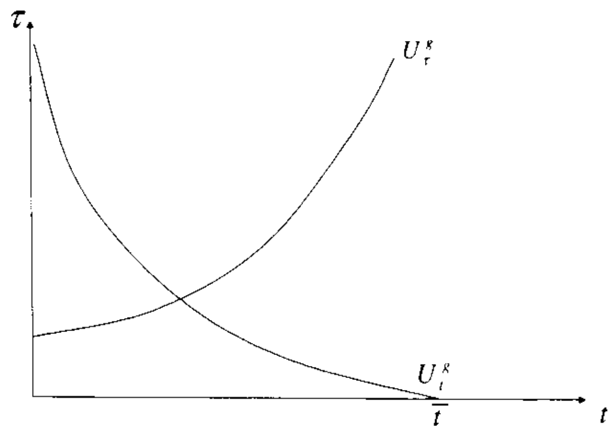

Figure 4.2: Determination of political equilibrium

conditions are met under a regularity condition, which is more restrictive than (R1) in the one-instrument case. This is the condition (R2) below.

$$\text{either (i) } \alpha+\beta \le \frac{1}{2}, \text{ or (ii) } \rho < \frac{\alpha}{2\alpha+\beta} < \frac{1}{2}. \tag{R2}$$

Note that (R2) is similar to (R1) in that it requires that either the price elasticity of the output of the importable be less than one, or that it be higher than one *and* the politicization parameter be low enough. It is illustrated in Figure 4.3 in the (α, β) space. Comparing with Figure 4.1, there is only one difference. First, according to (R2) for all values of α and β such that $\alpha + \beta > 1/2$, ρ needs to be less than $\alpha/(2\alpha + \beta)$, which is less than $1/2$. We assume that (R2) is met. Given the second-order conditions are met, the solutions are unique.

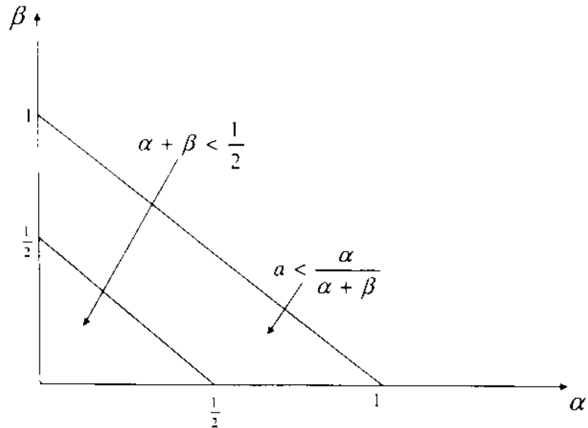

Figure 4.3: Regularity condition (R2)

We now characterize τ^l, which is particularly interesting. Observe that, unlike the case when only the pollution tax is political, the equilibrium pollution tax in our two-instrument case can *exceed* the Pigouvian level, i.e. it is possible that $\tau^l > \gamma$! This is because, as seen in (4.23), both the marginal gain and the marginal loss to the government's objective function from an increase in τ are first-order in magnitude. Since the possibility of $\tau^l > \gamma$ is interesting and "paradoxical" in the context of political economy, it would have been most desirable if a sufficient condition on the parametric configuration could be found under which it arises. However, it does not seem possible to obtain one. Hence, instead, a simulation exercise was undertaken to confirm this possibility as well as to obtain an understanding of conditions under which this possibility arises. Various combinations of parameter values were assigned.

The only restriction used here is that the regularity condition (R2) be met. The results of a representative sample are compiled in Table 4.1.

Table 4.1: Results of numerical simulations: full political equilibrium

Parameter	α	β	p^w	γ	a	t^l	τ^1	Δ in Lobby Surplus
Run 1	0.20	0.20	0.042	**0.50**	0.30	0.25	**0.51**	0.00057
Run 2	0.20	0.20	0.21	**0.50**	0.33	0.17	**0.47**	0.00629
Run 3	0.47	0.10	32.24	**0.50**	0.75	0.49	**0.51**	646.11
Run 4	0.47	0.10	18.69	**0.50**	0.80	0.48	**0.48**	176.96

In general, it is indicated that when the government has more than one policy instrument, it may, under some parametric configuration, "give in" to the lobby demand in respect of one policy instrument and not in respect of the other. This is amongst the most interesting results of this analysis. It is useful to think about the underlying intuition as follows. Since the government is politically inclined, it would like to transfer income to the lobbying industry. The most efficient way to do this would be through direct (lump sum) transfers. But recall that direct transfers are, by assumption, absent in this model. So, the issue is – what is the most efficient way to transfer income to the industry, while minimizing the harm to the consumers.

Recall that from (4.5), both a high tariff and a weaker (lower) pollution tax would subsidize the industry. However, a marginal rise in tariff offers a second-order loss in aggregate welfare in the form of deadweight loss but a first-order marginal gain in campaign contributions, as compared to a marginal increase in pollution tax that entails a first-order aggregate welfare gain from improved environmental quality and a first-order welfare loss due to marginal decline in campaign contributions. Therefore,following the efficiency property of G-H, government uses tariff protection to satisfy the lobbying industry in the import competing sector. At the same time, it applies pollution tax to counterbalance the distortion arising from use of trade policy as well as to address the externality caused by pollution. Whether equilibrium pollution policy entails a tax higher or lower than the Pigouvian tax depends on how political the government is, meaning as to how much weight it assigns to the welfare of the lobby in the utility function, which is denoted by a. For this, one could consider the following two cases.

First, consider the case when $\alpha + \beta \leq 1/2$ (i.e. the price elasticity of output of the importable good, X, is less than one) as in Runs 1 and 2 in Table 4.1. If this is associated with a high enough weight, a, on political contributions, and a high world price of the importable good, p^w, the increase in the marginal cost in terms of loss in political contributions due to marginal increase in τ in government's objective function exceeds its marginal benefits associated with improved environment quality. This entails $\tau^l < \gamma$ as in Run 2. Conversely, if the less than one price elasticity of output of X is associated with a relatively low value of a, and a low p^w, the rise in marginal cost of an increase in τ is offset by the increase in marginal benefits due to improved environment quality. Thus, in equilibrium, the government sets the pollution tax above the Pigouvian tax. This is the case in Run 1.

Next, consider the case when the price elasticity of output is greater than one, i.e., $\alpha + \beta > 1/2$. The results are enumerated in Runs 3 and 4 in Table 4.1. Even in this case, the pollution tax will exceed the Pigouvian tax if the government is not much politically inclined (i.e., the politicization parameter, a, is relatively small), and the world price, p^w, is higher, as indicated by the results in Run 3 (compared to Run 4). Thus, for low enough value of the politicization parameter, a, $\tau^l > \gamma$.

(Further, observe that in the all the four cases in Table 4.1 (as well as in all the simulations runs) the lobby's surplus at the political equilibrium compared to the social optimum, i.e. $\Delta U^i (\equiv U^i(\tau, t) - U^o(\gamma, 0) \equiv \Delta\pi^i)$, is higher, irrespective of $\tau^l \gtrless \gamma$.)

The government's policy stance in the political equilibrium is now summarized in Proposition 4.

Proposition 4: *(i) The government always concedes by offering a positive tariff protection to the domestic import-competing industry. (ii) However, in setting the environment policy, it may or may not concede in that it may set pollution tax higher than the Pigouvian tax.*

Intuitively, a marginal increase in t from $t = 0$ imparts only a second-order aggregate welfare loss but a first-order gain in political contribution. Thus $\partial U^g/\partial t > 0$ and thus the political equilibrium entails a positive tariff unambiguously. On the other hand, a marginal increase in pollution tax from the Pigouvian level, γ, has a first-order welfare gain and a first-order loss in terms of political contribution; this implies $\tau^l \gtrless \gamma$.

Even though τ^l may exceed γ, one would expect that there be an upper limit on τ^l, based on the magnitude of tariff protection granted. This is true. By multiplying the first-order condition (4.25) by $1 - \alpha - \beta$ and adding up with the other (i.e., eq. (4.23) to eliminate $a(1 - \alpha - \beta)$, we get,

Proposition 5:

$$\tau^l < (1 + t^l)\gamma \tag{4.29}$$

This is the upper limit on τ^l.

We can now compare the pollution at the political equilibrium (N_x^l) to that at the social optimum (N_x^o).

Recall that at the social optimum, $\tau = \gamma$ and $t = 0$. Then, from (4.3),

$$\begin{aligned} \frac{N_x^l}{N_x^o} &= \frac{(1+t^l)^{\frac{1}{1-\alpha-\beta}}}{(\tau^l/\gamma)^{\frac{1-\alpha}{1-\alpha-\beta}}} \\ &> \frac{(1+t^l)^{\frac{1}{1-\alpha-\beta}}}{(1+t^l)^{\frac{1-\alpha}{1-\alpha-\beta}}}, \qquad \text{by using (4.29)} \\ &= (1+t^l)^{\frac{\alpha}{1-\alpha-\beta}} > 1 \end{aligned} \tag{4.30}$$

Hence

Proposition 6: *Irrespective of $\tau^l \gtrless \gamma$, pollution is less at the political equilibrium than at* *the social optimum.*

4.4 Comparative statics of equilibrium policy

Having characterized the political equilibrium, the comparative statics of policy levels with respect to key parameters of the model are now carried out. We use the first-order conditions (4.23) and (4.26) for this purpose. Totally differentiating eq. (4.23) or (4.24), we get

$$\frac{d\tau^l}{dt^l} = \frac{(1-\alpha)\gamma}{\left((1-\alpha)+a(1-\alpha-\beta)-\frac{t^l}{1+t^l}\right)^2}\cdot\frac{1}{(1+t^l)^2} > 0. \tag{4.31}$$

Hence, if there is an increase in tariff, the government is induced to increase the pollution tax, i.e., it "offsets" a higher import tariff by raising the level of the pollution tax. This can be explained as follows. The increase in pollution tax lowers pollution and offers a marginal benefit to the government in terms of improved environment quality. At the same time, increase in tax reduces lobby rents, thus reducing political contributions. From Hotelling's lemma the loss in campaign contributions is proportional to the loss in lobby rent. This is the marginal cost of pollution tax to the government. *Ceteris paribus*, a higher tariff *offsets (reduces)* the marginal cost through positive impacts on lobby rents. At the same time, it *lowers* the marginal benefit from tax by encouraging the output of the polluting importable good. However, as the effect of tariff on the marginal costs of tax dominates its effect on the marginal benefits, government is induced to raise the pollution tax to offset the negative environmental effect of higher tariffs. This relationship between τ^l and t^l is shown by the positively sloped schedule U^g_τ in Figure 4.2.

Now turn to eq. (4.26). Totally differentiating we obtain,

$$\frac{dt^l}{d\tau^l} = -\frac{\beta}{\tau^l(1-\alpha-\beta)}\cdot\frac{t^l p^{w\,\frac{1-2(\alpha+\beta)}{1-\alpha-\beta}}\,\tau^{l\,\frac{\beta}{1-\alpha-\beta}}}{\Gamma(1+t^l)^{\frac{\alpha+\beta}{1-\alpha-\beta}}}\cdot\frac{1}{Z} < 0, \tag{4.32}$$

where Z is defined and proven to be positive in Appendix C. The negative sign of $dt^l/d\tau^l$ says that if there is an increase in τ, there is a decrease in tariff protection granted by

the government. This may appear "surprising" in the sense that the politically motivated government responds to higher pollution tax – which harms the lobby – by lowering tariff protection, which also harms the lobby. But, it can be explained as follows. The marginal benefit to the government from tariff is proportional to the marginal effect of tariff on the benefit to the lobbyists, who supply campaign funds, which, by the envelope theorem, is equal to the output. An increase in the pollution tax lowers output, and from the policy maker's perspective, *lowers* the marginal benefit to it from tariff. Hence, the policy maker is induced to reduce tariff. This relationship generates the locus U_t^g in Figure 4.2.
The intersection of the two schedules, U_τ^g and U_t^g defines the political equilibrium.

We now examine the exogenous changes in three basic parameters: pollution disutility, γ, world price of the importable good, p^w, and government's weight on contributions, a. Each of these comparative statics is addressed separately in the three sub-sections below.[12]

4.4.1 Disutility of pollution

Suppose the society becomes more environmentally conscious and attaches a higher weight to disutility from pollution. That is, γ increases.

In (4.24) we see that $\partial\tau^l/\partial\gamma > 0$, as one would expect. This implies that in Figure 4.2 the U_τ^g curve shifts up. The U_t^g curve does not shift since γ does not appear in (4.25) or (4.26). As a result,

$$\frac{d\tau^l}{d\gamma} > 0; \quad \frac{dt}{d\gamma} < 0.$$

Intuitively, an increase in γ leads to a higher pollution tax. Since trade protection is a strategic substitute of pollution tax, the former falls.

The effect on pollution is clear: it decreases on both accounts. Thus,

[12]There is another important parameter, namely the bargaining power index, λ. However, λ does not appear in either of the first-order conditions (4.23) or (4.25). Hence, equilibrium τ^l and t^l are independent of λ. But a change in λ affects the allocation of surplus between the government and the lobby.

Proposition 7: *If the marginal disutility from pollution increases, pollution tax increases, tariff protection falls and the amount of pollution decreases.*

4.4.2 World price of importable good

Suppose p^w increases. Eq. (4.24) is not affected, since p^w does not appear in it. The U^g_τ curve does not shift. But eq. (4.26) is affected. Partially differentiating (4.26), we have $\partial h/\partial p^w \lesseqgtr 0$, i.e., the U^g_t curve shifts in or out as $\alpha + \beta \lesseqgtr 1/2$. Hence,

$$\frac{d\tau^l}{dp^w} \quad \text{and} \quad \frac{dt^l}{dp^w} \lesseqgtr 0 \quad \text{as} \quad \alpha + \beta \lesseqgtr \frac{1}{2}.$$

Recall that $\alpha + \beta \gtrless 1/2$ respectively refers to output of importable good X being elastic or inelastic.

Hence,

Proposition 8: *As world price of the importable good increases, the pollution tax increases or decreases according as the price elasticity of supply of the importable good exceeds or falls short of one.*

However, tariff protection can be seen in terms of the absolute difference between the domestic price and the world price, i.e., by $T \equiv p^w t$, rather than by the "ad valorem" tariff t. When t^l increases, it is obvious that T increases too. When t falls, the effect on T is not clear by simple inspection. But it is shown below that T rises unambiguously regardless of the sign of $\alpha + \beta - 1/2$.

Hence,

Proposition 9: *As world price of the importable good increases, tariff protection measured by the absolute difference between the domestic price and the world price rises.*

The proof of this proposition is as follows. Using $T^l = p^w t^l$, eqs. (4.23) and (4.26) can be restated as

$$\tilde{f}(\tau^l, T^l) = -(1-\alpha)\left(\frac{\tau^l - \gamma}{\tau^l}\right) + \frac{T^l}{p^w + T^l} - a(1-\alpha-\beta) = 0 \quad (4.33)$$

$$\tilde{h}(\tau^l, T^l) = a(1-\alpha-\beta) - \alpha\frac{T^l}{p^w + T^l} - (1-\alpha)\frac{T^l \tau^{l\frac{\alpha+\beta}{1-\alpha-\beta}}}{(p^w + T^l)^{\frac{\alpha+\beta}{1-\alpha-\beta}}}. \quad (4.34)$$

These two equations respectively define a positively and a negatively sloped locus between τ^l and T^l, which are analogous to U^g_τ and U^g_t curves. In Figure 4.4 these are respectively denoted as $\tilde{U}^g_\tau$ and $\tilde{U}^g_{T^l}$ curves. It is straightforward to check that as p^w increases, both these curves shift to the right, to $\tilde{U}^{g1}_\tau$ and $\tilde{U}^{g1}_{T^l}$. This implies that T^l increases unambiguously. Proposition 9 should not be surprising. It ties with the issue of protection to declining

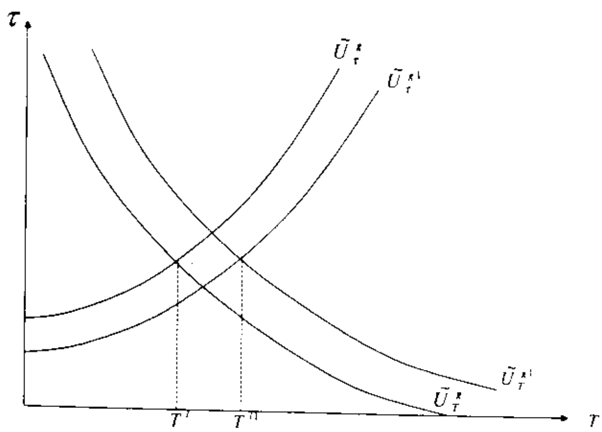

Figure 4.4: Comparative statics with respect to world price, p^w

industries in the presence of political economy, as analyzed, for example, by Hillman (1982). Hillman finds that, as the world price facing a small, importing-competing industry falls, the government is inclined to grant less protection in terms of the discrepancy between the domestic price and the world price. Proposition 9 says the same, and for the same reason. That is, at the original level of protection, a decrease in world price tends to reduce the profit-gain to the firm owners from protection. There is less political support at the margin.

Hence, the policy maker is induced to reduce protection.

Why pollution tax may increase or decrease can now be explained. An increase in T^l implies that the domestic price increases unambiguously. This tends to increase the demand for the pollutive input and hence increase pollution. If the price elasticity of output exceeds one, the increase in pollution from the increase in domestic price is very large. This entails a very high marginal welfare cost. The government then "contains" the pollution increase by increasing the pollution tax. If the price elasticity of output is less than one, the marginal welfare loss from pollution is not high, and, the government further supports the lobbyist by lowering the tax on pollution.

How does an increase in p^w affect pollution? Note that since T^l rises, the domestic price unambiguously increases. This tends to increase the demand for the pollutive input and hence increase pollution. If τ^l falls, it also tends to increase pollution. Therefore, pollution rises unambiguously. However, if τ^l rises (when $\alpha + \beta > 1/2$), the effects of changes in domestic price and τ^l on pollution are opposite of each other, leaving the overall impact on pollution unclear.

Numerical simulations were undertaken to evaluate the effect of an increase in p^w on pollution, when $\alpha + \beta > 1/2$. Interestingly, it was found that for all the permissible values of the parameters, the effect on pollution was positive, i.e., pollution rose unambiguously as p^w increased. Table 4.2 contains a sample of different values of p^w and the associated levels of pollution when other parameters were chosen values, $\alpha = 0.47$, $\beta = 0.10$, $a = 0.80$ and $\gamma = 0.5$.

Table 4.2: Effect of changes in the world price on pollution: $\alpha + \beta > 1/2$

Parameter	α	β	a	γ	p^w	Pollution
Run 1	0.47	0.10	0.80	0.5	0.187	0.0025
Run 2					0.934	0.1123
Run 3					1.868	0.5822
Run 4					9.344	27.0234
Run 5					18.689	108.3255
Run 6					28.033	375.6700
Run 7					37.377	749.2474

4.4.3 Weight on political contributions

Suppose the government becomes more political in the sense that it attaches a higher weight on the welfare of the lobby in its utility function. That is, there is an increase in a. From (4.24), observe that, at given τ, an increase in a implies an increase in t. Thus the U^g_τ curve in Figure 4.2 shifts out. Similarly, from (4.26), $\partial t/\partial a > 0$. Hence the U^g_t curve shifts out also. Since both the first-order conditions imply that, at given τ, t increases, we have $dt/da > 0$. However, $d\tau/da \gtreqless 0$. An interesting possibility emerges to the effect that as a government becomes more politically inclined, it may not relent with respect to pollution tax.

Simulation exercises do confirm the above.

Table 4.3: Comparative statics with respect to politicization parameter, a

Parameter	α	β	p^w	γ	a	t^l	τ^l	$\frac{d\tau^l}{da}$	Pollution
$\alpha + \beta < 1/2$									
Run 1	0.20	0.20	0.042	0.5	0.225	0.179	0.511	0.029	0.00111
Run 2					0.330	0.279	0.513	0.011	0.00126
Run 3	0.20	0.20	0.21	0.5	0.225	0.113	0.480	-0.091	0.01614
Run 4					0.330	0.173	0.471	-0.917	0.01810
$\alpha + \beta > 1/2$									
Run 5	0.47	0.10	18.689	0.5	0.55	0.277	0.482	-0.012	100.82
Run 6					0.80	0.479	0.482	0.011	142.08
Run 7	0.47	0.10	32.24	0.5	0.55	0.314	0.502	0.026	364.07
Run 8					0.80	0.554	0.512	0.056	525.34

Runs 3, 4 and 5 in Table 4.3 indicate parametric configurations under which $d\tau/da < 0$, whereas the others illustrate examples where $d\tau/da > 0$. However, the impact of an increase in the politicization of the government is always detrimental to the environment, as is depicted in the last column of Table 4.3.

Proposition 10: *As the government gets more political it offers higher protection to the importable sector. However, the effect on the environment policy is ambiguous.*

See Appendix D for the detailed derivations.

4.5 Conclusions

The chapter analyzes the political-economy interaction between trade and environment policies in the context of a small import-competing industry. Two alternative cases are studied. Under the first, we let only one policy instrument (either pollution tax or import tariff) be politically determined, whilst in the second, both trade and environment are political. For the first, it is shown that the government is induced to choose the policy that entails a compromise in social welfare: environmental tax is set lower than the Pigouvian tax and a positive tariff protection provided to the importable sector. Clearly, in either case the effect on environment is negative.

In the second scenario, both the trade and environment policies are influenced by political pressure. Bargaining over more than one policy instrument allows the government to trade-off one policy with another. We find that whilst the government always "concedes" by providing positive tariff protection to the import-competing sector at home, it may or may *not* give in to lobby's demand for lower pollution tax. In situations when the government is not very much politically inclined, it is possible that it would offset a higher tariff with a pollution tax that is *higher* than the Pigouvian tax. There is, however, an upper limit on the magnitude by which the equilibrium pollution tax could exceed the socially optimal tax. Nevertheless, at the political equilibrium the pollution is always worsened as compared to the social optimum.

An exogenous increase in the preference for "cleaner" environment induces the government to raise the pollution tax and lower tariff protection. As expected, the pollution decreases unambiguously.

As the world market price of the importable good rises, it is interesting that the absolute level of tariff protection, measured by the difference between the domestic and world price of the importable good, *rises*, which ties up well the existing literature on political economy of protection to declining industries. The effect on the pollution tax is more predictable. It is conditional on whether the elasticity of output of the importable good exceeds one or falls short of one; in the first case the tax rises and in the second it falls as the price of the world importable good rises. The effect on the environment is always negative, however.

As the government becomes more political, i.e., it weighs political contribution relatively more in its utility function, it grants higher tariff protection. But it may *not* lower the pollution tax. It is surprising that it may trade-off higher import tariff with a stricter environmental regulation. The environment quality is always adversely affected.

In sum, the analysis in this chapter provides useful insights into how, in the presence of political economy, the trade and environment policies interact with each other.

Appendix A

It is shown here that when only the pollution tax is political, the second-order condition of "political-utility" maximization is met.

Before eliminating λ the first-order condition (4.17) is:

$$-\left(\frac{1-\alpha}{1-\alpha-\beta}\right)\lambda\left(\frac{\tau-\gamma}{\tau}\right)N_x - a\lambda N_x = 0,$$

whose partial with respect to τ is

$$\begin{aligned}\frac{\partial^2 U^g}{\partial \tau^2} &= \left(\frac{1-\alpha}{1-\alpha-\beta}\right)^2\lambda\left(\frac{\tau-\gamma}{\tau}\right)\frac{N_x}{\tau} \\ &\quad -\left(\frac{1-\alpha}{1-\alpha-\beta}\right)\gamma\lambda\frac{N_x}{\tau^2} + a\left(\frac{1-\alpha}{1-\alpha-\beta}\right)\lambda\frac{N_x}{\tau}.\end{aligned}$$

Substituting for $(\tau-\gamma)/\tau$ from (4.18) in the r.h.s. above and cancelling out terms,

$$\frac{\partial^2 U^g}{\partial \tau^2} = -\left(\frac{1-\alpha}{1-\alpha-\beta}\right)\gamma\lambda\frac{N_x}{\tau^{e2}} < 0.$$

Hence, we have the desired result.

Appendix B

It is shown here that, when only import tariff is politically determined, the regularity condition (R1) ensures that $t^f \in R_+$ and the second-order condition of "political-utility" maximization is met.

For notational simplicity superscript "f" has been ignored in this appendix.

Recall that first-order condition (4.20) can be expressed as:

$$m(t) \equiv -t\left[\frac{\bar{L}p^{w\frac{1-2(\alpha+\beta)}{1-\alpha-\beta}}\gamma^{\frac{\beta}{1-\alpha-\beta}}}{\Gamma(1+t)^{\frac{\alpha+\beta}{1-\alpha-\beta}}} + \frac{\alpha+\beta}{(1-\alpha-\beta)(1+t)}\right] + a = 0, \tag{B1}$$

where $\tau = \gamma$ (by assumption) and $\Gamma \equiv [(\alpha+\beta)/\kappa_x]^{\frac{\alpha+\beta}{1-\alpha-\beta}}$.

Note that $m(0) > 0$. When $t \to \infty$, by applying L'Hospital's rule,

$$\lim_{t\to\infty} m(t) = \left(a - \frac{\alpha+\beta}{1-\alpha-\beta}\right) - \frac{1-\alpha-\beta}{\alpha+\beta}\,\frac{\bar{L}p^{w\frac{1-2(\alpha+\beta)}{1-\alpha-\beta}}\gamma^{\frac{\beta}{1-\alpha-\beta}}}{\Gamma(1+t)^{\frac{2(\alpha+\beta)-1}{1-\alpha-\beta}}}\Bigg|_{t\to\infty}$$

$$< 0,$$

if either $\alpha+\beta < 1/2$ or $a \leq 1 < (\alpha+\beta)/(1-\alpha-\beta)$ ($\Leftrightarrow \rho \leq 1/2$); this is the regularity condition (R1). Hence $m(t)|_{t\to\infty} < 0$ and thus a solution $t^f \in (0,\infty)$ exists if (R1) is met.

Next, differentiating $m(t)$,

$$m'(t) = -\frac{\bar{L}p^{w\frac{1-2(\alpha+\beta)}{1-\alpha-\beta}}\gamma^{\frac{\beta}{1-\alpha-\beta}}}{\Gamma(1+t)^{\frac{\alpha+\beta}{1-\alpha-\beta}}}\left(1 - \frac{\alpha+\beta}{1-\alpha-\beta}\,\frac{t}{1+t}\right) \tag{B2}$$

In view of (B2), $m'(t) < 0$ if the coefficient of $\bar{L}$ is negative, i.e.,

$$\frac{\alpha+\beta}{1-\alpha-\beta} < \frac{1+t}{t}.$$

This is satisfied in $\alpha+\beta \leq 1/2$. Suppose $\alpha+\beta > 1/2$. Then also, in view of Proposition 1, we have

$$1 - \frac{\alpha+\beta}{1-\alpha-\beta}\,\frac{t}{1+t} > 1 - a$$

which is positive if $a \leq 1$ ($\Leftrightarrow \rho \leq 1/2$). Hence the condition (R1) also ensures that $m'(t) < 0$ and the second-order condition is met.

Appendix C

In this appendix it is shown that, when both tariff and tax are politically determined, the regularity condition (R2) (in the text) ensures that the second-order conditions relating to

(4.23) and (4.25) hold, which, in turn, implies that the solutions τ^l and t^l are unique. For notational ease, let us here ignore the superscript "l" on τ or t.

The second-order conditions require that

$$f_\tau < 0, \tag{C1}$$

$$g_t < 0, \tag{C2}$$

$$f_\tau g_t - f_t g_\tau > 0, \tag{C3}$$

where $f(\cdot) = 0$ and $g(\cdot) = 0$ are the first-order conditions (4.23) and (4.25) respectively.

We begin with the proof for (C1). By differentiating $f(\cdot)$ with respect to τ, we have

$$f_\tau = -\frac{(1-\alpha)\gamma}{\tau^2} < 0. \tag{C4}$$

This proves (C1).

Next, turn to (C2). Differentiating $g(\cdot)$ with respect to t,

$$g_t = -\left[\frac{p^{w\frac{1-2(\alpha+\beta)}{1-\alpha-\beta}}\tau^{\frac{\beta}{1-\alpha-\beta}}}{\Gamma(1+t)^{\frac{\alpha+\beta}{1-\alpha-\beta}}}\left(1-\frac{\alpha+\beta}{1-\alpha-\beta}\cdot\frac{t}{1+t}\right)+\frac{\alpha+\beta}{(1-\alpha-\beta)(1+t)^2}\right] \tag{C5}$$

$$= -\left[Z+\frac{\beta}{(1-\alpha)(1-\alpha-\beta)(1+t)^2}\right], \tag{C6}$$

$$\text{where } Z \equiv \frac{p^{w\frac{1-2(\alpha+\beta)}{1-\alpha-\beta}}\tau^{\frac{\beta}{1-\alpha-\beta}}}{\Gamma(1+t)^{\frac{\alpha+\beta}{1-\alpha-\beta}}}\left(1-\frac{\alpha+\beta}{1-\alpha-\beta}\cdot\frac{t}{1+t}\right)+\frac{\alpha}{(1-\alpha)(1+t)^2}. \tag{C7}$$

From (C5) note that when $\alpha+\beta \leq 1/2$, $g_t < 0$. Now suppose $\alpha+\beta > 1/2$, then turn to (C6). The following Lemma proves that under our regularity condition (R2), $Z > 0$. This would imply that $g_t < 0$.

Lemma 1: *Given (R2), $Z > 0$.*

Proof: Observe that $Z > 0$ if $\alpha + \beta \leq 1/2$. Suppose $\alpha + \beta > 1/2$. Then.

$$
\begin{aligned}
Z &= \frac{1}{t}\left[\left(\frac{\beta}{1-\alpha-\beta}\right)\left(\frac{\tau^l - \gamma}{\gamma}\right) + a - \left(\frac{\alpha+\beta}{1-\alpha-\beta}\right)\frac{t}{1+t}\right]\left(1 - \left(\frac{\alpha+\beta}{1-\alpha-\beta}\right)\frac{t}{1+t}\right) \\
&\quad + \frac{\alpha}{(1-\alpha)(1+t)^2} \qquad \text{(by using (4.25))} \\
&= \frac{1}{t}\left[\frac{\beta}{(1-\alpha-\beta)(1-\alpha)}\left(\frac{t}{1+t} - a(1-\alpha-\beta)\right) + a - \left(\frac{\alpha+\beta}{1-\alpha-\beta}\right)\frac{t}{1+t}\right] \\
&\quad \left(1 - \left(\frac{\alpha+\beta}{1-\alpha-\beta}\right)\frac{t}{1+t}\right) + \frac{\alpha}{(1-\alpha)(1+t)^2} \qquad \text{(by using (4.23))} \\
&= \frac{1}{t}\left[\frac{1}{1-\alpha-\beta}\left(\frac{\beta}{1-\alpha} - (\alpha+\beta)\right)\frac{t}{1+t} + a\left(1 - \frac{\beta}{1-\alpha}\right)\right] \\
&\quad \left(1 - \left(\frac{\alpha+\beta}{1-\alpha-\beta}\right)\frac{t}{1+t}\right) + \frac{\alpha}{(1-\alpha)(1+t)^2} \\
&= \frac{1}{t}\left[\frac{a(1-\alpha-\beta)}{1-\alpha} - \frac{\alpha}{(1-\alpha)}\frac{t}{(1+t)}\right]\left(1 - \left(\frac{\alpha+\beta}{1-\alpha-\beta}\right)\frac{t}{1+t}\right) + \frac{\alpha}{(1-\alpha)(1+t)^2} \\
&= \frac{1}{(1-\alpha)t}\left[a(1-\alpha-\beta) + \frac{\alpha(\alpha+\beta)}{1-\alpha-\beta}\left(\frac{t}{1+t}\right)^2 - a(\alpha+\beta)\frac{t}{1+t}\right] \\
&\quad - \frac{\alpha}{1-\alpha}\frac{t}{(1+t)^2}.
\end{aligned} \tag{C8}
$$

By collecting terms, this will be

$$
= \frac{\alpha t}{(1-\alpha)(1+t)^2}\left(\frac{\alpha+\beta}{1-\alpha-\beta} - 1\right) + \frac{a}{t(1-\alpha)}\left[(1-\alpha-\beta) - (\alpha+\beta)\frac{t}{1+t}\right] \tag{C9}
$$

The first term in the r.h.s. is positive since $\alpha + \beta > 1/2$. The second term is positive if $(1-\alpha-\beta) - (\alpha+\beta)(t/(1+t)) > 0$, for which it is sufficient that

$$
\begin{aligned}
(1-\alpha-\beta) - (\alpha+\beta)\frac{a(1-\alpha-\beta)}{\alpha} &> 0 \qquad \text{(from Proposition 3)} \\
\Leftrightarrow a &< \frac{\alpha}{\alpha+\beta},
\end{aligned} \tag{C10}
$$

which is (iib) of the regularity condition (R2). This completes the proof of (C2).

Next, turn to (C3). Differentiating $f(\cdot)$ with respect to t,

$$
f_t = \frac{1}{(1+t)^2}. \tag{C11}
$$

Similarly, differentiating $g(\cdot)$ with respect to τ, we have

$$g_\tau = -\frac{\beta}{(1-\alpha-\beta)\tau}\left[\frac{tp^{w\frac{1-2(\alpha+\beta)}{1-\alpha-\beta}}\tau^{\frac{\beta}{1-\alpha-\beta}}}{\Gamma(1+t)^{\frac{\alpha+\beta}{1-\alpha-\beta}}} - \frac{\gamma}{\tau}\right].$$

Using (4.25) to eliminate $\frac{tp^{w\frac{1-2(\alpha+\beta)}{1-\alpha-\beta}}\tau^{\frac{\beta}{1-\alpha-\beta}}}{\Gamma(1+t)^{\frac{\alpha+\beta}{1-\alpha-\beta}}}$, the r.h.s. is

$$\begin{aligned} &= -\frac{\beta}{(1-\alpha-\beta)\tau}\left[\frac{\beta}{1-\alpha-\beta}\left(\frac{\tau-\gamma}{\tau}\right) + a - \frac{\alpha+\beta}{1-\alpha-\beta}\frac{t}{1+t} - \frac{\gamma}{\tau}\right] \\ &= -\frac{\beta}{(1-\alpha-\beta)\tau}\left[\left(\frac{-\alpha+1}{1-\alpha}\right)\frac{t}{1+t} - 1\right] = -\frac{\beta}{(1-\alpha-\beta)\tau(1+t)}, \end{aligned}$$

by using (4.23) to eliminate $(\tau-\gamma)/\tau$.

Collecting the partials f_τ, g_t, f_t and g_τ, we have

$$\begin{aligned} f_\tau g_t - f_t g_\tau &= \frac{(1-\alpha)\gamma}{\tau^2}\left[Z + \frac{\beta}{(1-\alpha-\beta)(1-\alpha)(1+t)^2}\right] - \frac{1}{(1+t)^2}\frac{\beta}{(1-\alpha-\beta)\tau(1+t)} \\ &= \frac{(1-\alpha)\gamma}{\tau^2}Z + \frac{\beta}{(1-\alpha-\beta)\tau(1+t)^2}\left[\frac{\gamma}{\tau} - \frac{1}{(1+t)}\right] \\ &> 0 \end{aligned} \tag{C12}$$

since, given $Z > 0$ (see Lemma 1), the first term is positive, and the second is also positive because $[\gamma/\tau - 1/(1+t)] > 0$ in view of Proposition 5. Hence, (C3) is also proven.

The results in (C1)-(C3) imply that the second-order conditions corresponding to (4.23) and (4.25) are met and the equilibrium is unique.

Appendix D

When both tariff and tax are political, the effect of an increase in the politicization parameter, a, on τ is discussed. Again, for notational brevity, the superscript "l" has been ignored in this appendix.

Totally differentiating the first-order condition, (4.24), with respect to a, we have

$$\frac{1}{(1+t)^2}\frac{dt}{da} - (1-\alpha)\frac{\gamma}{\tau^2}\frac{d\tau}{da} = 1-\alpha-\beta. \tag{D1}$$

Similarly, by differentiating the other first-order condition, we get

$$\left[\frac{\alpha}{(1+t)^2} + \frac{(1-\alpha)p^{w\,\frac{1-2(\alpha+\beta)}{1-\alpha-\beta}}\tau^{\frac{\beta}{1-\alpha-\beta}}}{\Gamma(1+t)^{\frac{\alpha+\beta}{1-\alpha-\beta}}}\left(1-\frac{\alpha+\beta}{1-\alpha-\beta}\frac{t}{1+t}\right)\right]\frac{dt}{da}$$
$$+\frac{(1-\alpha)\beta}{1-\alpha-\beta}\frac{tp^{w\,\frac{1-2(\alpha+\beta)}{1-\alpha-\beta}}\tau^{\frac{\beta}{1-\alpha-\beta}}}{\Gamma(1+t)^{\frac{\alpha+\beta}{1-\alpha-\beta}}}\frac{1}{\tau}\frac{d\tau}{da} = 1-\alpha-\beta. \tag{D2}$$

Eqs. (D1) and (D2) together constitute the matrix system

$$\begin{bmatrix} \frac{1}{(1+t)^2} & -(1-\alpha)\frac{\gamma}{\tau^2} \\ \frac{\alpha}{(1+t)^2} + \frac{(1-\alpha)p^{w\,\frac{1-2(\alpha+\beta)}{1-\alpha-\beta}}\tau^{\frac{\beta}{1-\alpha-\beta}}}{\Gamma(1+t)^{\frac{\alpha+\beta}{1-\alpha-\beta}}}\left(1-\frac{\alpha+\beta}{1-\alpha-\beta}\frac{t}{1+t}\right) & \frac{(1-\alpha)\beta}{1-\alpha-\beta}\frac{tp^{w\,\frac{1-2(\alpha+\beta)}{1-\alpha-\beta}}\tau^{\frac{\beta}{1-\alpha-\beta}}}{\Gamma(1+t)^{\frac{\alpha+\beta}{1-\alpha-\beta}}}\frac{1}{\tau} \end{bmatrix}\begin{bmatrix}\frac{dt}{da}\\ \frac{d\tau}{da}\end{bmatrix}$$
$$=\begin{bmatrix}1-\alpha-\beta\\ 1-\alpha-\beta\end{bmatrix}$$

If Y denotes the coefficient matrix in the l.h.s., then $|Y|>0$, given that the second-order conditions hold.

Applying Cramer's Rule, we have

$$\frac{dt}{da} = (1-\alpha-\beta)\left[\frac{(1-\alpha)\beta}{1-\alpha-\beta}\frac{tp^{w\,\frac{1-2(\alpha+\beta)}{1-\alpha-\beta}}\tau^{\frac{\beta}{1-\alpha-\beta}}}{\Gamma(1+t)^{\frac{\alpha+\beta}{1-\alpha-\beta}}}\frac{1}{\tau} + \frac{(1-\alpha)\gamma}{\tau^2}\right]\Big/|Y|>0. \tag{D3}$$

$$\frac{d\tau}{da} = (1-\alpha-\beta)(1-\alpha)\left[\frac{1}{((1+t)^2} - \frac{p^{w\,\frac{1-2(\alpha+\beta)}{1-\alpha-\beta}}\tau^{\frac{\beta}{1-\alpha-\beta}}}{\Gamma(1+t)^{\frac{\alpha+\beta}{1-\alpha-\beta}}}\left(1-\frac{\alpha+\beta}{1-\alpha-\beta}\frac{t}{1+t}\right)\right]\Big/|Y| \gtreqless 0. \tag{D4}$$

Chapter 5

North-South Capital Movement and Global Environment

5.1 Introduction

Similar to free trade in goods between "Northern" and "Southern" countries, free capital movement between these countries is believed to worsen global environment. It would induce the North to export capital to the South for two reasons. One is the greater abundance of capital in the North and the other is a more lenient pollution policy in the South, both of which lead to return on capital in the North to be lower than that in the South. The argument goes that as capital moves from North to South, driven by higher returns, pollution increases in the South, and if pollution is transnational, global environment is adversely affected.

It is somewhat surprising that very little formal economic analysis of North-South capital movement and environment exists to date, although there is a growing literature on North-South trade *in goods* and environment (e.g. Chichilinsky (1994), C-T (1994 and 1995)). A survey of theoretical and empirical literature on foreign direct investment (FDI) and environment is already provided in Chapter 2. This chapter is an attempt toward filling the gap in theoretical analysis of the issue. Amongst the studies reviewed, the framework of analysis here is the closest to Rauscher (1992, 1997), which analyze implications of economic integration via capital mobility on the state of the environment under alternative assumptions of fixed and optimal environment policies, separately for both small and large open economies. Rauscher (1997), in particular, derives several possible outcomes – in terms of implications for FDI, regional pollution and welfare – depending on the interplay of various parameters and policy regimes. The model in this chapter differs from Rauscher (1997) in two significant ways. First, it incorporates a more defined structure of the economy, in terms of technology and preferences. Accordingly, our analysis generates more definitive predictions. Second, Rauscher's model assumes that environment is a neutral good, i.e., there are zero-income effects on the demand for environment. Against this, our analysis considers both – a basic model that incorporates zero-income effects on the demand for environment, and a variant of the basic model that postulates a preference structure wherein environment is a normal good.

Specifically, the chapter revisits the "pollution haven" debate in the context of FDI by focusing on transnational/transfrontier pollution, where each region is as much affected by its own pollution as that from the other.[1]

Our basic point of departure from the layman perception of this issue (as capsuled above) is that pollution policy of South may be less stringent than North's not because of difference in preference toward environment but due to other differences such as endowment. It is reasonable to suppose that in each country the government is conscious of the state of the environment and sets an optimal pollution policy by weighing its marginal economic benefit and its marginal cost toward social welfare. Then, capital movement (from North to South) would affect the environment policies of countries. Hence it is not *a priori* clear as to whether global pollution will increase or decrease - or whether more pollution is associated

[1]The examples of transfrontier pollution are emissions of carbon dioxide from energy production or use leading to concerns of global warming and climate change, or chlorofluorocarbons damaging the ozone layer.

necessarily with higher level of FDI. Furthermore, given various attempts by countries to cooperate on global environmental issues, it is also natural to ask what pattern of pollution policies cooperation implies (as opposed to non-cooperation) and whether it is a deterrent to direct foreign investment. Also it is not clear how FDI may affect the welfare of both the North and the South. All these issues call for formal scrutiny.

Similar to Chapters 3 and 4, in this chapter also we analyze resource-based pollution, that is, pollution arising from the use of a factor of production.[2] Furthermore, like Chapter 3, the government in each country controls the total supply (release) of the polluting resource to the production sector, which then gets leased to the private sector in a competitive market. The private sector pays a market-determined per-unit 'pollution tax' to the government for the use of the resource. The environmental 'good' is proportional to how much is preserved of the resource, that is, the difference between the (exogenous) endowment of this resource and the amount released for production.

Our analysis captures the following mechanisms of how environment policy affects welfare. In the absence of capital movement between countries, the benefit from increasing the amount released of the resource lies in its expansionary impact on national output. This can be called the *output effect*. In the presence of capital movement, if we assume that governments behave non-cooperatively there is an additional effect, that is, the *factor terms-of-trade effect*. These effects, in relation to the marginal cost of pollution, influence the optimal pollution policy of a particular country. When, instead, regions cooperate the factor terms-of-trade effects wash out and the *public good* nature of global environment is fully internalized.

The conclusions of our analysis in general terms are that zero to positive level of FDI worsens global pollution. However, as countries move from non-cooperation to cooperation in setting environmental policies and world environment improves as a result, there is *more* FDI, not less. Thus, stringency in environment policy is not incompatible with or a disincentive

[2] Examples include the use of coal in power or steel plants, raw wood in furniture manufacturing etc.

to FDI, as is commonly feared. More specifically we obtain the following results.

1. Both in autarky and in the presence of capital flows, North's contribution to global pollution is higher than that of the South, irrespective of North's endowment of the natural resource relative to South's.

2. An outflow of capital from the North induces it to reduce its pollution level, and correspondingly South's pollution increases. But not surprisingly, the sum of regional pollution, that is, global pollution, increases.

3. As the economies move from autarky to free FDI equilibrium, South unambiguously gains in terms of welfare, whilst the North may or may not gain. In the special case where the endowment differences are small enough, such that the equilibrium level of FDI is low enough, North unambiguously suffers a loss in welfare. In general, the global welfare may be higher or lower. But, in the special case mentioned above, global welfare is less at the free FDI equilibrium than that under autarky.

4. The above conclusions hold when the governments regulate their environment in a non-cooperative fashion. In the cooperative free FDI equilibrium, the level of FDI is *greater* than at the non-cooperative free FDI equilibrium.

5. Moreover, the cooperative solution involves a reduction in pollution originating from the North but *may not* entail a similar adjustment in the South.

6. In the cooperative equilibrium global environment is better compared to non-cooperative free FDI or autarky equilibria.

We now turn to formal analysis.

5.2 The model

The world consists of two countries: North and South. Each produces and consumes one and the same good (Y). Hence the standard commodity terms-of-trade effects and sectoral factor intensities are ignored and we are able to focus entirely on the implications of international capital movement or FDI.

The production process uses three factors - labor (L), capital (K) and a pollution generating natural resource (T). Let the endowments be denoted by a bar on the top and the country, North or South, by the superscript N or S. For instance, $\bar{T}^S$ is the endowment of the natural resource in the South. Let the population in each country be normalized to one, and let $\bar{L}^j$ denote the (per capita) human capital coefficient of population in country j. It is realistic to suppose that $\bar{L}^N > \bar{L}^S$ (as in C-T (1994)).[3] But, for technical simplicity, we assume here that $\bar{L}^N = \bar{L}^S$, which we call as the symmetric case. However, most of our results hold when $\bar{L}^N > \bar{L}^S$, which we refer to as the asymmetric case; this is considered in section 5.3 of the chapter. Most critically for our purpose, we assume $\bar{K}^N > \bar{K}^S$, that is, North is more capital abundant.[4]

The production function, which is linearly homogeneous in the three inputs, Cobb-Douglas in form and same in both countries is denoted by

$$Y = K^{\alpha}T^{\beta},\ \alpha,\ \beta > 0,\ \alpha + \beta < 1, \tag{5.1}$$

where the labor endowments are normalized to one, and, K and T are the total *use* of respective factors. When capital is not internationally mobile, $K = \bar{K}$; otherwise $K \neq \bar{K}$. Note that T is a policy variable. Let r and τ denote the rent/price for the use of capital and natural resource respectively. Put differently, τ is the pollution tax. Perfect competition and

[3]That is, North is sufficiently more skilled labor abundant so that in effective labor units, it is the labor abundant country.

[4]The ranking between $\bar{T}^N$ and $\bar{T}^S$ does not affect our analysis, so that $\bar{T}^N \gtrless \bar{T}^S$.

profit maximization imply

$$r = Y_K = \alpha K^{\alpha-1}T^{\beta}; \quad \tau = Y_T = \beta K^{\alpha}T^{\beta-1}. \tag{5.2}$$

Let a country's social welfare function be defined as:

$$U = C + \gamma\Phi(\bar{T} - T^W),\ \Phi' > 0 > \Phi'',\ \gamma > 0, \tag{5.3}$$

where C is the aggregate national consumption of good Y, $\bar{T} = \bar{T}^N + \bar{T}^S$, the global endowment of the natural resource, $T^W = T^N + T^S$, the global use (release) of the natural resource, and $\gamma\Phi(\bar{T} - T^W)$ is the utility from environmental good. Note that the utility function is quasi-linear with respect to C and strictly concave with respect to the environment good, equal to $(\bar{T} - T^W)$. This implies that there is zero-income effect on the environment good, that is, the environment good is a neutral good. We refer to this as our basic model or the zero-income effect model. (In section 5.4 we relax this assumption.) It is further assumed that γ is sufficiently large (to be made precise in the following section). This assumption is consistent with environment being our central issue. Also, we assume that the Inada conditions with respect to marginal utility from the environment good hold, that is, $\lim_{\bar{T}-T^W \to 0} \Phi'(\bar{T} - T^W) = \infty$. This ensures that $T^W < \bar{T}$ at the optimum.

The sequence of our analysis is as follows. The autarky or no-capital mobility equilibrium is examined first. This is followed by analysis of the free capital mobility equilibrium. Under the latter, two alternative cases - one that assumes Nash non-cooperative behavior in setting of pollution policies by the regional governments, and the other that presumes coordination of regional pollution policies – are examined.

We begin with autarky.

5.2.1 Autarky

Initially, suppose that the two countries are in isolation. Then, for any country $C = Y$. The welfare level is expressed as: $U = \bar{K}^{\alpha}T^{\beta} + \gamma\Phi(\bar{T} - T^W)$. Since the welfare of one country is dependent on its own pollution as well as that of the other, there is a strategic interdependence in the setting of the optimum pollution policy. We assume here that T^N and T^S are determined in a non-cooperative Nash fashion. (The case of cooperation between countries in setting the environment policy is also analyzed later in section 5.2.4). The rule for optimum T^j for country j is

$$\tau(K^j, T^j) = \gamma\Phi'(\bar{T} - T^W), \quad j = N, S. \tag{5.4}$$

The l.h.s. is the marginal benefit, equal to the marginal product of the resource. This is the *output effect*. The r.h.s. is the marginal cost in terms of an increase in global pollution. These are respectively decreasing and increasing functions of the resource.

Before moving to the effects on regional pollution levels, it is important to observe that the Inada condition on the marginal utility from pollution ensures that $T^W < \bar{T}$. But, to be meaningful, it is also required that total use of the natural resource in *each* country be less than the respective endowment, that is, $T^j < \bar{T}$, $j = N, S$. A high enough value of γ ensures this. For example, suppose $\Phi(\cdot) = \ln(\cdot)$. Then, for any country, say the North, the first-order condition (5.4) can be expressed as

$$\frac{\beta \bar{K^N}^{\alpha}}{{T^N}^{1-\beta}} = \frac{\gamma}{\bar{T} - T^N - T^S} \tag{5.5}$$

From (5.4), the equality of marginal products of the resource yields the relationship:

$$\left(\frac{T^S}{T^N}\right)^{1-\beta} = \left(\frac{\bar{K}^S}{\bar{K}^N}\right)^{\alpha} \Rightarrow T^S = \left(\frac{\bar{K}^S}{\bar{K}^N}\right)^{\frac{\alpha}{1-\beta}} T^N,$$

which is utilized in the r.h.s. of (5.5) to yield

$$\frac{\beta \bar{K^N}^{\alpha}}{{T^N}^{1-\beta}} = \frac{\gamma}{\bar{T} - \left(1 + \left(\frac{\bar{K}^S}{\bar{K}^N}\right)^{\frac{\alpha}{1-\beta}}\right) T^N}. \tag{5.6}$$

The l.h.s. of (5.6), representing the marginal benefit of pollution, is decreasing in T^N. The r.h.s., the marginal costs of pollution, is increasing in T^N. Given these slopes of marginal benefit and marginal costs, it is easy to see that, *ceteris paribus*, a larger value of γ would imply an inward (upward) shift in the marginal cost schedule, and, at high enough γ the marginal benefit and marginal cost curves would intersect at $T^N < \bar{T}^N$. Likewise a high enough γ would also imply $T^S < \bar{T}^S$. It is presumed that γ is large enough such that $T^N < \bar{T}^N$ and $T^S < \bar{T}^S$.

Next, in view of diminishing returns, $\partial\tau^j/\partial T^j < 0$ $(j = N, S)$, and $\Phi'' < 0$ by assumption. It is, therefore, straightforward to show that the second-order conditions are met. Now, turn to analyzing the regional pollution levels. We can write the first-order condition (5.4) as

$$\tau(\bar{K}^N, T^N) = \tau(\bar{K}^S, T^S) = \gamma\Phi'(\bar{T} - T^W). \tag{5.7}$$

Thus the resource price (tax on use of the resource) is equal across the countries on account of common marginal costs.

In view of (5.4) again, $\bar{K}^N > \bar{K}^S$ implies that

$$T^{N^a} > T^{S^a}, \tag{5.8}$$

where superscript "a" denotes autarky. (Note that this holds whether $\bar{T}^N \gtrless \bar{T}^S$.) Thus, North uses more of the resource and hence contributes more to global pollution, even if North's endowment of the natural resource may be lower than that of the South.

Proposition 1: *In the autarky equilibrium, North's contribution to world pollution is higher than South's.*

The solution of T^{N^a} and T^{S^a} is illustrated in Figure 5.1. The curve $\tau^j = MB^{j^a}$ $(j = N, S)$ represents $\tau(\bar{K}^j, T^j)$ as a function of T^j; this is the respective marginal benefit curve. For any given T^j, the marginal benefit is higher in North than in South since North is more capital abundant and capital and natural resource are complementary inputs. Graphically, this is shown by the benefit curve for North, MB^{N^a}, lying to the right of that for the South, MB^{S^a}. The curve B^a is the *lateral* sum of the respective marginal benefit curves. The MC

curve is the marginal cost of world pollution: it represents $\gamma\Phi'(\bar{T} - T^W)$ as a function of $T^W = T^N + T^S$. The intersection of the B^a and the MC curves determines the equilibrium world pollution. The regions' contribution toward world pollution is read off the respective MB^a curves. Clearly, $T^{N^a} > T^{S^a}$.

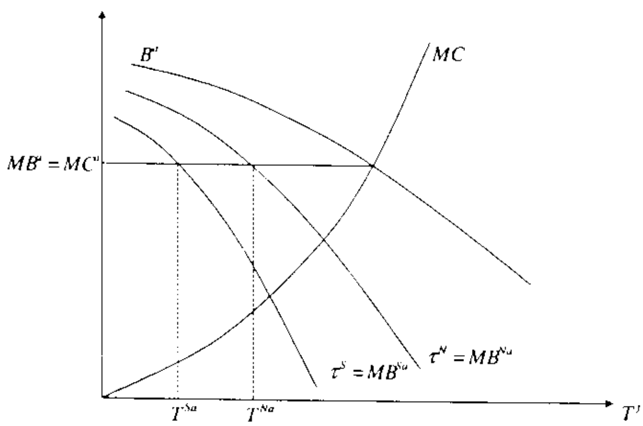

Figure 5.1: Autarky equilibrium

The autarky equilibrium provides a basis for capital to move from the North to the South. We have $\tau^{N^a} = \beta \bar{K^N}^{\alpha} {T^N}^{\beta - 1} = \tau^{S^a} = \beta \bar{K^S}^{\alpha} {T^S}^{\beta - 1}$ implying $T^{N^a}/T^{S^a} = (\bar{K}^N/\bar{K}^S)^{\frac{\alpha}{1-\beta}}$. Hence,

$$\frac{r^{N^a}}{r^{S^a}} = \left(\frac{\bar{K}^N}{\bar{K}^S}\right)^{\alpha - 1} \left(\frac{T^{N^a}}{T^{S^a}}\right)^{\beta} = \left(\frac{\bar{K}^S}{\bar{K}^N}\right)^{\frac{1-\alpha-\beta}{1-\beta}} < 1, \quad \text{since } \bar{K}^N > \bar{K}^S.$$

Therefore, in autarky, capital earns a higher return in the South. This would imply that as capital movement is permitted across countries, North will export capital to South.

5.2.2 International capital mobility

Suppose the two countries allow free movement of good(s) and capital.[5] Consider first the short run during which the supplies of the resource are not readjusted, i.e. autarky pollution policies are unchanged. Since $r^{S^a} > r^{N^a}$, capital moves from North to South, i.e., North exports capital. In equilibrium, the rental rates are equalized. In turn South exports goods (good Y) to the North. There is no change in the pollution level in either country by definition and there are standard gains from capital movement (see MacDougall (1960)).

In response to movement of capital suppose the countries reset their pollution policies optimally (in the long run). Let I denote the export of capital from North to South or the level of FDI. The capital mobility equilibrium is achieved when $r^N = r^S \equiv r$, that is

$$(\bar{K}^N - I)^{\alpha-1} T^{N^\beta} = (\bar{K}^S + I)^{\alpha-1} T^{S^\beta}, \tag{5.9}$$

where T^N and T^S are policy choices. This equation implicitly yields

$$I = I(\underset{(-)}{T^N}, \underset{(+)}{T^S}); \quad r = r(\underset{(+)}{T^N}, \underset{(+)}{T^S}), \tag{5.10}$$

where r is the (common) reward to capital in the world economy. Equation (5.9) indeed yields a closed-form solution of I in terms of T^N and T^S. Denoting $\theta \equiv \beta/(1-\alpha)$, $\eta \equiv T^{N^\theta}/(T^{N^\theta} + T^{S^\theta})$ and $\bar{K} \equiv \bar{K}^N + \bar{K}^S$,

$$I = \bar{K}^N - \eta \bar{K}. \tag{5.11}$$

Graphically, the equilibrium condition as well as the comparative statics in (5.10) are seen in Figure 5.2. 0^N and 0^S are the origins for North and South and $0^N 0^S$ measures the world capital stock. $0^N A$ and $0^S A$ are respectively the capital endowments of North and South. K^N and K^S denote the total capital in use in the respective country, where

[5] Allowing trade in goods but no movement of capital between the two countries does not have any real effects and replicates the autarky equilibria since there is no relative price change. Each country consumes whatever it produces.

$K^N = \bar{K}^N - I$ and $K^S = \bar{K}^S + I$. The marginal product curves are drawn at given levels of T^N and T^S. The equilibrium is at point E. AB is the level of FDI. Suppose there is an increase in T^N. The $r(K^N;T^N)$ curve shifts to the right. Consequently, there is less FDI since the marginal product of (and hence the return on) capital in the source country North is higher and some capital returns to the North. The reward to capital in the international economy is greater. If T^S is higher, the level of FDI responds in the opposite way but the reward to capital also rises. Thus an increase in the resource use in either country implies that in the international economy capital is working with a higher level of a complementary input; its marginal product therefore increases.

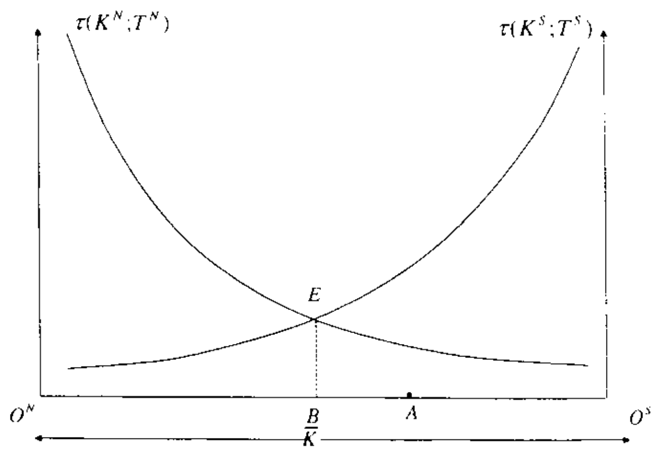

Figure 5.2: Capital market equilibrium

Choice of pollution levels

In the presence of capital mobility, the gross domestic product and the gross national product are not the same, that is, $C^j \neq Y^j$. We have $C^N = Y^N + rI$ and $C^S = Y^S - rI$, where rI represents net factor income from abroad. Thus, the respective social welfare levels can be expressed as:

$$
\begin{aligned}
U^N(T^N, T^S) &= (\bar{K}^N - I(T^N, T^S))^{\alpha} T^{N\beta} + r(T^N, T^S) I(T^N, T^S) + \gamma\Phi(\bar{T} - T^W); \quad (5.12)\\
U^S(T^N, T^S) &= (\bar{K}^S + I(T^N, T^S))^{\alpha} T^{S\beta} - r(T^N, T^S) I(T^N, T^S) + \gamma\Phi(\bar{T} - T^W). \quad (5.13)
\end{aligned}
$$

Evidently, unlike in autarky, the marginal benefit of a country's own pollution policy is a function of the other country's level of pollution as well. Hence, there exists even more strategic interdependence in the determination of pollution policies of the two countries. We continue to assume that pollution policies are set non-cooperatively. At the Nash equilibrium, $\partial U^N/\partial T^N = 0$ and $\partial U^S/\partial T^S = 0$. These first-order conditions are respectively spelt out as:

$$
\begin{aligned}
\tau(\bar{K}^N - I(\cdot), T^N) + I(\cdot)\frac{\partial r(\cdot)}{\partial T^N} &= \gamma\Phi'(T - T^W); \quad (5.14)\\
\tau(\bar{K}^S + I(\cdot), T^S) - I(\cdot)\frac{\partial r(\cdot)}{\partial T^S} &= \gamma\Phi'(\bar{T} - T^W). \quad (5.15)
\end{aligned}
$$

Compared to autarky, it is seen that besides the *output effect* (mentioned already in section 5.2.1) there is an additional effect on the marginal benefit of T^j, namely, the *factor terms-of-trade effect*. This is captured by the terms $I\partial r/\partial T^N$ and $I\partial r/\partial T^S$. The North (South) being the creditor (debtor) country, an increase in r, due to an increase in the resource input use, implies a positive (negative) terms-of-trade effect for the North (South). Both the output and the factor terms-of-trade effects on the marginal benefits are critical in understanding how the optimal pollution policies differ from their autarky levels.

Recalling that $K^N \equiv \bar{K}^N - I$ and $K^S \equiv \bar{K}^S + I$ the expressions for I in (5.11) and those for the marginal product of capital in (5.2) imply

$$
\frac{\partial r}{\partial T^N} = \frac{\alpha\tau^N}{\bar{K}}; \quad \frac{\partial r}{\partial T^S} = \frac{\alpha\tau^S}{\bar{K}}. \quad (5.16)
$$

We now substitute (5.16) into (5.14) and (5.15) and rewrite the first-order conditions as:

$$
\begin{aligned}
\bar{f}^N(T^N, I(\cdot)) \equiv f^N(T^N, T^S) \equiv \tau(K^N, T^N)\left[1 + \frac{\alpha I(T^N, T^S)}{\bar{K}}\right] &= \gamma\Phi'(\bar{T} - T^W); (5.17)\\
f^S(T^S, I(\cdot)) \equiv f^S(T^N, T^S) \equiv \tau(K^S, T^S)\left[1 - \frac{\alpha I(T^N, T^S)}{\bar{K}}\right] &= \gamma\Phi'(\bar{T} - T^W). (5.18)
\end{aligned}
$$

In each equation the l.h.s. represents the marginal benefit and the r.h.s. is the marginal cost of T^j. The two equations give rise to the respective reaction functions, R^N and R^S, for North and South. These are shown graphically in Figure 5.3. It is straightforward to establish that the respective second-order conditions hold under the following "regularity" condition (R1):

$$\alpha < \frac{\bar{K}^N + \bar{K}^S}{2(\bar{K}^N - \bar{K}^S)}. \qquad (R1)$$

See Appendix A for detailed derivations.

Note that if $\bar{K}^N - \bar{K}^S \leq 2/3\bar{K}^N$, the r.h.s. of (R1) is greater than or equal to one; since $\alpha < 1$, the condition (R1) is not binding. It is binding if and only if $\bar{K}^N - \bar{K}^S > 2/3\bar{K}^N$. In this case the upper limit on α ensures that the direct effect on the marginal benefits, $\bar{f}^j(T^j, I)$ $(j = N, S)$, of increase in pollution, T^j, which is negative in sign, outweighs the positive (indirect) effect on $\bar{f}^j$ through its impact on the level of FDI, I.

We assume that (R1) holds. Moreover, under (R1) the Nash equilibrium is unique and T^N and T^S are strategic substitutes of each other. See Appendix A for detailed derivations.

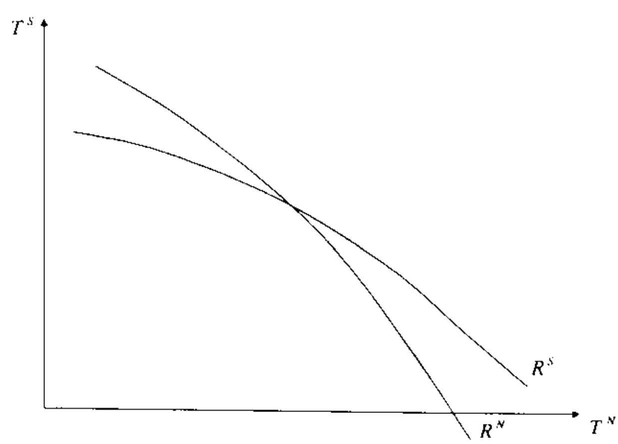

Figure 5.3: Best response functions

Pollution levels and the level of FDI

We now turn to the equilibrium FDI. Observe that the first-order conditions (5.17) and (5.18) together with the capital market clearing equation (5.9) constitute the equilibrium conditions under capital mobility. These are three equations in three variables: I, T^N and T^S.

It will be mathematically convenient to collapse these three into two equations in two variables, I and η, where recall that $\eta = T^{N\theta}/(T^{N\theta} + T^{S\theta})$. The first equation, which is (5.11), is derived from the capital market clearing condition (5.9). The second is derived by taking the ratio of the two first-order conditions (5.17) and (5.18) and substituting the capital market equation (5.9) in it. That is:

$$\left(\frac{1+\frac{\alpha I}{\bar{K}}}{1-\frac{\alpha I}{\bar{K}}}\right)^{\frac{1}{1-\beta}} = \left(\frac{T^N}{T^S}\right)^{\frac{1-\alpha-\beta}{(1-\alpha)(1-\beta)}} = \left(\frac{\eta}{1-\eta}\right)^{\frac{1-\alpha-\beta}{\beta(1-\beta)}}. \tag{5.19}$$

Equations (5.11) and (5.19) solve I and η. By definition η is positively related to T^N/T^S. Hence these equations solve I and T^N/T^S. These solutions are illustrated graphically in Figure 5.4. The curve FDI_1 graphs eq. (5.11) whilst FDI_2 graphs eq. (5.19). It is straightforward to see that eqs. (5.11) and (5.19) respectively generate negatively and positively sloped schedules in I and T^N/T^S space.[6]

As shown in Figure 5.4, FDI_1 has the vertical intercept at $\bar{K}^N$ and it is asymptotic to the horizontal axis at $-\bar{K}^S$. The FDI_2 curve has the vertical intercept at $-\bar{K}/\alpha$ and is

[6] Using the definition of η, (5.11) could be expressed in terms of T^N/T^S as:

$$I = \bar{K}^N - \frac{(T^N/T^S)^\theta}{1+(T^N/T^S)^\theta}\bar{K}.$$

Hence, $\lim_{T^N/T^S\to\infty} I = -\bar{K}^S$; $\lim_{T^N/T^S\to 0} I = \bar{K}^N$. These limits define the shape of FDI_1 curve. Turning next to (5.19),

$$\left(\frac{1+\frac{\alpha I}{\bar{K}}}{1-\frac{\alpha I}{\bar{K}}}\right) = \left(\frac{T^N}{T^S}\right)^{1-\theta} \Rightarrow \frac{\alpha}{\bar{K}}I = 1 - \frac{2}{1+(T^N/T^S)^\theta}$$

In the limit, $\lim_{T^N/T^S\to\infty} I = \bar{K}/\alpha$; $\lim_{T^N/T^S\to 0} I = -\bar{K}/\alpha$, which defines the shape of the FDI_2 curve.

asymptotic to the horizontal axis at $\bar{K}/\alpha$. Thus a solution exists and it is unique at point O. It follows directly from eq. (5.19) that as long as $I > 0$, $T^{N^o}/T^{S^o} > 1$, where superscript

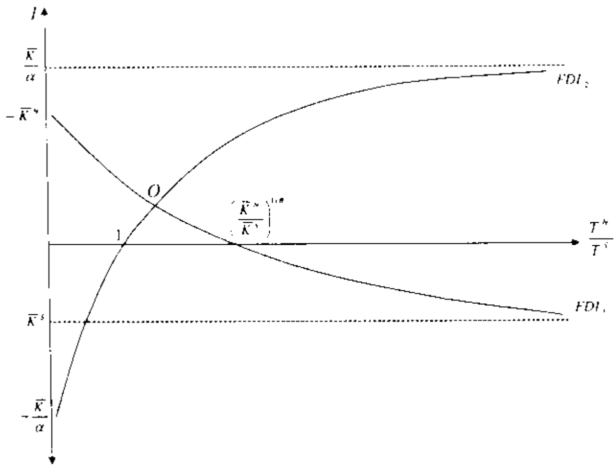

Figure 5.4: Locus of FDI_1 and FDI_2

"o" denotes non-cooperation. Given $T^{N^o} > T^{S^o}$, it follows from (5.9) that $K^{N^o} > K^{S^o}$. Hence,

Proposition 2: *At the free FDI equilibrium,*

(i) the pollution contribution of the North is higher than that of the South, and

(ii) (despite capital outflow from North to South) capital in use in the North exceeds that in the South.

That

$$K^{N^o} > K^{S^o} \Rightarrow I^o < \frac{\bar{K}^N - \bar{K}^S}{2}. \tag{5.20}$$

The last inequality will be used later to compare FDI at the non-cooperative equilibrium with that at the cooperative equilibrium.

Comparison with autarky

The groundwork is now ready to compare the pollution level to that in the absence of

FDI. Note that if we substitute $I = 0$ in the marginal benefit expressions (l.h.s.) in (5.17) and (5.18), these equations reduce to their counterparts in autarky. On the other hand, the marginal cost schedule is the same between autarky and free movement of capital. Therefore, the comparison between autarky and capital mobility can be characterized by an exogenous change in I even if it is an endogenous variable.

Ceteris paribus, if the marginal benefit of T^j increases or decreases with I, the equilibrium T^j in the presence of capital movement is greater or smaller than in the absence of capital movement. In Appendix B, we derive that, for any $I > 0$, $\partial \bar{f}^N/\partial I < 0$ and $\partial \bar{f}^S/\partial I > 0$. That is, everything else the same, FDI causes the marginal benefit schedule for North to shift down and that for South to shift up. But, at the same time, since marginal costs are a function of aggregate world pollution, capital mobility will induce a movement along the marginal cost curve. This will also impact the equilibrium level of pollution.

Taking into account these effects, on both the marginal cost and marginal benefits, we show that the overall change in regional pollution levels in response to FDI is that $dT^N/dI < 0$ and $dT^S/dI > 0$ (see Appendix B for mathematical proofs). Hence,

Proposition 3: *As economies move from autarky to free FDI equilibrium, the pollution generation from the North decreases and that from the South goes up.*

Intuitively, since capital and resource input are complements of each other in production, South accommodates capital inflow by releasing more of the resource input and North responds to capital outflow by releasing less of the resource input to the market.

We next look at aggregate global pollution.

We have just seen that, with FDI, T^N falls and T^S rises, and, moreover, the changes in T^N or T^S are the net effect of output and factor terms-of-trade effects which move in opposite ways. Thus, it is not very straightforward to predict the impact of FDI on global pollution, which is the sum of T^N and T^S.

However, the global pollution level at the free FDI non-cooperative equilibrium can be compared to that at the autarky equilibrium. Consider the free FDI first-order conditions (5.17) and (5.18). Substituting the expressions for τ^N and τ^S from (5.2) in the l.h.s. of each, manipulating and adding up, it is obtained that

$$(\bar{K}^N - I)^{\frac{\alpha}{1-\beta}}\left(1+\frac{\alpha I}{\bar{K}}\right)^{\frac{1}{1-\beta}} + (\bar{K}^S + I)^{\frac{\alpha}{1-\beta}}\left(1-\frac{\alpha I}{\bar{K}}\right)^{\frac{1}{1-\beta}} = T^W\left[\frac{\gamma}{\beta}\Phi'(\bar{T}-T^W)\right]^{\frac{1}{1-\beta}} \equiv g(T^W). \tag{5.21}$$

Next, express the l.h.s. of the above equation in terms of η, by using (5.11) and (5.19):

$$h(\eta) \equiv \frac{2^{\frac{1}{1-\beta}}\left[\eta^{\frac{1-\alpha}{\beta}} + (1-\eta)^{\frac{1-\alpha}{\beta}}\right]}{\left[\eta^{\frac{1-\alpha-\beta}{\beta}} + (1-\eta)^{\frac{1-\alpha-\beta}{\beta}}\right]^{\frac{1}{1-\beta}}}\bar{K}^{\frac{\alpha}{1-\beta}}.$$

Hence, (5.21) can be re-stated as

$$h(\eta) = g(T^W).$$

Now turn to the autarky first-order condition (eq. (5.4)), which could be similarly manipulated and summed up to yield

$$\lambda \equiv \bar{K^N}^{\frac{\alpha}{1-\beta}} + \bar{K^S}^{\frac{\alpha}{1-\beta}} = g(T^W). \tag{5.22}$$

Since $g(\cdot)$ is increasing in T^W, it follows that $T^{W^o} \gtrless T^{W^a}$ as $h(\eta) \gtrless \lambda$. It is shown in Appendix C that $h(\eta) > \lambda$, hence, as one would expect,

Proposition 4: *As compared to autarky, global pollution is higher with capital mobility.*

5.2.3 Welfare implications

So far we have focused on the effect of FDI on environment. How it affects aggregate welfare of countries is analyzed below. In general, the welfare effects take the form of *direct* and *indirect* effects of FDI on the factor terms-of-trade, the latter arising due to the effect of capital flows on the environment policies of countries that, in turn, affect the factor terms-of-trade. Moreover, with pollution impacting welfare directly, the change in the *own* and *other country's* environment policy also has a *direct* bearing on the welfare of a particular country. These effects are similar to those analyzed by Killinger (2000).

As in Rauscher (1997), we show below that welfare losses are possible, both at regional and global levels, even as countries adjust their environmental policies in an optimal fashion.

We can state the respective welfare functions as:

$$\begin{aligned} U^N(T^N, T^S; I) &= Y(\bar{K}^N - I, T^N) + r(\bar{K}^N - I, T^N)I + \gamma\Phi(\bar{T} - T^W); \\ U^S(T^N, T^S; I) &= Y(\bar{K}^S + I, T^S) - r(\bar{K}^S + I, T^S)I + \gamma\Phi(\bar{T} - T^W). \end{aligned}$$

In each expression the first two terms equal the consumption of the product and the last term represents utility from the environmental good.

The welfare effects of FDI can be evaluated by dU^j/dI (even though I is an endogenous variable). We have

$$\frac{dU^N}{dI} = \underbrace{\underset{(+)}{\frac{\partial r^N}{\partial I}}I + \underset{(+)}{\frac{\partial r^N}{\partial T^N}}\underset{(-)}{\frac{dT^N}{dI}}I}_{(+)} + \underset{(-)}{\left(\tau^N - \gamma\Phi'\right)}\underset{(-)}{\frac{dT^N}{dI}} - \gamma\Phi'\underset{(+)}{\frac{dT^S}{dI}} \gtrless 0;; \tag{5.23}$$

$$\frac{dU^S}{dI} = \underbrace{-\underset{(-)}{\frac{\partial r^S}{\partial I}}I - \underset{(+)}{\frac{\partial r^S}{\partial T^S}}\underset{(+)}{\frac{dT^S}{dI}}I}_{(+)} + \underset{(+)}{\left(\tau^S - \gamma\Phi'\right)}\underset{(+)}{\frac{dT^S}{dI}} - \gamma\Phi'\underset{(-)}{\frac{dT^N}{dI}} > 0. \tag{5.24}$$

There are four effects at play, represented by the four terms in the r.h.s. of each equation. The first is the direct effect of investment on the factor terms-of-trade. Both the countries have a gain on this account due to better allocation of capital between them. The second is the indirect effect on the factor terms-of-trade as countries adjust their environmental policies in response to change in the level of FDI, which in turn affects the return on capital. Complementarity between productive inputs implies that $\partial r^j/\partial T^j > 0$. This, together with $dT^N/dI < 0$ and $dT^S/dI > 0$ implies that the second effect is negative for both the countries. The sum of the *direct and indirect effects* may be positive or negative. However, as is shown in Appendix D, the sum of these two effects is unambiguously positive for both the countries.

The third is the *direct* welfare effect through a change in the country's *own emissions.* This is the net effect given by the difference in the marginal benefit and marginal cost of own pollution. and how T^N and T^S is affected by I. In view of the first-order conditions (5.17) and (5.18), $\tau^N < \gamma\Phi' < \tau^S$, which yields that the sign of this effect is positive for both North and South.[7] It is positive because of optimal adjustment of individual environmental policies by the governments of North and South.

The last is the *transboundary pollution effect* that arises due to the *spillover of pollution from the partner country.* Clearly, since North reduces its pollution and South increases it, the sign of this effect is negative (positive) for the North (South).

The overall welfare change is first examined for the South. It is found that South would always experience an increase in its welfare from FDI. This is because, as discussed earlier, the sum of the direct and indirect factor terms-of-trade effects, the own pollution change effect and the transboundary pollution effect are all positive for the South.

Next, the welfare change for the North is analyzed. It is derived (in Appendix D) that even for the North the direct factor terms-of-trade gains dominate the indirect losses in it, such that North also experiences net factor terms-of-trade gains. Moreover, as the South, North also has gains on account of own pollution change effect. However, inspite of these positive effects. the overall change in North's welfare may still be inconclusive as North has an additional source of welfare loss, which is due to the negative spillover effect of higher pollution in the South. Hence, in general, North may lose or gain from FDI.

However, if the capital endowment differences between the North and South are small enough, and such that the equilibrium FDI is small enough, North unambiguously incurs

[7]Note that from (5.17) and (5.18) we have

$$\begin{aligned} \tau^N < \tau^N\left(1 + \frac{\alpha I}{K}\right) &= \gamma\Phi' \\ \tau^S > \tau^N\left(1 - \frac{\alpha I}{K}\right) &= \gamma\Phi'. \end{aligned}$$

a welfare loss. The different effects work as follows. As $\bar{K}^N \to \bar{K}^S$, then $I \to 0$ and the direct and indirect factor terms-of-trade effects in (5.23) and (5.24) wash out. Given optimal pollution policy setting behavior the own pollution effect (the third term) also vanishes (as $I \to 0$) as this is equivalent to a move toward autarky equilibrium. This leaves the pollution spillover effect, which could be expressed for the North as: $\lim_{I\to 0} dU^N/dI = -\gamma\Phi'(dT^S/dI) < 0$. Thus, in the limiting case of FDI being very small, North loses from capital mobility unambiguously.

Another intuitive way to think of this result is as done by C-T (1995) and Copeland (2000), both of which are in the context of global pollution. Although both papers are about trade in goods and not factor mobility, the logic used therein might be useful to explain the welfare effects in our model.

Since pollution is a global externality, an increase in pollution in the South raises its marginal damage for the North, through the transboundary pollution spillover effect, inducing the North to reduce its pollution. Hence, North's and South's pollution levels are strategic substitutes of each other. Given that capital, K, and polluting input, T, are complements in production, in the free capital mobility regime, as capital moves from North to South this increases the marginal benefit of pollution in the South and, hence, South's pollution rises. On the other hand, North experiences a decline in the marginal benefit from the polluting input and, hence, its pollution falls.

Thus, a direct effect of free capital mobility is that it commits countries to different environment policies. Free FDI commits South to credibly commit to pollute more. Thus, South not merely experiences standard factor terms-of-trade gains, but also gets a strategic advantage in the environment policy game as free capital mobility induces a credible commitment by the North to pollute less (as T^N and T^S are strategic substitutes). Therefore, free capital mobility puts North at a strategic disadvantage in the environment policy game. Consequently, North's gains in standard factor terms-of-trade are offset by its losses in the environment gain due to higher transboundary pollution spillovers from South. In the special case where the level of FDI is small enough and hence the standard gains from trade in capital are small enough, North could even lose from capital mobility.

We now analyze the effect of FDI on world welfare, $U^W = C^N + C^S + 2\gamma\Phi(\bar{T} - T^W)$. Totally differentiating U^W with respect to I, we get

$$\frac{dU^W}{dI} \equiv \frac{dU^N}{dI} + \frac{dU^S}{dI} = \underbrace{\left(\frac{\partial r^N}{\partial I}I + \frac{\partial r^N}{\partial T^N}\frac{dT^N}{dI}I\right)}_{(+)} + \underbrace{\left(-\frac{\partial r^S}{\partial I}I - \frac{\partial r^S}{\partial T^S}\frac{dT^S}{dI}I\right)}_{(+)}$$

$$+\underbrace{(\tau^N - \gamma\Phi')\frac{dT^N}{dI}}_{(+)} + \underbrace{(\tau^S - \gamma\Phi')\frac{dT^S}{dI}}_{(+)} \underbrace{- \gamma\Phi'\frac{dT^W}{dI}}_{(-)} \gtrless 0. \quad (5.25)$$

We have already seen that the net factor terms-of-trade change is positive for both the countries, implying that the first two collection of terms in the r.h.s. of (5.25) are positive. Moreover, optimal adjustment of environmental policies implies that the respective own pollution effects (depicted by the next two terms) are positive; this is also explained earlier under the discussion on regional welfare effects. But, the increase in global pollution implies a welfare loss, leaving the change in aggregate global welfare unclear.

However, in the special case of capital endowment differences between the North being small enough, such that equilibrium I being small enough, the factor terms-of-trade and the own pollution effects vanish: only the transboundary pollution effect remains. Since, even if $I \to 0$, $dT^W/dI > 0$, the world welfare declines.

The various welfare implications are summarized below.

Proposition 5: *As countries move from autarky to free capital mobility:*

(i) North may lose or gain in terms of welfare. In the special case where $\bar{K}^N - \bar{K}^S$ is sufficiently small such that the equilibrium FDI is small enough, North suffers a welfare loss. On the other hand, South unambiguously gains irrespective of the equilibrium level of FDI.

(ii) In general, the effect on global welfare is ambiguous. In the special case discussed in (i)

above, global welfare is less than in the autarky equilibrium.

5.2.4 Cooperation between regions

Evidently the countries of the world are striving toward cooperation with each other on transboundary environmental issues. For example, the Montreal Protocol to deal with ozone depleting substances, the Kyoto Protocol to address issues of greenhouse gas emissions and climate change, and the Convention on Biological Diversity to tackle the loss in flora and fauna, all emphasize the imperatives of international cooperation in dealing with the environmental concerns. In this subsection, we analyze the effect of environment policy cooperation between the governments of North and South.

In the cooperative equilibrium, regional governments set policies that are consistent with maximization of their joint welfare. Hence, by definition, cooperation implies that global welfare is higher than that under non-cooperation.[8] In what follows, the effect of cooperation on the level of FDI and (regional and global) pollution levels are analyzed.

Global welfare is expressed algebraically by

$$U^W = C^N + C^S + 2\gamma\Phi(\bar{T} - T^W), \tag{5.26}$$

the sum of individual country welfares. Substituting for $C^N = Y^N + rI$ and $C^S = Y^S - rI$ into this,

$$\begin{aligned} U^W &= Y(\bar{K}^N - I(\cdot), T^N) + r(\bar{K}^N - I(\cdot), T^N)I(\cdot) + Y(\bar{K}^S + I(\cdot), T^S) \\ &\quad - r(\bar{K}^S + I(\cdot), T^S)I(\cdot) + 2\gamma\Phi(\bar{T} - T^N - T^S). \end{aligned} \tag{5.27}$$

When this is maximized with respect to T^N and T^S, the two first-order conditions are:

$$\tau^N = \tau^S (\equiv \tau) = 2\gamma\Phi'(\bar{T} - T^W). \tag{5.28}$$

[8]If appropriate lumpsum side payments are made then each country is better off.

Utilizing $\partial \tau^j / \partial T^j < 0$, $j = N, S$ and $\Phi'' < 0$, it is easy to show that the second-order conditions hold.

The first-order conditions (in (5.28)) imply that the equilibrium charge on pollution is equalized between the North and the South. This is because, in joint welfare maximization, the factor terms-of-trade effects cancel out between the two regions. Also, capital market clearing implies $r^N = r^S = r$. Hence, global efficiency (through capital mobility and joint welfare maximization) implies factor rewards, τ and r, be equalized between North and South. This, in turn, implies the same level of employment of natural resource use by the two countries, that is, $T^{N^c} = T^{S^c}$ (superscript "c" denotes cooperation). The integration of global economy also entails that both countries choose the same amount of capital, namely $K^{Nc} = K^{Sc}$.

In the non-cooperative equilibrium considered earlier, the factor terms-of-trade effects explain the difference in the pollution charge and the optimal level of pollution chosen by countries, such that North employs more capital (and natural resource) than the South. In the cooperative equilibrium, since the factor terms-of-trade effects wash out (technology being the same between the two countries), $T^{N^c} = T^{Sc}$ and $K^{N^c} = K^{Sc}$.[9]

Since, by definition, $K^{Nc} = \bar{K}^N - I$, and $K^{Sc} = \bar{K}^S + I$, $K^{Nc} = K^{Sc}$ implies that

$$I^c = \frac{\bar{K}^N - \bar{K}^S}{2}. \tag{5.29}$$

Recall that in the non-cooperative equilibrium, $I^o < (\bar{K}^N - \bar{K}^S)/2$ (eq. (5.20)). Hence,

Proposition 6: *In moving from non-cooperative to cooperative equilibrium, the level of FDI increases.*

This is interesting as it amounts to saying that tightening of environmental policies through

[9]Does $T^{N^c} = T^{S^c}$ mean a case for international harmonization of environmental policies? As will be seen, this result is sensitive to the assumptions of symmetric labor endowments and absence of income effects on the demand for environmental quality in this model. Relaxation of either of these assumptions implies that $T^{N^c} \neq T^{S^c}$. Hence, there is little justification for harmonization. Many other implications of our basic model are, however, robust.

cooperation is conducive and *not* an impediment to FDI.

Proposition 6 is intuitively explained below in the course of analyzing the effects of cooperation on regional pollution levels are analyzed.

Effects on regional pollution levels

However, deriving the impact of the regime change on T^N and T^S is a more difficult task. Consider the following pair of equations:

$$\tau^N \left(1 + \frac{\alpha I(T^N, T^S)}{\bar{K}}(1-b)\right) = (1+b)\gamma\Phi'(\bar{T} - T^W); \tag{5.30}$$

$$\tau^S \left(1 - \frac{\alpha I(T^N, T^S)}{\bar{K}}(1-b)\right) = (1+b)\gamma\Phi'(\bar{T} - T^W). \tag{5.31}$$

Note that these equations represent the non-cooperative equilibrium or the cooperative equilibrium as $b = 0$ or 1. Hence, the movement from non-cooperation to cooperation can be captured through a comparative statics with respect to b in the interval $[0, 1]$.

Furthermore, let the eqs. (5.30) and (5.31) be viewed as having two endogenous variables, T^N and T^S, and two parameters, b and I (even though I is endogenous). Since we already know that I increases as the global economy moves from non-cooperative to cooperative equilibrium, we can assume $dI/db > 0 \;\forall\; b \in [0, 1]$. Effectively then, eqs. (5.30)-(5.31) implicitly define

$$T^N = T^N\left(b, I(b)\right); \quad T^S = T^S\left(b, I(b)\right), \quad \text{where } \frac{dI}{db} > 0. \tag{5.32}$$

The partials $\partial T^N/\partial b$ and $\partial T^S/\partial b$ capture the *direct effects* of the regime change at given I. The partials $(\partial T^j/\partial b)(dI/db)$, $j = N, S$ indicate the *indirect effects* through the accompanying change in I. These effects are now analyzed in turn. Particularly, as will be seen, the direct effects explain why FDI is higher in the cooperative equilibrium.

It is proven in Appendix E that

$$\frac{\partial T^N}{\partial b} < 0; \quad \frac{\partial T^S}{\partial b} \gtrless 0. \tag{5.33}$$

That is, the direct effects of cooperation are that North adopts a stricter environment policy whilst South may adopt a stricter or a more lenient policy.

Intuitively, there are two direct effects due to cooperation: internalization of the public good aspect of global pollution and nullification of factor terms-of-trade effects. These effects work as follows. When governments act non-cooperatively, they take into account the disutility-cost of pollution imposed on its nationals only. By comparison, in the cooperative equilibrium optimal pollution generation from each country is determined by taking into consideration the disutility-cost of pollution of the other country as well. Hence less pollution is released to the market in each country, i.e. T^N and T^S both fall.

Also, under non-cooperation there are terms-of-trade effects (on r) of a change in T^N or T^S. This is positive for the North and negative for the South.[10] Under cooperative behavior, however, joint welfare is considered and, therefore, there are no terms-of-trade effects. Hence, the absence of terms-of-trade effects implies that T^N will be smaller and T^S will be larger. These effects are summarized in columns two and three of Table 1.

The net direct effect of cooperation without any change in FDI is then that T^N falls unambiguously whilst T^S may increase or decrease.

These direct effects on T^N and T^S at given I explain why FDI increases from the non-cooperative to the cooperative equilibrium. As T^N falls, at the original level of FDI, the marginal product of capital in the North falls (since capital and resource input are complementary to each other). In the South, suppose T^S rises. Then, at the original level of FDI, the marginal product of capital rises. Hence, starting from $r^N = r^S$, the changes in T^S and T^S imply $r^N < r^S$. This induces further outflow of capital from the North to the South. Even when T^N falls, we have seen that it is an outcome of internalization and terms-of-trade effects which work in opposite ways. Hence, it is expected that the magnitude of decrease in T^S is relatively small. Indeed, it is shown in Appendix E that $|\partial T^S/\partial b| < |\partial T^N/\partial b|$, when

[10] As shown earlier, both $\partial r/\partial T^N$ and $\partial r/\partial T^S$ are positive; but an increase in r means an improvement (a deterioration) of factor terms-of-trade for the North (South).

$\partial T^S/\partial b < 0$. Thus, even though r^S falls as T^S increases, $r^N - r^S < 0$, at the original level of FDI. This induces FDI to increase. In summary, irrespective of whether T^S increases or decreases, the movement from non-cooperation to cooperation implies higher FDI.

We next ascertain the *indirect effects* of the regime change through the change in FDI. It is derived in Appendix E that for any given b, $\partial T^N/\partial I < 0$ and $\partial T^S/\partial I > 0$. Intuitively, an increase in I means less capital at work in the North, a lower marginal product of T^N and, thus, a lower marginal benefit from T^N. As a result, T^N falls. Just the opposite holds in the South, and T^S tends to rise as I increases.[11]

In summary, we then have that T^N falls whilst T^S may increase or decrease, on account of the regime change at given FDI. An increase in FDI induces T^N to fall and T^S to rise. Combining the two effects,

Proposition 7: *Compared to non-cooperation, at the cooperative equilibrium the pollution generated from North is less and that from South may be more or less.*

Effects on global pollution

Because of conflicting effects on it, the change in T^S is likely to be small. With T^N declining unambiguously one would conjecture that global pollution would decline. This is correct. Indeed, a stronger result holds, i.e.,

Proposition 8: *The global pollution at the cooperative FDI equilibrium is less than that under autarky.*

This proposition holds a strong message for staunch environmentalists who are typically opposed to freer FDI movement in the global economy. It says that even when global

[11] In more detail, referring back to eqs. (5.17) and (5.18), these are the output effects of an increase in T^j. There are also the factor terms-of-trade effects, captured by the terms $\alpha I/\bar{K}$ for the North and $-\alpha I/\bar{K}$ for the South. An increase in I increases $|\alpha I/\bar{K}|$. Hence, the marginal benefit from T^N tends to increase for the North and that from T^S tends to decrease for the South. Thus, the factor terms-of-trade effects run counter to the output effects. However, the latter remains dominant.

environment is the sole concern, it is better in a regime of free FDI, accompanied by global cooperation (coordination) on pollution policies than in the absence of FDI.

Proposition 8 is proved in Appendix F.

By substituting τ^N and τ^S given in (5.2) into (5.28) and manipulating, we first obtain

$$(\bar{K}^N - I^c)^{\frac{\alpha}{1-\beta}} + (\bar{K}^S + I^c)^{\frac{\alpha}{1-\beta}} = 2^{\frac{1}{1-\beta}} T^W \left[\frac{\gamma}{\beta}\Phi'(\bar{T} - T^W)\right]^{\frac{1}{1-\beta}}.$$

Using $I^c = (\bar{K}^N - \bar{K}^S)/2$, this is simplified to

$$\Omega \equiv 2^{-\frac{(\alpha+\beta)}{1-\beta}} \bar{K}^{\frac{\alpha}{1-\beta}} = \left[\frac{\gamma}{\beta}\Phi'(\bar{T} - T^W)\right]^{\frac{1}{1-\beta}} T^W \equiv g(T^W). \tag{5.34}$$

This equation solves for T^{W^c}.

Recall that under autarky, a similar manipulation of the first-order conditions yielded

$$\Lambda \equiv \bar{K^N}^{\frac{\alpha}{1-\beta}} + \bar{K^S}^{\frac{\alpha}{1-\beta}} = g(T^W);$$

see (5.22). It is derived in Appendix F that $\Omega < \Lambda$. Given that $g'(T^W) > 0$, it then follows that $T^{W^c} < T^{W^a}$.

Hence, the full internalization of the global environmental externality entails that aggregate world pollution is even lower than under autarky.

The analysis of our basic model of FDI and environment is complete at this stage. In what follows, we relax some assumptions in turn and analyze their implications.

5.3 Asymmetry in labor endowments

First, we relax the assumption on symmetry of labor endowments. Specifically, let North be the human-capital (or skilled-labor) abundant country in comparison with the South, i.e. $\bar{L}^N > \bar{L}^S$. It will be shown that most of the results of our basic model continue to hold.

Recall that the production functions are:

$$Y^N = \bar{L^N}^{1-\alpha-\beta} {K^N}^{\alpha} {T^N}^{\beta}; \tag{5.35}$$

$$Y^S = \bar{L^S}^{1-\alpha-\beta} {K^S}^{\alpha} {T^S}^{\beta}. \tag{5.36}$$

5.3.1 Autarky

In autarky, the first-order conditions with respect to T^N and T^S are the same as (5.4), except that $\bar{L}^N$ and $\bar{L}^S$ may not be equal to 1. We would now have:

$$\begin{aligned}
\tau^N(\equiv \beta \bar{L^N}^{1-\alpha-\beta} \bar{K^N}^{\alpha} {T^N}^{\beta-1}) &= \gamma\Phi'(\bar{T} - T^W);\\
\tau^S(\equiv \beta \bar{L^S}^{1-\alpha-\beta} \bar{K^S}^{\alpha} {T^S}^{\beta-1}) &= \gamma\Phi'(\bar{T} - T^W).
\end{aligned}$$

Dividing these conditions yields

$$\frac{T^{Na}}{T^{Sa}} = \left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{1-\frac{\alpha}{1-\beta}} \left(\frac{\bar{K}^N}{\bar{K}^S}\right)^{\frac{\alpha}{1-\beta}} > 1, \text{ since } \bar{L}^N > L^S \text{ and } \bar{K}^N > \bar{K}^S.$$

Thus, North pollutes more than the South and Proposition 1 continues to hold.

Note, however, that when $\bar{L}^N > \bar{L}^S$ an additional condition is required for capital to move from North to South, namely, $\bar{K}^N/\bar{L}^N > \bar{K}^S/\bar{L}^S$. This is equivalent to relative capital endowment ratio of the North to be higher than that of the South. This would imply $r^{Na} < r^{Sa}$.[12] The reason being, everything else the same, a higher labor endowment implies a relatively higher marginal product of capital in the North. Only when the relative capital endowment of North to that of the South is larger than the corresponding ratio of the labor endowments would capital earn a higher return in the South, and form the basis for North to export capital to the South.

[12]This is proved by substituting equality of τ^js from the first-order conditions (that are similar to (5.4)) into the ratio of marginal products of capital, such that

$$\begin{aligned}
\frac{r^{Na}}{r^{Sa}} &= \left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{1-\alpha-\beta} \left(\frac{\bar{K}^N}{\bar{K}^S}\right)^{\alpha-1} \left(\frac{T^N}{T^S}\right)^{\beta}\\
&= \left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{1-\alpha-\beta} \left(\frac{\bar{K}^N}{\bar{K}^S}\right)^{\alpha-1} \left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{\beta\left(\frac{1-\alpha-\beta}{1-\beta}\right)} \left(\frac{\bar{K}^N}{\bar{K}^S}\right)^{\beta\left(\frac{\alpha}{1-\beta}\right)} = \left(\frac{\bar{L}^N/\bar{L}^S}{\bar{K}^N/\bar{K}^S}\right)^{\frac{1-\alpha-\beta}{1-\beta}}.
\end{aligned}$$

This is less than 1 when $\bar{L}^N/\bar{L}^S < \bar{K}^N/\bar{K}^S$.

5.3.2 Free capital mobility

Non-cooperation in respect of environment policy

Analogous to the symmetric labor-endowment model, the solution to the level of FDI is obtained from the capital market clearing condition, $r^N = r^S$. This is equivalent to:

$$\begin{aligned} \bar{L^N}^{1-\alpha-\beta}(\bar{K}^N - I)^{\alpha-1}T^{N\beta} &= \bar{L^S}^{1-\alpha-\beta}(\bar{K}^S - I)^{\alpha-1}T^{S\beta} \\ \Leftrightarrow \frac{\bar{K}^N - I}{\bar{K}^S + I} &= \left(\frac{T^N}{T^S}\right)^{\frac{\beta}{1-\alpha}}\left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{\frac{1-\alpha-\beta}{1-\alpha}} \qquad (5.37) \\ \Rightarrow I &= \bar{K}^N - \eta'\bar{K}, \qquad (5.38) \end{aligned}$$

where $\eta' = \frac{l^{1-\theta}T^{N\theta}}{l^{1-\theta}T^{N\theta}+T^{S\theta}}$ and $l \equiv \bar{L}^N/\bar{L}^S$ by definition. Eq. (5.38) is the analog of (5.11).

Assuming non-cooperative behavior in respect to environment policy it is now shown that Propositions 2 and 3 also hold. That is, (a) a movement from autarky to free capital mobility induces the North to reduce its pollution, and South to raise it, (b) at the capital mobility equilibrium North pollutes more than the South, and (c) inspite of capital movement out of the North into the South, North employs a larger absolute quantity of capital than the South. The method of proof of (a) is similar to that in the basic model (Appendix B). Similarly, (b) and (c) are also easy to show.[13]

[13] Parallel to the calculations in the symmetric case, the first-order conditions of the free capital mobility equilibrium could be collapsed into

$$\begin{aligned} \left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{1-\alpha-\beta}\left(\frac{K^N}{K^S}\right)^{\alpha}\left(\frac{T^N}{T^S}\right)^{\beta-1} &= \frac{1-\alpha I/\bar{K}}{1+\alpha I/\bar{K}} \\ \Leftrightarrow \left(\frac{T^N}{T^S}\right) &= \left(\frac{1-\alpha I/\bar{K}}{1+\alpha I/\bar{K}}\right)^{-\frac{1}{1-\beta}}\left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{\frac{1-\alpha-\beta}{1-\beta}}\left(\frac{K^N}{K^S}\right)^{\frac{\alpha}{1-\beta}}. \end{aligned}$$

Substituting for the ratio K^N/K^S from (5.37) into the r.h.s., the above reduces to

$$\left(\frac{T^N}{T^S}\right)^{\frac{1-\alpha-\beta}{1-\alpha}} = \left(\frac{1+\alpha I/\bar{K}}{1-\alpha I/\bar{K}}\right)\left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{\frac{1-\alpha-\beta}{1-\alpha}}.$$

Since $\bar{L}^N > \bar{L}^S$ the r.h.s. exceeds one. Hence $T^{N^o} > T^{S^o}$. Further, complementarity of resource and capital entails that $K^{N^o} > K^{S^o}$. Mathematically, this could be seen from eq. (5.37), whose r.h.s. has both $T^{N^o}/T^{S^o} > 1$ and $\bar{L}^N/\bar{L}^S > 1$, implying $K^{N^o} > K^{S^o}$.

As for the impact on global pollution, the conclusion derived in Proposition 4 does not change when we consider differences in labor endowments between countries. That is, in relation to autarky, global pollution rises.

Cooperation between countries

Unlike in the symmetric case, the pollution ranking in the cooperative equilibrium differs between the two countries. Specifically, now North pollutes more than the South.[14] The underlying reason is as follows. Since labor is complementary to capital and natural resource, (and in the symmetric case the natural resource and capital levels were the same between North and South,) now that $\bar{L}^N > \bar{L}^S \Rightarrow T^{N^c} > T^{S^c}$ and $K^{N^c} > K^{S^c}$ at the cooperative equilibrium. The latter implies $I^c < (\bar{K}^N - \bar{K}^S)/2$, i.e., similar to the basic model, inspite of capital mobility the level of FDI is well below its natural upper limit, which is $\bar{K}^N$. However, the result that cooperation leads to higher FDI than non-cooperation also holds even when $\bar{L}^N > \bar{L}^S$; that is, Proposition 6 also continues to be true.[15]

The impact on regional as well as global pollution levels are also qualitatively similar to the symmetric case. That is, a move from non-cooperative to cooperative environment policies leads the North to reduce its pollution, whilst South's policy response is ambiguous. The world pollution falls, nonetheless.[16] Hence, the results stated under Propositions 7 and 8 for the symmetric labor endowment model also hold.

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[14] In the cooperative setting, capital market clearing condition, $r^{N^c} = r^{S^c}$, entails

$$\frac{K^{N^c}}{K^{S^c}} = \left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{\frac{1-\alpha-\beta}{1-\alpha}} \left(\frac{T^{N^c}}{T^{S^c}}\right)^{\frac{\beta}{1-\alpha}}.$$

Next, the first-order conditions of the cooperative equilibrium imply

$$\frac{K^{N^c}}{K^{S^c}} = \left(\frac{\bar{L}^N}{\bar{L}^S}\right)^{-\frac{1-\alpha-\beta}{\alpha}} \left(\frac{T^{N^c}}{T^{S^c}}\right)^{\frac{1-\beta}{\alpha}}.$$

Equating the r.h.s. of the above two equations, $T^{N^c}/T^{S^c} = \bar{L}^N/\bar{L}^S > 1$. Utilizing this result in the capital market clearing condition (the first of the above two) we get $K^{N^c}/K^{S^c} = \bar{L}^N/\bar{L}^S > 1$.

[15] The method of proof is analogous to the symmetric case.

[16] Calculations similar to those contained in Appendices E and F derive these outcomes.

To repeat, all the results of the basic model for the autarky and free FDI equilibria (under non-cooperation) hold even when labor endowment differences are introduced. Further, even when there is cooperation in environment policies, most of the implications of the symmetric labor endowment model hold even when $\bar{L}^N > \bar{L}^S$. The differences under cooperation arise in respect of the ranking of pollution levels and capital use between the two countries. In the basic model cooperation led to equality of utilization of the two factor inputs, natural resource and capital. In particular, the equality in the use of the natural resource between the two countries meant harmonization. However, with asymmetry in labor endowments, at cooperative equilibrium North uses a higher level of natural resource (and hence pollutes more) than the South. This means that harmonization is not implied when labor endowments differ. Moreover, complementarity between factor inputs implies that it also employs a larger quantity of capital than the South.

5.4 Environment: a normal good

We now return to the neutral assumption on labor endowments, that $\bar{L}^N = \bar{L}^S$, and normalize them to unity. But we abandon our assumption of a quasi-linear utility function that implies no direct income effects on the demand for environmental good. We wish to capture that environment is a normal good, i.e., *ceteris paribus*, higher incomes lead to a greater demand for environmental quality. Toward this end, we postulate a utility function that is strictly concave in both the consumption and the environmental good. For tractability, let the utility function be log-linear.

$$\widetilde{U} = \ln C + \gamma \ln (\bar{T} - T^N - T^S); \quad \gamma > 0. \tag{5.39}$$

Note that the $\Phi(\cdot)$ function in the basic model takes a specific functional form here.

5.4.1 Autarky

As $C^j = Y^j$, $j = N, S$, we have $\widetilde{U}^j = \ln(Y^j) + \gamma \ln(\bar{T} - T^W)$. The optimal T^j is governed by

$$\frac{1}{Y(\bar{K}^j, T^j)} \frac{\partial Y(\bar{K}^j, T^j)}{\partial T^j} = \frac{\gamma}{\bar{T} - T^W}$$
$$\Leftrightarrow \frac{\tau(\bar{K}^j, T^j)}{Y(\bar{K}^j, T^j)} = \frac{\gamma}{\bar{T} - T^W}. \tag{5.40}$$

The l.h.s. and the r.h.s. of (5.40) are respectively the marginal benefit and marginal cost of pollution. Given a logarithmic form of the utility function, the marginal benefit from pollution is equal to the ratio of the marginal product of the natural resource input, τ^j and the initial level of output, Y^j. Hence the marginal benefit (i) increases with the marginal product of the resource, and (ii) decreases with the initial level of output. As earlier, (i) is the *output effect*. We call (ii) as the *income effect*. It is (ii) that was absent in the previous model, which captures that environment is a normal good. However, similar to the previous model, the marginal cost is increasing in total global pollution, T^W.

Eq. (5.40) is equivalent to

$$\tau(\bar{K}^j, T^j) = \frac{\gamma}{(\bar{T} - T^W)} Y^j, \tag{5.41}$$

which is the analog of (5.4). Note that the optimum resource charge/price, besides depending on the marginal utility from the environmental good, depends on the level of income, Y^j. It is in this sense that environment is a normal good, i.e., there are positive-income effects on the demand for environment.

From the production side, we have $Y^j = \bar{K^j}^{\alpha} {T^j}^{\beta}$ and $\tau^j = \beta \bar{K^j}^{\alpha} {T^j}^{\beta}$. Substitution of this into eq. (5.40) gives

$$\frac{\beta}{T^N} = \frac{\beta}{T^S} = \frac{\gamma}{\bar{T} - T^W}. \tag{5.42}$$

This yields the two best response functions:

$$T^N = \frac{\beta(\bar{T} - T^S)}{\beta + \gamma}; \quad T^S = \frac{\beta(\bar{T} - T^N)}{\beta + \gamma}. \tag{5.43}$$

These are two linear equations in T^N and T^S. The solutions are:

$$T^{N^a} = T^{S^a} = \frac{\gamma\beta}{2\gamma\beta + \gamma^2}\bar{T}. \tag{5.44}$$

Thus, in the autarky equilibrium, the pollution level is the same between the two countries. It is easy to show that the respective second-order conditions are satisfied, T^N and T^S are strategic substitutes and the Nash equilibrium is unique.[17]

Intuitively, when the utility is log-linear, the income effect of a particular country's pollution policy change exactly offsets its output effect. Hence, the equilibrium pollution contributions of the two countries are equalized.[18] However, the equality of pollution levels in equilibrium does *not* imply that τ^js are equalized. Since North is richer in capital, and capital is combined with the same quantity of the resource as in the South, the respective marginal products are such that $\tau^{N^a} > \tau^{S^a}$ and $r^{N^a} < r^{S^a}$. Therefore,

Proposition 9: *When environment is a normal good, unlike the case of environment being a neutral good, in autarky*

(i) the log-linear form of utility entails that the pollution levels of the two countries are equalized, and

(ii) the pollution charge in the North is higher than in the South.

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[17] Defining the l.h.s. of (5.42) as $\tilde{f}^j$ $(j = N, S)$, the partial with respect to T^j, R^j_j would be

$$R^j_j \equiv \tilde{f}^j_j - \frac{\gamma}{(\bar{T} - T^W)^2} = -\frac{\beta}{T^{j2}} - \frac{\gamma}{(\bar{T} - T^W)^2} < 0.$$

Moreover, $R^N_S = R^S_N = -\gamma/(\bar{T} - T^W)^2 < 0$. From these expressions for the partials, the determinant

$$\begin{vmatrix} \tilde{f}^N_N - \frac{\gamma}{(\bar{T}-T^W)^2} & -\frac{\gamma}{(\bar{T}-T^W)^2} \\ -\frac{\gamma}{(\bar{T}-T^W)^2} & \tilde{f}^S_S - \frac{\gamma}{(\bar{T}-T^W)^2} \end{vmatrix} \equiv \tilde{f}^N_N \tilde{f}^S_S - (\tilde{f}^N_N + \tilde{f}^S_S)\frac{\gamma}{(\bar{T}-T^W)^2} > 0.$$

Thus, at the autarky equilibrium, the second-order conditions hold and the equilibrium is stable (and unique).

[18] This result holds irrespective of how the resource endowments, the capital endowments or even the labor endowments of the two countries compare with each other. But it is sensitive to our assumptions of Cobb-Douglas technology.

5.4.2 Free capital mobility

Since $\bar{K}^N > \bar{K}^S$ and $T^{N^a} = T^{S^a}$, it also follows that $r^{N^a} < r^{S^a}$. Thus, when the two countries open up capital mobility, North exports capital to the South. In equilibrium, $r^N = r^S (\equiv r)$. This implicitly yields $I = I(T^N, T^S)$, and, this function is the same as in the zero-income effect case.

In the presence of capital mobility, the welfare expressions are:

$$\tilde{U}^N(T^N, T^S) = \ln(Y^N + rI) + \gamma \ln(\bar{T} - T^W);$$
$$\tilde{U}^S(T^N, T^S) = \ln(Y^S - rI) + \gamma \ln(\bar{T} - T^W).$$

In comparison with the first-order conditions (5.17) and (5.18) for the zero-income effect model, we now have the following (non-cooperative) Nash equilibrium conditions:

$$\tilde{f}^N(T^N, T^S) \equiv \frac{\tau^N \left(1 + \frac{\alpha I(T^N, T^S)}{\bar{K}}\right)}{Y^N + rI} = \frac{\gamma}{\bar{T} - T^W}; \tag{5.45}$$
$$\tilde{f}^S(T^N, T^S) \equiv \frac{\tau^S \left(1 - \frac{\alpha I(T^N, T^S)}{\bar{K}}\right)}{Y^S - rI} = \frac{\gamma}{\bar{T} - T^W}. \tag{5.46}$$

Note that in contrast to the zero-income effect (eqs. (5.17) and (5.18)), the marginal benefit from pollution emanating from either country is "discounted" by the total national income, $Y^N + rI$ and $Y^S - rI$ respectively for North and South.

Appendix G derives that the second-order conditions hold and the Nash equilibrium is unique and "stable" under the regularity condition

$$\alpha < \frac{\bar{K}^N \bar{K}^S + \bar{K^S}^2}{\bar{K^N}^2}. \tag{R2}$$

This is similar to (R1) in that it is restrictive only when $\bar{K}^N - \bar{K}^S$ is large enough. But it may be more or less restrictive than (R1). We assume that (R2) holds.

Given Cobb-Douglas technology, eqs. (5.45) and (5.46) reduce to

$$\frac{\beta}{T^N}\left(\frac{1+\frac{\alpha I(\cdot)}{\bar{K}}}{1+\frac{\alpha I(\cdot)}{\bar{K}^N}}\right) = \frac{\gamma}{\bar{T}-T^W}; \tag{5.47}$$

$$\frac{\beta}{T^S}\left(\frac{1-\frac{\alpha I(\cdot)}{\bar{K}}}{1-\frac{\alpha I(\cdot)}{\bar{K}^S}}\right) = \frac{\gamma}{\bar{T}-T^W}. \tag{5.48}$$

As compared to the first-order conditions in the autarky equilibrium (in (5.42)), the l.h.s. (that captures the marginal benefit) of each of (5.47) and (5.48) now has an additional term because of FDI. Let these be defined as $p^N(I) \equiv \left(1+\frac{\alpha I(\cdot)}{\bar{K}}\right) \Big/ \left(1+\frac{\alpha I(\cdot)}{\bar{K}^N}\right)$ and $p^S(I) \equiv \left(1-\frac{\alpha I(\cdot)}{\bar{K}}\right) \Big/ \left(1-\frac{\alpha I(\cdot)}{\bar{K}^S}\right)$ for the North and South respectively. Observe that $p^N(\cdot) < 1$ and $p^S(\cdot) > 1$; these are respective factor terms-of-trade effects, adjusted for the marginal utility of income. We can henceforth call them the *income-adjusted factor terms-of-trade effects.*

Since $\bar{K}^N > \bar{K}^S$ (and $\bar{L}^N = \bar{L}^S$), the total income in North's economy is greater than that in the South. Hence, the income-adjusted factor terms-of-trade effect of an increase in pollution is less for the North than for the South. i.e. $p^N < p^S$. This implies that at any common level of pollution, the marginal benefit from an increase in pollution is less in the North than in the South. Hence,

Proposition 10: *At the non-cooperative free capital mobility equilibrium, the pollution emanating from the North is less than the pollution emanating from the South.*

Formally, just divide (5.47) by (5.48) and obtain

$$\frac{T^{N^o}}{T^{S^o}} = \left(\frac{1-\frac{\alpha I}{\bar{K}^S}}{1-\frac{\alpha I}{\bar{K}}}\right)\left(\frac{1+\frac{\alpha I}{\bar{K}}}{1+\frac{\alpha I}{\bar{K}^N}}\right),$$

where recall that the superscript "o" denotes non-cooperation. Both the ratios in the r.h.s. are less than one, implying $T^{N^o} < T^{S^o}$. Proposition 10 contrasts with the zero-income effect case where the pollution contributions in non-cooperative free FDI equilibrium were the just the opposite in terms of their ranking between the North and South.[19]

Given $T^{No} < T^{So}$, the capital mobility equilibrium condition $K^{No^{1-\alpha}}T^{No^{\beta}} = K^{So^{1-\alpha}}T^{So^{\beta}}$ implies that $K^{No} < K^{So}$. That is,

Proposition 11: *North uses less capital than the South at the non-cooperative free capital mobility equilibrium.*

This also contrasts with the zero-income effect case.

Comparison with autarky

Propositions 10 and 11 characterize the FDI non-cooperative equilibrium. How does this equilibrium compare with autarky? The implications are similar to the zero-income effect case, i.e.,

Proposition 12: *Compared to autarky, North pollutes less, South pollutes more and global pollution is higher.*

Appendix H provides the proof.

Welfare effects of capital mobility

In terms of welfare change, recall that in the zero-income effect case, South unambiguously gains from capital mobility but North may gain or lose (Proposition 5). In the presence of income effects, the impact of FDI on welfare change is ambiguous for both North and South.

As in the basic model, four effects due to FDI, namely, direct and indirect factor terms-of-trade effects, own pollution policy change effect and transboundary pollution spillover

[19]Further, it is straightforward, but lengthy, to show that

$$(2-\alpha)I^o < \bar{K}^N - \bar{K}^S \Leftrightarrow I^o < \frac{\bar{K}^N - \bar{K}^S}{2-\alpha},$$

that is despite the natural upper bound of $\bar{K}^N$, the actual upper limit on the level of FDI is much lower. This is also proved in Appendix G.

effect determine the overall change in a country's welfare. It is found, however, that whilst the direction of change of own and spillover pollution effects is the same as in the basic (zero-income effect) model, unlike there, the signs of the sum of the two factor terms-of-trade effects remain ambiguous here. This leaves the overall welfare change unclear. The impact on global welfare is also unclear, therefore. All mathematical expressions are given in Appendix I.

Intuitively, present income-effects, the marginal benefits of pollution are discounted by the level of income (compare eqs. (5.45) and (5.46) with those in the zero-income effect case, i.e., (5.17) and (5.18)). Ceteris paribus, this implies a relatively lower release of the pollution-intensive resource, T^j, by either country j ($j = N, S$) than if the income effects were absent. Complementarity between productive factors dictates that, in the world economy, the market clearing rate of return on capital is comparatively lower, and, hence, the factor terms-of-trade gains from capital mobility relatively smaller for each country than if the income effects were absent. When these are coupled with the welfare loss from increase in global pollution, the net effect on welfare of either country remains ambiguous.

However, when the capital endowment difference between the North and the South is sufficiently small and, hence, the level of FDI is small enough, the change in welfare is qualitatively similar to the zero-income effect model. Specifically, North loses, South gains and world welfare is reduced. The welfare loss suffered by the North could be explained in much the same way as in the zero-income effect model. As FDI commits countries to differing pollution policies, consequent to which, as South credibly commits itself to pollute more, it puts the North in a strategically disadvantageous position in the environment game. This induces the North to reduce its pollution, such that North's real income gains are offset by the losses in welfare on account of higher pollution spillover effect from the South. In particular, when the level of FDI is sufficiently small and, hence, the terms-of-trade gains are small enough, the loss on account of the pollution spillover effect will outweigh the real income gains such that North will incur a welfare loss from capital mobility.

5.4.3 Cooperation between regions

When the regional governments coordinate their pollution policies and maximize aggregate world welfare, $\tilde{U}^W = \tilde{U}^N + \tilde{U}^S$, where $\tilde{U}^N$ and $\tilde{U}^S$ are as defined in (5.45) and (5.45), the two first-order conditions are:

$$\frac{\partial \tilde{U}^W}{\partial T^N} = 0 \Leftrightarrow \frac{\tau^N(\bar{K}^N - I(\cdot), T^N) + I\frac{\partial r(\cdot)}{\partial T^N}}{Y^N(\bar{K}^N - I(\cdot), T^N) + r(\cdot)I(\cdot)} - \frac{I\frac{\partial r(\cdot)}{\partial T^N}}{Y^S(\bar{K}^S + I(\cdot), T^S) - r(\cdot)I(\cdot)} = \frac{2\gamma}{\bar{T} - T^W}; \tag{5.49}$$

$$\frac{\partial \tilde{U}^W}{\partial T^S} = 0 \Leftrightarrow \frac{I\frac{\partial r(\cdot)}{\partial T^S}}{Y^N(\bar{K}^N - I(\cdot), T^N) + r(\cdot)I(\cdot)} + \frac{\tau^S(\bar{K}^S + I(\cdot), T^S) - I\frac{\partial r(\cdot)}{\partial T^N}}{Y^S(\bar{K}^S + I(\cdot), T^S) - r(\cdot)I(\cdot)} = \frac{2\gamma}{\bar{T} - T^W}. \tag{5.50}$$

In comparison with the first-order conditions under non-cooperation (eqs. (5.45) and (5.46)) there is now an additional term in the l.h.s. (or the benefit side) that represents the effect on the (income adjusted) factor terms-of-trade of the partner country due to change in each country's *own* pollution policy. For the North this is captured by the second term in (5.49) and for the South by the first term in (5.50) in the respective benefit sides. These effects arise because, unlike the neutral-good case, the own- and partner-country's factor terms-of-trade effects under cooperative behavior do not wash out against each other. This is because the country size (in terms of aggregate output/income) influences the marginal benefit from pollution and country sizes differ.

Substituting for the partials, and expressing income, $Y^j \equiv K^{j^\alpha} T^{j^\beta}$, $(j = N, S)$, (5.49) and (5.50) reduce to their respective analogs in equation (5.28)

$$\frac{\beta}{T^N}\left(\frac{1+\frac{\alpha I}{\bar{K}}}{1+\frac{\alpha I}{K^N}}\right) - \frac{\beta}{T^N}\frac{Y^N}{Y^S}\left(\frac{\frac{\alpha I}{\bar{K}}}{1-\frac{\alpha I}{K^S}}\right) = \frac{2\gamma}{\bar{T}-T^W} \tag{5.51}$$

$$\frac{\beta}{T^S}\left(\frac{1-\frac{\alpha I}{\bar{K}}}{1-\frac{\alpha I}{K^S}}\right) + \frac{\beta}{T^S}\frac{Y^S}{Y^N}\left(\frac{\frac{\alpha I}{\bar{K}}}{1+\frac{\alpha I}{K^N}}\right) = \frac{2\gamma}{\bar{T}-T^W}. \tag{5.52}$$

Further, the capital market equilibrium condition (5.9) together with the fact that $K^N = \eta\bar{K}$ and $K^S = (1-\eta)\bar{K}$ yields $Y^N/Y^S = \eta/(1-\eta)$. Utilizing this expression in the l.h.s. of eqs. (5.51) and (5.52) one gets:

$$\tilde{f^N}^c(T^N, T^S) \equiv \frac{\beta}{T^N}\eta\left(\frac{\bar{K}+\alpha I}{K^N+\alpha I} - \frac{\alpha I}{K^S-\alpha I}\right) = \frac{2\gamma}{\bar{T}-T^W}; \tag{5.53}$$

$$\tilde{f^S}^c(T^N, T^S) \equiv \frac{\beta}{T^S}(1-\eta)\left(\frac{\bar{K}-\alpha I}{K^S-\alpha I} + \frac{\alpha I}{K^N+\alpha I}\right) = \frac{2\gamma}{\bar{T}-T^W}, \tag{5.54}$$

where $\tilde{f^N}^c$ and $\tilde{f^S}^c$ represent the respective marginal benefits from pollution.

It is shown in Appendix J that at the cooperative equilibrium as well, $T^{Nc} < T^{Sc}$ and $K^{Nc} < K^{Sc}$, where recall that superscript "c" denotes cooperation.

Proposition 13: *At the cooperative free FDI equilibrium, North pollutes less as well as uses less capital than the South.*

This contrasts with the zero-income effect case where, at the cooperative equilibrium, both North and South had the same pollution levels and used the same level of capital.

The second-order conditions associated with (5.53) and (5.54) are met under the following regularity condition:

$$\alpha < \frac{\bar{K^N}\bar{K^S} + \bar{K^S}^2}{\bar{K^N}^2 + \bar{K^S}^2}. \tag{R3}$$

The underlying intuition for (R3) is similar to that for (R1) and (R2), and observe that (R3) is more restrictive than (R2). We assume that (R3) holds. Under (R3) the cooperative equilibrium is found to be unique (and stable); see Appendix K for detailed proofs.

As for the effects of cooperation on FDI, regional and global pollution levels, similar conclusions as in the neutral-good model hold qualitatively. That is,

Proposition 14: *As countries cooperate on environment policies,*

(i) there is more FDI,

(ii) North's pollution falls, and South's may rise or fall, and

(ii) global pollution decreases even below the autarky level.

Again, see Appendix L for the mathematical derivations of this proposition.

To sum up, when there are positive-income effects on the demand for environment, most of the results that relate to the direction of change of regional pollution due to FDI flows (under both non-cooperative and cooperative regimes), the effect on magnitude of FDI in moving from non-cooperation to cooperation, and the welfare implications are qualitatively the same as in the zero-income effect model, except two differences. First, in moving from autarky to non-cooperative FDI equilibrium, even South may gain or lose as the North, whereas in the zero-income effect case at least the South had unambiguous welfare gains.

Second, the ranking of countries in terms of their absolute pollution levels differs. In contrast to the zero-income effect model, where North was a larger polluter in autarky, in the positive-income effect case, the autarky pollution levels are equalized. At the free FDI non-cooperation equilibrium, there is a reversal of ranking of North and South in terms of their contribution to aggregate world pollution. That is, whilst in the zero-income effect case North was a larger polluter, it is the South which is now a larger polluter. Even at the cooperative equilibrium, North pollutes less than the South.

5.5 Conclusions

This chapter contains an analysis of FDI and global environment. Capital moves from "capital-abundant" North to "capital-scarce" South. Pollution arises in the course of production. We first looked at the autarky situation, where there was no international capital mobility. Next, the FDI flows with no cooperation in environmental policies was examined. Finally, we considered the implications of capital mobility or FDI when countries coordinate in respect of their environmental policies.

It is found that in moving from autarky to the FDI regime (with non-cooperation in pollution policy) North reduces and South increases its pollution level. Despite North's and South's pollution levels changing in opposite directions, the net effect of FDI on global environment is negative, i.e. aggregate global pollution rises.

As for the effect on welfare levels, South always has gains from FDI whilst North may gain or lose. The change in the sum of the individual country welfares, i.e., global welfare, also remains ambiguous. However, at low enough level of FDI North suffers a clear welfare loss and global welfare also falls.

The above results hold when the regional governments do not coordinate their environment policies. If instead governments cooperate with each other in regulating their environment quality (or maximize their joint welfare) very different implications emerge: world environment quality improves and there is more FDI.

Thus, contrary to common perception, a stricter environment policy may not be an impediment to international capital flows. Environment quality is even better than under autarky. In terms of regional policies, North is induced to reduce its pollution even further and South's response remains ambiguous. Also, there is little rationale behind harmonization of environment policies across countries.

Appendix A

This appendix pertains to the model when there is zero-income effect on the demand for environment good. Capital mobility along with no cooperation in setting pollution policies is considered here. It is derived that under the regularity condition (R1), (a) the second-order conditions corresponding to (5.17) and (5.18) are met, (b) T^N and T^S are strategic substitutes of each other, and (c) the Nash equilibrium is unique.

Specifically, we show that

$$f_N^N < 0, \ f_S^N < 0; \tag{A1}$$

$$f_S^S < 0, \ f_N^S < 0; \tag{A2}$$

$$f_N^N f_S^S - f_S^N f_N^S - \gamma \left(f_N^N - f_S^N + f_S^S - f_N^S\right) \Phi'' \ > 0, \tag{A3}$$

where f^N and f^S are the respective marginal benefits from pollution, $f_j^j = \partial f^j/\partial T^j$, $j = N, S$, and $f_i^j = \partial f^j/\partial T^i$, $j \neq i$. Note that (A1) and (A2), together with $\Phi'' < 0$ prove (a) and (b), whilst (A3) proves (c).

To begin with, recall the following definitions and relations:

$$\theta \equiv \frac{\beta}{1-\alpha}; \quad K^N = \bar{K}^N - I; \quad K^S = \bar{K}^S + I; \quad \eta \equiv \frac{T^{N\theta}}{T^{N\theta} + T^{S\theta}} = \frac{K^N}{\bar{K}}; \tag{A4}$$

$$\tau^j = \beta K^{j\alpha} T^{j\beta - 1}, j = N, S; \quad I = \bar{K}^N - \eta \bar{K}; \quad T^N > T^S, \quad K^N > K^S. \tag{A5}$$

The last two inequalities follow from (5.17) and (5.18) and are discussed in the text.

Now, totally differentiating τ^j and I,

$$\hat{\tau}^j = \alpha \hat{K}^j - (1-\beta)\hat{T}^j, \tag{A6}$$

$$dI = -\bar{K} d\eta = -\bar{K}\theta\eta(1-\eta)(\hat{T}^N - \hat{T}^S), \tag{A7}$$

both of which are utilized below.[20] We begin with the proof for (a) and (b).

[20]Hats represent proportionate changes, e.g., with respect to variable x, $\hat{x} = dx/x$.

Turn first to (5.17). We have $\hat{f}^N = \hat{\tau}^N + \widehat{\left(1 + \frac{\alpha I}{K}\right)}$. Using (A6) and (A7),

$$\hat{f}^N = -(1-\beta)\hat{T}^N + \alpha\theta\eta(1-\eta)\frac{K^S + \alpha I}{K^N + \eta\alpha I}(\hat{T}^N - \hat{T}^S) \tag{A8}$$

$$= \left[-(1-\beta) + \alpha\theta\eta(1-\eta)\frac{K^S + \alpha I}{K^N + \eta\alpha I}\right]\hat{T}^N - \alpha\theta\eta(1-\eta)\frac{K^S + \alpha I}{K^N + \eta\alpha I}\hat{T}^S. \tag{A9}$$

Therefore,

$$\frac{\hat{f}^N}{\hat{T}^S} = -\alpha\theta\eta(1-\eta)\frac{K^S + \alpha I}{K^N + \eta\alpha I} < 0. \tag{A10}$$

The coefficient of $\hat{T}^S$ being negative

$$f_S^N \equiv \partial f^N / \partial T^S < 0. \tag{A11}$$

Next,

$$\frac{\hat{f}^N}{\hat{T}^N} = -(1-\beta) + \alpha\theta\eta(1-\eta)\frac{K^S + \alpha I}{K^N + \eta\alpha I}. \tag{A12}$$

We have

$$\frac{K^S + \alpha I}{K^N + \eta\alpha I} < \frac{K^S + \alpha I}{\eta K^S + \eta\alpha I} < \frac{1}{\eta}, \tag{A13}$$

since $K^N > K^S > \eta K^S$. Thus, the r.h.s. (A12) is less than $-(1-\beta) + \alpha\theta(1-\eta)$. Recalling that $\theta = \beta/(1-\alpha)$, this expression is equal to

$$-\frac{1 - \alpha - \beta + \alpha\beta\eta}{1-\alpha} < 0.$$

Thus,

$$f_N^N \equiv \partial f^N / \partial T^N < 0. \tag{A14}$$

Next, it is shown that

$$f_S^S < 0, f_N^S < 0, \tag{A15}$$

where $f_S^S \equiv \partial f^S / \partial T^S$ and $f_N^S \equiv \partial f^S / \partial T^N$. The results (A14) and (A11) together with (A15) imply (a) and (b).

Turn to (5.18) now. Again using (A6) and (A7),

$$\hat{f}^S = -(1-\beta)\hat{T}^S - \alpha\theta\eta(1-\eta)\frac{K^N - \alpha I}{K^S - (1-\eta)\alpha I}(\hat{T}^N - \hat{T}^S) \tag{A16}$$

$$= -\alpha\theta\eta(1-\eta)\frac{K^N - \alpha I}{K^S - (1-\eta)\alpha I}\hat{T}^N + \left[-(1-\beta) + \alpha\theta\eta(1-\eta)\frac{K^N - \alpha I}{K^S - (1-\eta)\alpha I}\right]\hat{T}^S. \tag{A17}$$

We have $K^S > I > \alpha I$, implying $K^N > \alpha I$. Thus, the coefficient of $\hat{T}^N$ in the r.h.s. of (A17) is negative, implying $f_N^S < 0$. Now, consider the coefficient of $\hat{T}^S$. We have

$$\frac{K^N - \alpha I}{K^S - (1-\eta)\alpha I} < \frac{K^N - \alpha I}{K^S - \alpha I} < \frac{K^N}{K^S} = \frac{\eta}{1-\eta},$$

where the last inequality follows from (A4). Hence,

$$\frac{K^N - \alpha I}{K^S - (1-\eta)\alpha I} < \frac{\eta}{1-\eta}. \tag{A18}$$

Using this, the coefficient of $\hat{T}^S$ in (A17) is less than

$$-(1-\beta) + \alpha\theta\eta^2 = -\frac{1-\alpha-\beta+\alpha\beta(1-\eta^2)}{1-\alpha} < 0, \tag{A19}$$

i.e., $f_S^S < 0$.

Thus far, the inequalities in (A1) and (A2) are proven. The second-order conditions require that

$$f_N^N + \gamma\Phi''(\cdot) < 0; \quad f_S^S + \gamma\Phi''(\cdot) < 0. \tag{A20}$$

Since $f_N^N < 0$, $f_S^S < 0$ and $\Phi''(\cdot) < 0$, it follows that (A20) is satisfied and (a) is proved.

We also have $f_S^N + \gamma\Phi''(\cdot)$ and $f_N^S + \gamma\Phi''(\cdot)$ both negative, since $f_S^N < 0$, $f_N^S < 0$. Together with (A20), it follows that T^N and T^S are strategic substitutes of each other and (b) is proved.

We now prove (c). First, it is shown that

$$f_N^N < f_S^N, \text{ and} \tag{A21}$$

$$f_S^S < f_N^S. \tag{A22}$$

These, together with $f_j^j < 0$, $j = N, S$ and $f_i^j < 0$, $j \neq i$ (derived already in (A14), (A11) and (A15)) and $\Phi'' < 0$ would imply that (A3) holds and prove (c).

For this, return to (A8), which yields

$$-\frac{T^N(f_N^N - f_S^N)}{f^N} = 1 - \beta - \left(1 + \frac{T^N}{T^S}\right)\alpha\theta\eta(1-\eta)\frac{K^S + \alpha I}{K^N + \eta\alpha I}. \tag{A23}$$

We need to show that the r.h.s. of (A23) is positive such that $f_N^N < f_S^N$.

From (5.19) we have

$$\begin{aligned} 1 + \frac{T^N}{T^S} &= 1 + \frac{\eta}{(1-\eta)}\frac{\bar{K} + \alpha I}{(\bar{K} - \alpha I)} \\ &= \frac{\bar{K} - (1-\eta)\alpha I + \eta\alpha I}{(1-\eta)(\bar{K} - \alpha I)} \\ &= \frac{\bar{K} - \alpha I + 2\eta\alpha I}{(1-\eta)(\bar{K} - \alpha I)} \\ &< \frac{\bar{K} - \alpha I + 2\alpha I}{(1-\eta)(\bar{K} - \alpha I)} = \frac{\bar{K} + \alpha I}{(1-\eta)(\bar{K} - \alpha I)}, \end{aligned} \tag{A24}$$

which when substituted into (A23) yields

$$\begin{aligned} -\frac{T^N(f_N^N - f_S^N)}{f^N} &> 1 - \beta - \alpha\theta\eta(1-\eta)\left(\frac{\bar{K} + \alpha I}{(1-\eta)(\bar{K} - \alpha I)}\right)\frac{K^S + \alpha I}{K^N + \eta\alpha I} \\ &> 1 - \beta - \alpha\theta\frac{K^S + \alpha I}{\bar{K} - \alpha I}. \end{aligned}$$

Since $\alpha + \beta < 1$ and $\theta < 1$,

$$1 - \beta - \alpha\theta\frac{K^S + \alpha I}{\bar{K} - \alpha I} > 0 \tag{A25}$$

is implied when

$$\frac{\bar{K}^S + (1+\alpha)I}{\bar{K} - \alpha I} < \frac{\bar{K}^S + (1+\alpha)\frac{\bar{K}^N - \bar{K}^S}{2}}{\bar{K} - \alpha\frac{\bar{K}^N - \bar{K}^S}{2}} < 1. \tag{A26}$$

This is in view of the ratio in the extreme l.h.s. of (A26) increasing in I and $I^o < (\bar{K}^N - \bar{K}^S)/2$ (from condition (5.20)). The condition in (A26)) is equivalent to

$$\Leftrightarrow \alpha < \frac{\bar{K}^N + \bar{K}^S}{2(\bar{K}^N - \bar{K}^S)}.$$

This is indeed our regularity condition (R1). Assuming that (R1) holds, it follows that $f_N^N < f_S^N$ and (A21) is proven.

Next, (A16) would imply

$$-\frac{T^S(f_S^S - f_N^S)}{f^S} = 1 - \beta - \left(1 + \frac{T^S}{T^N}\right)\alpha\theta\eta(1-\eta)\frac{K^N - \alpha I}{K^S - (1-\eta)\alpha I}. \tag{A27}$$

Again, if the r.h.s. is positive the inequality in (A22) is met. Recall that $T^S/T^N = (K^S/K^N)^{\frac{1}{\theta}}$; hence

$$\begin{aligned}\left(1 + \frac{T^S}{T^N}\right)\frac{K^N - \alpha I}{K^S - (1-\eta)\alpha I} &< \left[1 + \left(\frac{K^S}{K^N}\right)^{(1/\theta)}\right]\frac{K^N}{K^S} \\ &= \frac{K^N}{K^S} + \left(\frac{K^N}{K^S}\right)^{1-1/\theta} < \frac{K^N}{K^S} + 1 \\ &< \frac{\bar{K}}{K^S} = \frac{1}{1-\eta}.\end{aligned}$$

Substituting this into (A27),

$$-\frac{T^S(f_S^S - f_N^S)}{f^N} > 1 - \beta - \alpha\theta\eta = \frac{1 - \alpha - \beta + \alpha\beta(1-\eta)}{1-\alpha} > 0,$$

which implies (A22).

The best response curve R^N is steeper than R^S, i.e., the Nash equilibrium is unique (and stable) if

$$\begin{vmatrix} f_N^N + \gamma\Phi'' & f_S^N + \gamma\Phi'' \\ f_N^S + \gamma\Phi'' & f_N^N + \gamma\Phi'' \end{vmatrix}$$

$$= f_N^N f_S^S - f_S^N f_N^S + \gamma\Phi''(f_N^N - f_S^N + f_S^S - f_N^S) > 0. \tag{A28}$$

(A21) and (A22) imply $|f_N^N| > |f_S^N|$, $|f_S^S| > |f_N^S|$, $f_N^N - f_S^N < 0$ and $f_S^S - f_N^S < 0$. Hence, (A28) is satisfied and (c) is proved.

Appendix B

This appendix also refers to the zero-income effect case. The effect of capital mobility on regional pollution levels, in moving from autarky to capital mobility (in the absence of cooperation), is derived.

To begin with, refer to the two first-order conditions (5.17) and (5.18). Recall that in both I can be treated as exogenous such that at $I = 0$, the two eqs. reduce to the autarky equilibrium condition (5.4). Hence, comparison between autarky and free capital mobility regimes can be characterized by an exogenous change in I.

Totally differentiating (5.17) and (5.18) with respect to I, the following system of equations is derived:

$$\begin{pmatrix} \frac{\partial \tau^N}{\partial T^N}\left(1+\frac{\alpha I}{\bar{K}}\right)+\gamma\Phi'' & \gamma\Phi'' \\ \gamma\Phi'' & \frac{\partial \tau^S}{\partial T^S}\left(1-\frac{\alpha I}{\bar{K}}\right)+\gamma\Phi'' \end{pmatrix} \begin{bmatrix} \frac{dT^N}{dI} \\ \frac{dT^S}{dI} \end{bmatrix} = \begin{bmatrix} -\frac{\partial \bar{f}^N}{\partial I} \\ -\frac{\partial \bar{f}^S}{\partial I} \end{bmatrix}$$

Let X be the first matrix in the l.h.s.. Given diminishing returns, $\partial\tau^j/\partial T^j < 0$, and we have assumed $\Phi'' < 0$. Using these, it is straightforward to derive that $|X| > 0$.

Also, from (5.17) and (5.18)

$$\begin{aligned} \frac{\partial \bar{f}^N}{\partial I} &= -\frac{\alpha(K^S+\alpha I)}{\bar{K}(K^N+\eta\alpha I)}\bar{f}^N < 0 \\ \frac{\partial \bar{f}^S}{\partial I} &= \frac{\alpha(K^N-\alpha I)}{\bar{K}\left(K^S-(1-\eta)\alpha I\right)}\bar{f}^S > 0. \end{aligned} \quad \text{(B1)}$$

Application of the Cramer's rule and taking into account the signs of the various terms,

$$\frac{dT^N}{dI} = \left[-\underset{(-)}{\frac{\partial \bar{f}^N}{\partial I}}\left(\underset{(-)}{\gamma\Phi''}+\underset{(-)}{\frac{\partial \tau^S}{\partial T^S}}\underset{(+)}{\left(1-\frac{\alpha I}{\bar{K}}\right)}\right)+\underset{(+)}{\frac{\partial \bar{f}^S}{\partial I}}\underset{(-)}{\gamma\Phi''}\right]\Big/\underset{(+)}{|X|} < 0;$$

$$\frac{dT^S}{dI} = \left[-\underset{(+)}{\frac{\partial \bar{f}^S}{\partial I}}\left(\underset{(-)}{\gamma\Phi''}+\underset{(-)}{\frac{\partial \tau^N}{\partial T^N}}\underset{(+)}{\left(1+\frac{\alpha I}{\bar{K}}\right)}\right)+\underset{(-)}{\frac{\partial \bar{f}^N}{\partial I}}\underset{(-)}{\gamma\Phi''}\right]\Big/\underset{(+)}{|X|} > 0.$$

Appendix C

For the zero-income effects model, the effect of FDI flows under non-cooperative environment policy setting is derived. Specifically, it is shown that a move from autarky to free FDI non-cooperative equilibrium will lead to an increase in global pollution. To this end, it is shown that $h(\eta) > \lambda$, which is equivalent to

$$\frac{2^{\frac{1}{1-\beta}}\left[\eta^{\frac{1-\alpha}{\beta}}+(1-\eta)^{\frac{1-\alpha}{\beta}}\right]}{\left[\eta^{\frac{1-\alpha-\beta}{\beta}}+(1-\eta)^{\frac{1-\alpha-\beta}{\beta}}\right]^{\frac{1}{1-\beta}}}\bar{K}^{\frac{\alpha}{1-\beta}} > \bar{K^N}^{\frac{\alpha}{1-\beta}} + \bar{K^S}^{\frac{\alpha}{1-\beta}} \tag{C1}$$

Let r.h.s. be expressed as $q^a(\bar{K}^N) \equiv \bar{K^N}^{\frac{\alpha}{1-\beta}} + (\bar{K}-\bar{K}^N)^{\frac{\alpha}{1-\beta}}$. Then.

$$\frac{dq^a}{d\bar{K}^N} = \frac{\alpha}{1-\beta}\left(\frac{1}{\bar{K^N}^{\frac{1-\alpha-\beta}{1-\beta}}} - \frac{1}{\bar{K^S}^{\frac{1-\alpha-\beta}{1-\beta}}}\right) < 0,$$

since $\bar{K}^N > \bar{K}^S$. Moreover, given $\bar{K}^N > \bar{K}^S$, it follows that $\bar{K}^N > \bar{K}/2$. Hence $dq^a/d\bar{K}^N < 0$ implies that,

$$q^a(\bar{K}^N) < q^a\left(\frac{\bar{K}^N}{2}\right) = \frac{\bar{K}}{2}^{\frac{\alpha}{1-\beta}} + \left(\bar{K}-\frac{\bar{K}}{2}\right)^{\frac{\alpha}{1-\beta}} = 2^{\frac{1-\alpha-\beta}{1-\beta}}\,\bar{K}^{\frac{\alpha}{1-\beta}}. \tag{C2}$$

Hence, for (C1) to hold it suffices to prove that $h(\eta) > 2^{\frac{1-\alpha-\beta}{1-\beta}}$. This is equivalent to

$$q(\eta) \equiv \frac{\left[\eta^{\frac{1-\alpha}{\beta}}+(1-\eta)^{\frac{1-\alpha}{\beta}}\right]^{1-\beta}}{\left[\eta^{\frac{1-\alpha-\beta}{\beta}}+(1-\eta)^{\frac{1-\alpha-\beta}{\beta}}\right]} > \frac{1}{2^{\alpha+\beta}}$$

Log-differentiating the l.h.s. and noting that $\eta > 1-\eta$, it is straightforward to derive that $q'(\eta) > 0$. Hence, it follows that

$$q(\eta) > q\left(\frac{1}{2}\right) = \frac{1}{2^{\alpha+\beta}}.$$

Thus, $q(\eta) > 1/(2^{\alpha+\beta})$, implying that $h(\eta) > \lambda$.

Appendix D

For the zero-income effect model, the change in South's and North's welfare (in moving from autarky to free capital mobility and non-cooperation) due to net change in the factor terms-of-trade effects of FDI are analyzed here. It is shown that both countries would have welfare gains on account of sum of the direct and indirect factor terms-of-trade effects.

In (5.23) and (5.24) in the text, the welfare change on account of these effects are represented by the sum of the first two terms in the r.h.s.. Explicitly, these could be expressed as

$$F^N = (1-\alpha)\frac{r^N}{K^N}I + \beta\frac{r^N}{T^N}\frac{dT^N}{dI}I; \tag{D1}$$
$$F^S = (1-\alpha)\frac{r^S}{K^S}I - \beta\frac{r^S}{T^S}\frac{dT^S}{dI}I. \tag{D2}$$

We first require the expressions for dT^N/dI and dT^S/dI be worked out. By differentiating the first-order conditions (5.17) and (5.18) with respect to I,

$$-\left(\frac{1-\beta}{T^N} - \frac{\Phi''}{\Phi'}\right)\frac{dT^N}{dI} + \frac{\Phi''}{\Phi'}\frac{dT^S}{dI} = \alpha\left(\frac{1}{K^N} - \frac{1}{\bar{K}+\alpha I}\right); \tag{D3}$$
$$\frac{\Phi''}{\Phi'}\frac{dT^N}{dI} - \left(\frac{1-\beta}{T^S} - \frac{\Phi''}{\Phi'}\right)\frac{dT^S}{dI} = -\alpha\left(\frac{1}{K^S} - \frac{1}{\bar{K}-\alpha I}\right). \tag{D4}$$

Solving these simultaneously

$$\frac{dT^N}{dI}\frac{1}{T^N} = \frac{\alpha\kappa\frac{\Phi''}{\Phi' T^N} - \alpha\frac{(1-\beta)}{T^N T^S}\left(\frac{1}{K^N} - \frac{1}{\bar{K}+\alpha I}\right)}{\frac{(1-\beta)^2}{T^N T^S} - \frac{\Phi''}{\Phi'}(1-\beta)\left(\frac{1}{T^N} + \frac{1}{T^S}\right)} < 0; \tag{D5}$$
$$\frac{dT^S}{dI}\frac{1}{T^S} = \frac{-\alpha\kappa\frac{\Phi''}{\Phi' T^S} + \frac{\alpha(1-\beta)}{T^N T^S}\left(\frac{1}{K^S} - \frac{1}{\bar{K}-\alpha I}\right)}{\frac{(1-\beta)^2}{T^N T^S} - \frac{\Phi''}{\Phi'}(1-\beta)\left(\frac{1}{T^N} + \frac{1}{T^S}\right)} > 0, \tag{D6}$$

where $\kappa \equiv \left(\frac{1}{K^N} - \frac{1}{\bar{K}+\alpha I} + \frac{1}{K^S} - \frac{1}{\bar{K}-\alpha I}\right)$. Note that $\kappa > 0$ as both $\frac{1}{K^N} - \frac{1}{\bar{K}+\alpha I} > 0$ and $\frac{1}{K^S} - \frac{1}{\bar{K}-\alpha I} > 0$.

Since $dT^N/dI < 0$ and $dT^S dI > 0$, the sign of either F^N or F^S is undetermined *a priori* from (D1) and (D2). However, given $\beta < (1-\alpha)$, we observe from (D1) and (D2) that F^N and F^S are positive if

$$\frac{T^N}{K^N} + \frac{dT^N}{dI} > 0; \tag{D7}$$
$$\frac{T^S}{K^S} - \frac{dT^S}{dI} > 0. \tag{D8}$$

It is easier to prove (D8) first.

Adding $-\alpha\kappa\left(\frac{\Phi''}{\Phi' T^N}\right) > 0$ and $\alpha\frac{(1-\beta)}{T^N T^S}\left(\frac{1}{K^N} - \frac{1}{\bar{K}+\alpha I}\right) > 0$ to the numerator in the r.h.s. of (D6), it turns out that

$$\begin{aligned}\frac{dT^S}{dI}\frac{1}{T^S} &< \frac{-\alpha\kappa\frac{\Phi''}{\Phi' T^S} - \alpha\kappa\frac{\Phi''}{\Phi' T^N} + \frac{\alpha(1-\beta)}{T^N T^S}\kappa}{(1-\beta)\left(\frac{1-\beta}{T^N T^S} - \frac{\Phi''}{\Phi'}\left(\frac{1}{T^N} + \frac{1}{T^S}\right)\right)} \\ &< \frac{\alpha\kappa}{1-\beta}\left[\frac{-\frac{\Phi''}{\Phi'}\left(\frac{1}{T^N} + \frac{1}{T^S}\right) + \frac{1-\beta}{T^N T^S}}{\frac{1-\beta}{T^N T^S} - \frac{\Phi''}{\Phi'}\left(\frac{1}{T^N} + \frac{1}{T^S}\right)}\right] \\ &< \frac{\alpha\kappa}{1-\beta} < \kappa, \quad \text{since } \frac{\alpha}{1-\beta} < 1. \end{aligned} \tag{D9}$$

Thus,

$$\begin{aligned}\frac{1}{K^S} - \frac{1}{T^S}\frac{dT^S}{dI} &> \frac{1}{K^S} - \kappa \\ &> \frac{(\alpha I)^2 + 2K^N\bar{K} - \bar{K}^2}{K^N(\bar{K} - \alpha I)(\bar{K} + \alpha I)} > 0 \end{aligned} \tag{D10}$$

since $K^N > K^S \Leftrightarrow 2K^N\bar{K} > \bar{K}^2$. The chain of inequalities in (D10) implies (D8).

We next turn to (D7).

As stated in Proposition 4, a move from autarky to free capital mobility leads to increase in world pollution, $T^W(\equiv T^N + T^S)$. Combining this with regional pollution changes implied in (D5) and (D6) we have

$$\left|\frac{dT^N}{dI}\right| < \left|\frac{dT^S}{dI}\right|. \tag{D11}$$

Moreover, capital market clearing condition (5.9) yields

$$\frac{K^N}{K^S} = \left(\frac{T^N}{T^S}\right)^{\frac{\beta}{1-\alpha}} < \frac{T^N}{T^S}, \quad \text{since } T^N > T^S \text{ and } \beta/(1-\alpha) < 1. \tag{D12}$$

The relations in (D10), (D11) and (D12) together imply

$$\frac{T^N}{K^N} > \frac{T^S}{K^S} > \left|\frac{dT^S}{dI}\right| > \left|\frac{dT^N}{dI}\right|. \tag{D13}$$

This proves (D7).

Appendix E

In the case of neutral-environment good, the effects of cooperative behavior on regional pollution levels are derived here. This is done in two steps. First, the effect of change in the pollution policies of countries is considered as they move from non-cooperative to cooperative regime, whilst there is no change in FDI. Second, the level of FDI is allowed to change.

Step 1:

Define $m \equiv \alpha I/\bar{K}$. Then eqs. (5.30)-(5.31) are expressed as

$$\tau^N(1 + m(1-b)) = (1+b)\gamma\Phi'(\bar{T} - T^W) \tag{E1}$$

$$\tau^S(1 - m(1-b)) = (1+b)\gamma\Phi'(\bar{T} - T^W). \tag{E2}$$

The non-cooperative equilibrium is defined at $b = 0$, and cooperative equilibrium at $b = 1$. Therefore, an increase in "b" would capture the change of regime from non-cooperative to cooperative equilibrium.

It is shown that (a) $\partial T^N/\partial b < 0$; $\partial T^S/\partial b \gtrless 0$, and (b) $|\partial T^N/\partial b| > |\partial T^S/\partial b|$ if $\partial T^S/\partial b < 0$.

Totally differentiating (E1) and (E2) with respect to b, at given I, yields the matrix system

$$\begin{pmatrix} \frac{\partial \tau^N}{\partial T^N}(1 + m(1-b)) + (1+b)\gamma\Phi'' & (1+b)\gamma\Phi'' \\ (1+b)\gamma\Phi'' & \frac{\partial \tau^S}{\partial T^S}(1 - m(1-b)) + (1+b)\gamma\Phi'' \end{pmatrix} \begin{bmatrix} \frac{\partial T^N}{\partial b} \\ \frac{\partial T^S}{\partial b} \end{bmatrix} = \begin{bmatrix} m\tau^N + \gamma\Phi' \\ -m\tau^S + \gamma\Phi' \end{bmatrix}$$

Let Y denote the coefficient matrix in the l.h.s.. Since $\partial\tau^j/\partial T^j < 0$, $\Phi'' < 0$, and $(1 + m(1-b))$ and $(1 - m(1-b)) > 0$, it follows that $|Y| > 0$.

Using Cramer's rule

$$|Y|\frac{\partial T^N}{\partial b} = \left(m\tau^N + \gamma\Phi'\right)\left(\frac{\partial \tau^S}{\partial T^S}(1 - m(1-b)) + (1+b)\gamma\Phi''\right) - \left(\gamma\Phi' - m\tau^S\right)(1+b)\gamma\Phi''$$

$$= \underbrace{m(\tau^N + \tau^S)}_{(+)}(1+b)\gamma\underset{(-)}{\Phi''} + \underbrace{(m\tau^N + \gamma\Phi')}_{(+)}\left(\underset{(-)}{\frac{\partial \tau^S}{\partial T^S}}(1 - m(1-b))\right); \quad \text{(E3)}$$

$$|Y|\frac{\partial T^S}{\partial b} = \left(\gamma\Phi' - m\tau^S\right)\left(\frac{\partial \tau^N}{\partial T^N}(1 + m(1-b)) + (1+b)\gamma\Phi''\right) - \left(m\tau^N + \gamma\Phi'\right)(1+b)\gamma\Phi''$$

$$= \underbrace{-m(\tau^N + \tau^S)}_{(-)}(1+b)\gamma\underset{(-)}{\Phi''} + \underbrace{(\gamma\Phi' - m\tau^S)}_{(+)}\left(\underset{(-)}{\frac{\partial \tau^N}{\partial T^N}}(1 + m(1-b))\right). \quad \text{(E4)}$$

Given $|Y| > 0$, $\partial\tau^j/\partial T^j < 0$ and $\Phi'' < 0 < \Phi'$, it follows that $\partial T^N/\partial b < 0$ whilst $\partial T^N/\partial b \gtrless 0$. The ambiguity in the sign of $\partial T^S/\partial b$ arises because the first term in the r.h.s. of (E4) is positive (in view of $\Phi'' < 0$) whilst the sign of the second terms is ambiguous as $\gamma\Phi' - m\tau^S \gtrless 0$. Now, observe that from (E2)

$$\tau^S = \frac{(1+b)\gamma\Phi'}{1 - m(1-b)}$$

$$\Leftrightarrow \gamma\Phi' - m\tau^S = \gamma\Phi'\frac{(1-2m)}{1 - m(1-b)}.$$

From $I < \left(\bar{K}^N - \bar{K}^S\right)/2$, we have

$$m < \frac{I}{\bar{K}} < \frac{(\bar{K}^N - \bar{K}^S)}{2\bar{K}} < \frac{1}{2} \Leftrightarrow 1 - 2m > 0 \Rightarrow \gamma\Phi' - m\tau^S > 0.. \quad \text{(E5)}$$

Given the sign of $\gamma\Phi' - m\tau^S$ in (E5), it follows that the second term of (E4) is negative. Hence, $\partial T^S/\partial b \gtrless 0$, and this together with $\partial T^N/\partial b < 0$ proves (a).

We now prove (b). As discussed in the text, this is used in explaining the increase in the level of FDI in moving from non-cooperation to cooperation.

When $\partial T^S/\partial b < 0$, substituting for $\partial\tau^j/\partial T^j$, $j = N, S$ in (E3) and (E4), the absolute difference

$$\left|\frac{\partial T^N}{\partial b}\right| - \left|\frac{\partial T^S}{\partial b}\right| = \frac{1}{|Y|}\Big| - \left(m\tau^N + \gamma\Phi'\right)(1-\beta)\frac{\tau^S}{T^S}\left(1 - m(1-b)\right)$$
$$- \left(\gamma\Phi' - m\tau^S\right)(1-\beta)\frac{\tau^N}{T^N}\left(1 + m(1-b)\right) + 2(1+b)m(\tau^N + \tau^S)\gamma\Phi''\Big|$$
$$= \frac{1}{|Y|}(1-\beta)(1+b)\gamma\frac{\Phi'}{T^N T^S}\left[m\tau^N T^N + m\tau^S T^S + \gamma\Phi'(T^N - T^S)\right]$$
$$+\frac{2}{|Y|}\left|(1+b)m(\tau^N + \tau^S)\gamma\Phi''\right| > 0$$

in view of $T^N > T^S$ and $\Phi'' < 0 < \Phi'$.

Hence, (b) is proved.

Step 2:

Next, we differentiate eqs. (E1) and (E2) with respect to I at given b, $b \in (0,1)$. This yields

$$\begin{pmatrix} \frac{\partial\tau^N}{\partial T^N}\left(1 + m(1-b)\right)\gamma\Phi'' & (1+b)\gamma\Phi'' \\ (1+b)\gamma\Phi'' & \frac{\partial\tau^S}{\partial T^S}\left(1 - m(1-b)\right) + (1+b)\gamma\Phi'' \end{pmatrix} \begin{bmatrix} \frac{dT^N}{dI} \\ \frac{dT^S}{dI} \end{bmatrix} = \begin{bmatrix} -\frac{\partial\tau^N}{\partial I}(1 + m(1-b)) - \frac{\alpha}{\bar{K}}\tau^N(1-b) \\ -\frac{\partial\tau^S}{\partial I}(1 - m(1-b)) + \frac{\alpha}{\bar{K}}\tau^S(1-b) \end{bmatrix}.$$

The matrix system is solved to obtain

$$|Y|\frac{\partial T^N}{\partial I} = \underset{(-)}{(1+b)\gamma\Phi''}\left\{\left[\frac{\alpha\tau^N}{K^N}\left(\underbrace{\frac{\bar{K} - (K^N - \alpha I)(1-b)}{\bar{K}}}_{(+)}\right)\right] + \left[\frac{\alpha\tau^S}{K^S}\left(\underbrace{\frac{\bar{K} - (K^S + \alpha I)(1-b)}{\bar{K}}}_{(+)}\right)\right]\right\}$$
$$+\underset{(-)}{\frac{\partial\tau^S}{\partial T^S}}(1 - m(1-b))\left\{\left[\frac{\alpha\tau^N}{K^N}\left(\underbrace{\frac{\bar{K} - (K^N - \alpha I)(1-b)}{\bar{K}}}_{(+)}\right)\right]\right\}; \qquad \text{(E6)}$$

$$|Y|\frac{\partial T^S}{\partial I} = \underset{(-)}{(1+b)\gamma\Phi''}\left\{\left[-\frac{\alpha\tau^S}{K^S}\left(\underbrace{\frac{\bar{K} - (K^S + \alpha I)(1-b)}{\bar{K}}}_{(+)}\right)\right]\left[-\frac{\alpha\tau^N}{K^N}\left(\underbrace{\frac{\bar{K} - (K^N - \alpha I)(1-b)}{\bar{K}}}_{(+)}\right)\right]\right\}$$
$$+\underset{(-)}{\frac{\partial\tau^N}{\partial T^N}}(1 + m(1-b))\left\{-\left[\frac{\alpha\tau^S}{K^S}\left(\underbrace{\frac{\bar{K} - (K^S + \alpha I)(1-b)}{\bar{K}}}_{(+)}\right)\right] - \underbrace{(m\tau^N - \gamma\Phi'')}_{(-)}\right\}. \qquad \text{(E7)}$$

It is now shown that $\partial T^N/\partial I < 0$, whilst $\partial T^S/\partial I > 0$.

Let $b_1(b) \equiv [\bar{K} - (K^N - \alpha I)(1-b)]/\bar{K}$, and $b_2(b) \equiv [\bar{K} - (K^S + \alpha I)(1-b)]/\bar{K}$. Since $b_1(\cdot)$ and $b_2(\cdot)$ are increasing in b, both attain their minimum at $b = 0$. Therefore, it follows that $b_1(b) > (K^S + \alpha I)/\bar{K}$, which is positive. Moreover, $b_2(b) > (K^N - \alpha I)/\bar{K}$, which is also positive in view of $I^o < (K^N - K^S)/2$ (see (5.20)). These, together with $\partial\tau^j/\partial T^j < 0$, $\Phi'' < 0$, and $1 - m(1-b) > 0$ and $1 + m(1-b) > 0$, imply that for any given b, $\partial T^N/\partial I < 0$ and $\partial T^S/\partial I > 0$.

Combining results of Steps 1 and 2, and the fact that $dI/db > 0$, it is straightforward that $dT^N/db < 0$, whilst $dT^S/db \gtrless 0$.

Appendix F

In case of the neutral-environment good model, the implications of cooperation on world pollution are derived. We need to prove that Ω, as defined in (5.34) is less than Λ as defined in (5.22). This implies that $T^{W^c} < T^{W^a}$.

To prove $\Omega < \Lambda$ is equivalent to proving

$$2^{-\frac{\alpha+\beta}{1-\beta}} \bar{K}^{\frac{\alpha}{1-\beta}} \quad < \quad \bar{K^N}^{\frac{\alpha}{1-\beta}} + \bar{K^S}^{\frac{\alpha}{1-\beta}}. \tag{F1}$$

Note that we have earlier defined the r.h.s. as $q^a(\bar{K}^N)$, and, further, $dq^a/d\bar{K}^N < 0$ (see Appendix C). This implies that

$$q^a(\bar{K}^N) > q^a(\bar{K}) = \bar{K}^{\frac{\alpha}{1-\beta}} > 2^{-\frac{\alpha+\beta}{1-\beta}} \bar{K}^{\frac{\alpha}{1-\beta}},$$

which proves that $\Omega < \Lambda$.

Appendix G

When there are positive-income effects on the demand for environment quality it is derived that, under the regularity conditions (R2), (a) the second-order conditions with respect to the equilibrium (defined by (5.45) and (5.46)) hold, (b) whilst T^S is a strategic substitute of T^N, T^N may be a strategic complement of T^S, and (c) the equilibrium is stable and unique. The proof closely follows the one for the neutral-environmental good model given in Appendix A. More specifically, it is shown that

$$\tilde{f}_N^N < 0,\ \tilde{f}_S^N < 0; \tag{G1}$$

$$\tilde{f}_S^S < 0,\ \tilde{f}_N^S \gtrless 0; \tag{G2}$$

$$\tilde{f}_N^N \tilde{f}_S^S - \tilde{f}_S^N \tilde{f}_N^S - \gamma\left(\tilde{f}_N^N - \tilde{f}_S^N + \tilde{f}_S^S - \tilde{f}_N^S\right)\Phi'' \quad > 0, \tag{G3}$$

where $\tilde{f}^j$, $(j = N, S)$ is the marginal benefit from pollution for country j, $\tilde{f}_j^j = \partial \tilde{f}^j / \partial T^j$, and $\tilde{f}_i^j = \partial \tilde{f}^j / \partial T^i$, $j \neq i$. The signs of $\tilde{f}_N^N$, $\tilde{f}_S^N$, $\tilde{f}_S^S$, and $\tilde{f}_N^S$ in (G1) and (G2) together with $\Phi'' < 0$ would prove (a) and (b), whilst (G3) would prove (c). But first note the following definitions in relations, which are used in proving (a), (b) and (c) above.

All the definitions and relations in (A4) and the first two expressions, relating to $\hat{\tau}^j$ and dI in (A5), that were used in Appendix A in case of the zero-income effect model, hold true in the positive-income effect case as well. The exception is in respect of the ranking between the factor employment levels. In what follows we first address these.

Recall the following eq. in section 5.4.2:

$$\frac{T^{N^o}}{T^{S^o}} = \left(\frac{1 - \frac{\alpha I}{K^S}}{1 - \frac{\alpha I}{\bar{K}}}\right)\left(\frac{1 + \frac{\alpha I}{\bar{K}}}{1 + \frac{\alpha I}{K^N}}\right) < 1, \tag{G4}$$

which was derived by taking the ratio of the two first-order conditions (5.47) and (5.48). Now, using $K^N = \eta\bar{K}$ and $K^S = (1-\eta)\bar{K}$, (G4) this is equivalent to

$$\frac{T^{N^o}}{T^{S^o}}\frac{(1-\eta)}{\eta} = \left(\frac{(1-\eta)\bar{K} - \alpha I}{\bar{K} - \alpha I}\ \frac{\bar{K} + \alpha I}{\eta\bar{K} + \alpha I}\right) \Leftrightarrow \left(\frac{T^N}{T^S}\right)^{1-\theta} = \left(\frac{(1-\eta)\bar{K} - \alpha I}{\bar{K} - \alpha I}\ \frac{\bar{K} + \alpha I}{\eta\bar{K} + \alpha I}\right) \tag{G5}$$

Since the l.h.s. is less than 1, the r.h.s. is less than 1 also. The latter is equivalent to[21]

$$(\bar{K}+\alpha I)((1-\eta)\bar{K}-\alpha I) < (\bar{K}-\alpha I)(\eta\bar{K}+\alpha I) \quad \text{(G6)}$$

$$\Leftrightarrow (1-\eta)\bar{K}-\eta\bar{K} < \alpha I \Leftrightarrow K^S < K^N+\alpha I \quad \text{(G7)}$$

$$\Leftrightarrow \bar{K}^N-\bar{K}^S > (2-\alpha)I \Rightarrow I^o < \frac{\bar{K}^N-\bar{K}^S}{2-\alpha}. \quad \text{(G8)}$$

In the rest of this appendix, we ignore the use of superscript "o" for notational simplicity.

From (G4), (G6), and (G7) the following additional relations are used for the various proofs in this appendix.

$$T^N < T^S;\ K^N < K^S; K^S < K^N + \alpha I; \quad \text{(G9)}$$

$$\frac{(1-\eta)\bar{K}-\alpha I}{\eta\bar{K}+\alpha I} \equiv \frac{K^S-\alpha I}{K^N+\alpha I} = \frac{\bar{K}-\alpha I}{\bar{K}+\alpha I} < 1. \quad \text{(G10)}$$

We now turn toward proving (a), (b) and (c).

Total differentiation of (5.45) and (5.46) yields

$$\widehat{\tilde{f}^N} = -\hat{T^N} + \widehat{\left(1+\frac{\alpha I}{\bar{K}}\right)} - \widehat{\left(1+\frac{\alpha I}{K^N}\right)}; \quad \text{(G11)}$$

$$\widehat{\tilde{f}^S} = -\hat{T^S} + \widehat{\left(1-\frac{\alpha I}{\bar{K}}\right)} - \widehat{\left(1-\frac{\alpha I}{K^S}\right)}. \quad \text{(G12)}$$

We now prove (G1). Using (A4), (A5) and (A6), (G11) can be expressed as

$$\widehat{\tilde{f}^N} = -\hat{T^N} - \alpha\theta\eta(1-\eta)\bar{K}\left(\frac{K^N(K^N+\alpha I)-\bar{K}^N(\bar{K}+\alpha I)}{\eta\bar{K}(\bar{K}+\alpha I)(K^N+\alpha I)}\right)\cdot \left(\hat{T^N}-\hat{T^S}\right). \quad \text{(G13)}$$

Thus,

$$\frac{\widehat{\tilde{f}^N}}{\hat{T^N}} = -1+\alpha\theta(1-\eta)\left(\frac{\bar{K}^N(\bar{K}+\alpha I)-K^N(K^N+\alpha I)}{(\bar{K}+\alpha I)(K^N+\alpha I)}\right); \quad \text{(G14)}$$

$$\frac{\widehat{\tilde{f}^N}}{\hat{T^S}} = -1+\alpha\theta(1-\eta)\left(\frac{K^N(K^N+\alpha I)-\bar{K}^N(\bar{K}+\alpha I)}{(\bar{K}+\alpha I)(K^N+\alpha I)}\right). \quad \text{(G15)}$$

[21]Note that it is the last inequality below that provides the upper limit on the magnitude of equilibrium FDI, which is evidently much lower than the natural bound on I^o, i.e. $\bar{K}^N$.

Define $\tilde{k}^N \equiv \frac{K^N(K^N+\alpha I)-\bar{K}^N(\bar{K}+\alpha I)}{(\bar{K}+\alpha I)(K^N+\alpha I)}$. Observe that $\tilde{k}^N < 0$ in view of $\bar{K} > \bar{K}^N > K^N$. This implies that

$$
\begin{aligned}
(1-\eta)(-\tilde{k}^N) &< \frac{(1-\eta)\bar{K}(\bar{K}+\alpha I)}{(\bar{K}+\alpha I)(K^N+\alpha I)} \\
&< \frac{K^S}{K^N+\alpha I} < 1,
\end{aligned}
\tag{G16}
$$

in view of (G10). Hence,

$$
\frac{\widehat{\tilde{f}^N}}{\hat{T^N}} < -1+\alpha\theta < 0 \quad \Rightarrow \quad \tilde{f}^N_N \equiv \frac{\partial \tilde{f}^N}{\partial T^N} < 0. \tag{G17}
$$

Moreover, from $\tilde{k}^N < 0$,

$$
\frac{\widehat{\tilde{f}^N}}{\hat{T^S}} < 0 \Rightarrow \tilde{f}^N_S \equiv \frac{\partial \tilde{f}^N}{\partial T^S} < 0 \tag{G18}
$$

Results in (G17) and (G18) prove (G1) .

Next, (G2) is proved. Taking (G12) and utilizing the expression for dI from (A6),

$$
\widehat{\tilde{f}^S} = -\hat{T^S} + \alpha\theta\eta(1-\eta)\bar{K}\left(\frac{K^S(K^S-\alpha I)-\bar{K}^S(\bar{K}-\alpha I)}{(1-\eta)\bar{K}(\bar{K}-\alpha I)(K^S-\alpha I)}\right)\left(\hat{T^N}-\hat{T^S}\right). \tag{G19}
$$

Define $\tilde{k}^S \equiv \frac{K^S(K^S-\alpha I)-\bar{K}^S(\bar{K}-\alpha I)}{(\bar{K}-\alpha I)(K^S-\alpha I)}$. Note that $\tilde{k}^S \gtrless 0$. Specifically, for large enough $\bar{K}^S$, $\tilde{k}^S < 0$.

We first examine the case where $\tilde{k}^S < 0$. In view of $\bar{K}^S < \bar{K}^S + (1-\alpha)I (= K^S - \alpha I)$

$$
\begin{aligned}
-\tilde{k}^S &< \frac{\bar{K}^S}{(K^S-\alpha I)} < 1 && \text{(G20)} \\
\Rightarrow \frac{\widehat{\tilde{f}}^S}{\hat{T^S}} &= -1+\alpha\theta\eta(-\tilde{k}^S) < 0. && \text{(G21)}
\end{aligned}
$$

Moreover, it is easy to see that,

$$
\frac{\widehat{\tilde{f}}^S}{\hat{T^N}} = \alpha\theta\eta\tilde{k}^S < 0 \tag{G22}
$$

Next, when $\tilde{k}^S > 0$, it is easy to see (G18) holds. But, then

$$
\frac{\widehat{\tilde{f}}^S}{\hat{T^N}} > 0. \tag{G23}
$$

Gathering the results in (G18), (G22), (G23) it follows that $\tilde{f}_S^S \equiv \partial f^S/\partial T^S < 0$, whilst $\tilde{f}_N^S \equiv \partial f^S/\partial T^N \gtrless 0$. Hence, (G2) is also proved. (G1) and (G2) together with $\Phi'' < 0$ imply (a) and (b). Thus, the second-order conditions hold. Moreover, in the North T^S is a strategic substitute of T^N, but in the South T^N may turn out to be a strategic complement of T^S.

Now, turn to the proof for (c), which will imply that the Nash equilibrium is unique and stable. It is first shown that $\tilde{f}_N^N < \tilde{f}_S^N$, and that $\tilde{f}_S^S < \tilde{f}_N^S$ next.

Return to the expressions in (G14) and (G15), which together imply

$$\begin{aligned}
-\frac{T^N}{\tilde{f}^N}\left(\tilde{f}_N^N - \tilde{f}_S^N\right) &= 1 + \alpha\theta(1-\eta)\tilde{k}^N\left(1 + \frac{T^N}{T^S}\right) \\
&> 1 + \alpha\theta(1-\eta)\tilde{k}^N\left(1 + \frac{T^{N\theta}}{T^{S\theta}}\right) \quad \left(\text{since } T^N/T^S < 1 \text{ and } \theta < 1\right) \\
&> 1 - \alpha\theta(1-\eta)(-\tilde{k}^N)\frac{1}{1-\eta} \\
&> 1 - \alpha\theta(-\tilde{k}^N). \qquad \text{(G24)}
\end{aligned}$$

In what follows it is shown that (G24) is positive. Utilizing the definition of $\tilde{k}^N$ we have

$$\begin{aligned}
-\alpha\tilde{k}^N - 1 &\equiv \left(\frac{\alpha\bar{K}^N(\bar{K}+\alpha I) - \alpha K^N(K^N+\alpha I)}{(\bar{K}+\alpha I)(K^N+\alpha I)}\right) - 1 \\
&= \frac{\alpha\bar{K}^N}{\bar{K}^N - (1-\alpha)I} - \frac{\alpha(\bar{K}^N - I)}{\bar{K}+\alpha I} - 1 \\
&= -\frac{(1-\alpha)(\bar{K}^N - I)}{\bar{K}^N - (1-\alpha)I} - \frac{\alpha(\bar{K}^N - I)}{\bar{K}+\alpha I} < 0 \\
&\Leftrightarrow -\alpha\tilde{k}^N < 1 \Rightarrow -\alpha\theta\tilde{k}^N < -\alpha\tilde{k}^N < 1, \qquad \text{(G25)}
\end{aligned}$$

since $\tilde{k}^N < 0$ and $\theta \equiv \beta/(1-\alpha) < 1$. Thus, the r.h.s. of (G24) is positive implying that

$$\tilde{f}_N^N < \tilde{f}_S^N. \qquad \text{(G26)}$$

Next, (G21) and (G22) together imply

$$-\frac{T^S}{\tilde{f}^S}\left(\tilde{f}_S^S - \tilde{f}_N^S\right) = 1 + \alpha\theta\eta\tilde{k}^S\left(1 + \frac{T^S}{T^N}\right). \qquad \text{(G27)}$$

To prove $\tilde{f}_S^S < \tilde{f}_N^S$ we need to show that (G27) is positive. This is straightforward in the case where $\tilde{k}^S > 0$. Suppose $\tilde{k}^S < 0$, then (G27) may or may not be positive. In what follows we derive the sufficient condition for (G27) to be positive.

For this, first look at the expression $(1 + T^N/T^S)$. From (G5),

$$1 + \frac{T^S}{T^N} = \frac{(1-\eta)(\bar{K} - \alpha I)(\eta\bar{K} + \alpha I) + \eta((1-\eta)\bar{K} - \alpha I)(\bar{K} + \alpha I)}{\eta(\bar{K} + \alpha I)((1-\eta)\bar{K} - \alpha I)} \tag{G28}$$

Next, from (G10) we already know that $(1-\eta)\bar{K} - \alpha I < \eta\bar{K} + \alpha I$. This implies that the r.h.s. of (G28) is

$$\begin{aligned}
&< \frac{(\eta\bar{K} + \alpha I)\left[(1-\eta)\bar{K} - (1-\eta)\alpha I + \eta\bar{K} + \alpha\eta I\right]}{\eta(\bar{K} + \alpha I)((1-\eta)\bar{K} - \alpha I)} \\
&< \frac{(\eta\bar{K} + \alpha I)(\bar{K} + \alpha\eta I)}{\eta(\bar{K} + \alpha I)((1-\eta)\bar{K} - \alpha I)} < \frac{(\eta\bar{K} + \alpha I)(\bar{K} + \alpha I)}{\eta(\bar{K} + \alpha I)((1-\eta)\bar{K} - \alpha I)} \\
&\equiv \frac{\eta\bar{K} + \alpha I}{\eta((1-\eta)\bar{K} - \alpha I)} \\
&\equiv \frac{\bar{K}^N - (1-\alpha)I}{\eta(\bar{K}^S + (1-\alpha)I)}
\end{aligned} \tag{G29}$$

Next, turn to the expression for $\tilde{k}^S$. In view of $\bar{K}^S < K^S - \alpha I$,

$$-\tilde{k}^S < \frac{(K^S - \alpha I)(\bar{K} - \alpha I) - K^S(K^S - \alpha I)}{(\bar{K} - \alpha I)(K^S - \alpha I)} \equiv \frac{\bar{K} - \alpha I - K^S}{\bar{K} - \alpha I} \equiv \frac{K^N - \alpha I}{\bar{K} - \alpha I} \tag{G30}$$

In view of the chain of inequalities in (G29) and the ranking in (G30), the r.h.s. of (G27) will be positive if

$$1 - \alpha\theta\left(\frac{\bar{K}^N - (1+\alpha)I}{\bar{K} - \alpha I}\right)\left(\frac{\bar{K}^N - (1-\alpha)I}{\bar{K}^S + (1-\alpha)I}\right) > 0.$$

Further, given $\theta \equiv \beta/(1-\alpha) < 1$, it is sufficient that

$$\alpha\left(\frac{\bar{K}^N - (1+\alpha)I}{\bar{K} - \alpha I}\right) < \frac{\bar{K}^S + (1-\alpha I)I}{\bar{K}^N - (1-\alpha)I}. \tag{G31}$$

It is straightforward to derive that the term in brackets in the l.h.s. is decreasing in I, whilst the r.h.s. is increasing in I. These imply that at $I = 0$, the l.h.s. (r.h.s.) would attain its maximum (minimum) value. Utilizing this, for (G31) to hold it is sufficient that

$$\alpha\left(\frac{\bar{K}^N-(1+\alpha)I}{\bar{K}-\alpha I}\right)\Bigg|_{I=0} < \frac{\bar{K}^S+(1-\alpha)I}{\bar{K}^N-(1-\alpha)I}\Bigg|_{I=0}$$
$$\Leftrightarrow \alpha\frac{\bar{K}^N}{\bar{K}^N+\bar{K}^S} < \frac{\bar{K}^S}{\bar{K}^N} \Leftrightarrow \alpha < \frac{\bar{K}^S}{\bar{K}^N}\left(1+\frac{\bar{K}^S}{\bar{K}^N}\right) \equiv \frac{\bar{K}^N\bar{K}^S+\bar{K}^{S^2}}{\bar{K}^{N^2}}. \quad \text{(G32)}$$

This is the regularity condition (R2). Assuming that (R2) holds,

$$\tilde{f}_S^S < \tilde{f}_N^S. \quad \text{(G33)}$$

The rankings in (G26) and (G33) imply that $|\tilde{f}_N^N| > |\tilde{f}_S^N|$, $|\tilde{f}_S^S| > |\tilde{f}_N^S|$, $(\tilde{f}_N^N - \tilde{f}_S^N) < 0$ and $(\tilde{f}_S^S - \tilde{f}_N^S) < 0$. These results together with $\Phi'' < 0$ imply that (G3) holds and (c) is also proved.

Appendix H

When there are positive-income effects on the demand for environment, the effect on global and regional pollution in moving from autarky to capital mobility (non-cooperative Nash) equilibrium is worked out.

We first look at the impact on global pollution. It is derived that global pollution at the free FDI equilibrium is higher than under at the autarky equilibrium.

Consider the Nash first-order conditions (5.47)-(5.48). Multiplying (5.47) by T^N, (5.48) by T^S and adding them up give rise to

$$\left(\frac{1+\frac{\alpha I}{K}}{1+\frac{\alpha I}{K^N}}\right)+\left(\frac{1-\frac{\alpha I}{K}}{1-\frac{\alpha I}{K^S}}\right)=\frac{\gamma T^W}{\beta(\bar{T}-T^W)}\equiv\tilde{g}(T^W). \quad \text{(H1)}$$

Next turn to the autarky first-order condition (5.42), which could be similarly manipulated to yield

$$2=\tilde{g}(T^W). \quad \text{(H2)}$$

Since $\tilde{g}(\cdot)$ is increasing in T^W, the Nash equilibrium global pollution (T^{W^o}) will be higher (lower) as compared to autarky pollution, T^{W^a}, as

$$\left(\frac{1+\frac{\alpha I}{\bar{K}}}{1+\frac{\alpha I}{\bar{K}^N}}\right)+\left(\frac{1-\frac{\alpha I}{\bar{K}}}{1-\frac{\alpha I}{\bar{K}^S}}\right)>(<)2. \tag{H3}$$

Utilizing $\bar{K}^N = \eta\bar{K}$, $\bar{K}^S = (1-\eta)\bar{K}$ and $\alpha I/\bar{K} \equiv m$, this is equivalent to

$$\frac{1+m}{1+\frac{m}{\eta}}+\frac{1-m}{1-\frac{m}{1-\eta}}>(<)2. \tag{H4}$$

$$\Leftrightarrow (1-2\eta-m)>(<)2(1-2\eta-m)$$

Therefore, global pollution would fall (rise) as compared to autarky if

$$1-2\eta-m\left(\equiv\frac{\bar{K}^S-\bar{K}^N+(2-\alpha)I}{\bar{K}}\right)\quad>(<)\quad 0 \tag{H5}$$

$$\Leftrightarrow I^o \quad >(<)\quad \frac{\bar{K}^N-\bar{K}^S}{2-\alpha}. \tag{H6}$$

From (G8) we have $I^o < (\bar{K}^N - \bar{K}^S)/(2-\alpha)$. Thus, $T^{W^o} > T^{W^a}$.

We now consider the effect on regional pollution levels, T^N and T^S.

The impacts on regional pollution levels depend on the effects on marginal benefits and marginal costs of pollution as countries move from autarky to free capital mobility. It is already shown in section 5.4.2 that compared to autarky, the marginal benefit of pollution is affected by the by an additional effect – the income adjusted factor terms-of-trade effect. This is captured by the term $p^N(\cdot) < 1$ and $p^S(\cdot) > 1$ for the North and South. *Ceteris paribus*, this implies that the marginal benefits are lowered (raised) for North (South). At the same time, it is derived above that aggregate global pollution increases, implying an increase marginal costs of pollution. Combining the effects on the marginal benefits and costs, it is clear that North's will fall in moving from autarky to free FDI equilibrium. That the pollution in South will rise follows from the fact that North's pollution level has gone down whilst global pollution has increased. Hence, $T^{N^o} < T^{N^a}$ and $T^{S^o} > T^{S^a}$.

Appendix I

When environment is a normal good, the effect of capital mobility on the regional and global welfare levels is analyzed here. It is derived that the change in welfare at both the regional and global levels remains ambiguous in general. However, at sufficiently small levels of FDI, the implications are similar to that for the earlier model, i.e., South has a welfare gain, North incurs a welfare loss and global welfare is reduced.

Observe that the pair of expressions:

$$\begin{aligned}\widetilde{U}^N &= \ln\left[Y^N(\bar{K}^N - I, T^N) + r^N(\bar{K}^N - I, T^N)I\right] + \gamma\ln(\bar{T} - T^W);\\ \widetilde{U}^S &= \ln\left[Y^S(\bar{K}^S + I, T^S) - r^S(\bar{K}^S + I, T^S)I\right] + \gamma\ln(\bar{T} - T^W),\end{aligned}$$

represent North's and South's welfare in "generic" form, that is, they hold true for any value of I. As $I \to 0$, welfare levels approach their counterparts in autarky and when $I > 0$, they express welfare under non-cooperation.[22] Using I as the parameter, the total change in

[22]Recall that although I is an endogenous variable, it is valid to use it as a parameter here to characterize the move from autarky to non-cooperation.

welfare levels is expressed as:

$$d\widetilde{U}^N = \frac{1}{Y^N + r^N I}\left(-r^N dI + \tau^N dT^N + (1-\alpha)\frac{r^N}{K^N} IdI + \beta\frac{r^N}{T^N} IdT^N + r^N dI\right) - \frac{\gamma}{\bar{T} - T^W}(dT^N + dT^S) \tag{I1}$$

$$\Rightarrow \frac{d\widetilde{U}^N}{dI} = \underbrace{\frac{1}{Y^N + r^N I}\left((1-\alpha)\frac{r^N}{K^N} I + \beta\frac{r^N}{T^N} I \underset{(-)}{\frac{dT^N}{dI}}\right)}_{(+)/(-)} + \underbrace{\left(\underset{(-)}{\frac{\tau^N}{Y^N + r^N I} - \frac{\gamma}{\bar{T} - T^W}}\right)\underset{(-)}{\frac{dT^N}{dI}}}_{(+)}$$

$$\underbrace{-\frac{\gamma}{\bar{T} - T^W}\underset{(+)}{\frac{dT^S}{dI}}}_{(+)} \gtrless 0, \text{ and} \tag{I2}$$

$$d\widetilde{U}^S = \frac{1}{Y^S - r^S I}\left(r^S dI + \tau^S dT^S + (1-\alpha)\frac{r^S}{K^S} IdI - \beta\frac{r^S}{T^S} IdT^S - r^S dI\right) - \frac{\gamma}{\bar{T} - T^W}(dT^N + dT^S). \tag{I3}$$

$$\Rightarrow \frac{d\widetilde{U}^S}{dI} = \underbrace{\frac{1}{Y^S - r^S I}\left((1-\alpha)\frac{r^S}{K^S} I - \beta\frac{r^S}{T^S} I \underset{(+)}{\frac{dT^S}{dI}}\right)}_{(+)/(-)} + \underbrace{\left(\underset{(+)}{\frac{\tau^S}{Y^S - r^S I} - \frac{\gamma}{\bar{T} - T^W}}\right)\underset{(+)}{\frac{dT^S}{dI}}}_{(+)}$$

$$\underbrace{-\frac{\gamma}{\bar{T} - T^W}\underset{(-)}{\frac{dT^N}{dI}}}_{(-)} \gtrless 0. \tag{I4}$$

As in the earlier model, the first bracketed term in the r.h.s. of (I2) and (I4) is the sum of the *direct and indirect factor terms-of-trade* effects, that is, the sum of gains from pure rate of return change and change in the return due to country's *own* pollution policy change. (The only difference is that this is now adjusted for the marginal utility of income.) From Proposition 10, we have $dT^N/dI < 0$ and $dT^S/dI > 0$, and hence *a priori* the sign of this effect remain unclear for either country. Unlike the neutral-environment good model, analytically it could not be proved whether the regional welfare change on account of net factor terms-of-trade effect would be positive or negative.

The second terms in the r.h.s. of (I2) and (I4) respectively represent the change in welfare due to optimal adjustment of countries' *own* pollution policies. The first-order conditions (5.45) and (5.46) imply that $\tau^N/(Y^N + r^N I) - \gamma/(\bar{T} - T^W) < 0$ and $\tau^S/(Y^S - r^S I) - \gamma/(\bar{T} - T^W) > 0$.[23] Together with $dT^N/dI < 0$ and $dT^S/dI > 0$, the second term is positive. Thus, the change in welfare of both the countries on account of this effect is positive. The third effect refers to change in welfare on account of change in the pollution policy of the *other*/partner country; this effect is negative (positive) for the North (South) as South (North) increases (reduces) its pollution. Note that the directions of change of both – own and spillover pollution – effects on welfare are qualitatively the same as in the neutral-good model.

In the aggregate, summing these effects, the welfare implications for either country remain ambiguous. As expected, the effect on global welfare is also ambiguous. The aggregate welfare change is expressed as:

$$\begin{aligned}
\frac{d\tilde{U}^W}{dI} &\equiv \frac{d\tilde{U}^N}{dI} + \frac{d\tilde{U}^S}{dI} \\
&= \frac{1}{Y^N + r^N I}\underbrace{\left((1-\alpha)\frac{r^N}{K^N}I + \beta\frac{r^N}{T^N}I\underset{(-)}{\frac{dT^N}{dI}}\right)}_{(+)/(-)} + \frac{1}{Y^S - r^S I}\underbrace{\left((1-\alpha)\frac{r^S}{K^S}I - \beta\frac{r^S}{T^S}I\underset{(+)}{\frac{dT^S}{dI}}\right)}_{(+)/(-)} \\
&\quad \underbrace{+\left(\underset{(-)}{\frac{\tau^N}{Y^N + r^N I} - \frac{\gamma}{\bar{T} - T^W}}\right)\underset{(-)}{\frac{dT^N}{dI}}}_{(+)} + \underbrace{\left(\underset{(+)}{\frac{\tau^S}{Y^S - r^S I} - \frac{\gamma}{\bar{T} - T^W}}\right)\underset{(+)}{\frac{dT^S}{dI}}}_{(+)} \\
&\quad \underbrace{-\frac{\gamma}{\bar{T} - T^W}\underset{(+)}{\frac{dT^W}{dI}}}_{(+)} \gtrless 0. \qquad \text{(I7)}
\end{aligned}$$

---

[23]This is so since from (5.45) and (5.46) we have

$$\frac{\tau^N}{Y^N + r^N I} < \frac{\tau^N\left(1 + \frac{\alpha I}{K}\right)}{Y^N + r^N I} = \frac{\gamma}{\bar{T} - T^W}; \qquad \text{(I5)}$$

$$\frac{\tau^S}{Y^S - r^S I} > \frac{\tau^S\left(1 - \frac{\alpha I}{K}\right)}{Y^S - r^S I} = \frac{\gamma}{\bar{T} - T^W}. \qquad \text{(I6)}$$

As discussed, the signs of the first two terms (that represent the sum of the factor terms-of-trade effects) are ambiguous, the second and third terms are positive on account of optimal adjustment of own pollution levels by countries, and the last term is negative as global pollution rises with FDI, that is $dT^W/dI > 0$ (this is derived in Appendix H).

However, in the special case of capital endowment differences between the North and the South being sufficiently small, and hence the magnitude of FDI being small enough, welfare predictions similar to the neutral-good model emerge. That is,

$$\lim_{I\to 0}\frac{d\widetilde{U}^N}{dI} = -\frac{\gamma}{\bar{T}-T^W}\frac{dT^S}{dI} < 0; \qquad \lim_{I\to 0}\frac{d\widetilde{U}^S}{dI} = -\frac{\gamma}{\bar{T}-T^W}\frac{dT^N}{dI} > 0; \tag{I8}$$

$$\lim_{I\to 0}\frac{d\widetilde{U}^W}{dI} = -\frac{\gamma}{\bar{T}-T^W}\frac{dT^W}{dI} < 0. \tag{I9}$$

Appendix J

It is shown that, when environment is a normal good, at the cooperative equilibrium North's contribution to pollution is lower than South's.

Define $k^{Nc} \equiv \frac{\bar{K}+\alpha I}{K^N+\alpha I} - \frac{\alpha I}{K^S-\alpha I}$ and $k^{Sc} \equiv \frac{\bar{K}-\alpha I}{K^S-\alpha I} + \frac{\alpha I}{K^N+\alpha I}$. Now, the first-order conditions (5.53)-(5.54) in the text could be combined to yield

$$\frac{k^{Nc}}{k^{Sc}} = \left(\frac{T^{Nc}}{T^{Sc}}\right)^{1-\theta} < 1 \Leftrightarrow T^{Nc} < T^{Sc}. \tag{J1}$$

This is proved by contradiction. Suppose (J1) is not true, then

$$\frac{T^{Nc}}{T^{Sc}} > 1 \;\Rightarrow\; k^{Nc} > k^{Sc}. \tag{J2}$$

$$\begin{aligned}\Rightarrow \frac{\bar{K}+\alpha I}{K^N+\alpha I} - \frac{\alpha I}{K^S-\alpha I} &> \frac{\bar{K}-\alpha I}{K^S-\alpha I} + \frac{\alpha I}{K^N+\alpha I}\\ \Rightarrow \frac{\bar{K}}{K^N+\alpha I} &> \frac{\bar{K}}{K^S-\alpha I} \Rightarrow K^S-\alpha I > K^N+\alpha I\\ \Rightarrow K^S &> K^N. \end{aligned} \tag{J3}$$

Utilizing the last inequality in the capital market clearing condition (5.9) yields

$$T^{Sc} > T^{Nc}, \tag{J4}$$

which contradicts (J2). Thus, under cooperation,

$$T^{N^c} < T^{S^c}, \text{ and this implies } K^{N^c} < K^{S^c}. \tag{J5}$$

Appendix K

It is proved that when environment is a normal good, under the regularity condition (R3), (a) the second-order conditions relating to first-order conditions of the cooperative equilibrium (5.53)-(5.54) are met , (b) T^S is a strategic substitute of T^N, whilst T^N may be strategically complementary to T^S, and (c) the equilibrium is unique (and stable).

In what follows, it is shown that

$$\tilde{f}_N^{N^c} < 0, \ \tilde{f}_S^{N^c} < 0; \tag{K1}$$

$$\tilde{f}_S^{S^c} < 0, \ \tilde{f}_N^{S^c} < 0; \tag{K2}$$

where $\tilde{f}^{j^c}$, $j = N, S$ is the marginal benefit from pollution for country j under cooperation, $\tilde{f}_j^{j^c} = \partial \tilde{f}^{j^c} / \partial T^j$, and $\tilde{f}_i^{j^c} = \partial \tilde{f}^{j^c} / \partial T^i$, $j \neq i$. Given $\Phi'' < 0$, the results in (K1) and (K2) prove (a) and (b), whilst (c) will be proven as follows.

The Nash equilibrium is be unique (and stable) if the determinant

$$\begin{vmatrix} \tilde{f}_N^{N^c} + 2\gamma\Phi'' & \tilde{f}_S^{N^c} + 2\gamma\Phi'' \\ \tilde{f}_N^{S^c} + 2\gamma\Phi'' & \tilde{f}_N^{N^c} + 2\gamma\Phi'' \end{vmatrix}$$

$$\equiv \tilde{f}_N^{N^c} \tilde{f}_S^{S^c} - \tilde{f}_S^{N^c} \tilde{f}_N^{S^c} + 2\gamma\Phi'' \left(\tilde{f}_N^{N^c} - \tilde{f}_S^{N^c} + \tilde{f}_S^{S^c} - \tilde{f}_N^{S^c} \right) > 0$$

$$\equiv \frac{\tilde{f}^{N^c}}{T^N} \frac{\widehat{\tilde{f}^N}^c}{\hat{T^N}} \cdot \frac{\tilde{f}^{S^c}}{T^S} \frac{\widehat{\tilde{f}^S}^c}{\hat{T^S}} - \frac{\tilde{f}^{N^c}}{T^S} \frac{\widehat{\tilde{f}^N}^c}{\hat{T^S}} \cdot \frac{\tilde{f}^{S^c}}{T^N} \frac{\widehat{\tilde{f}^S}^c}{\hat{T^N}} + 2\gamma\Phi'' \left(\frac{\tilde{f}^{N^c}}{T^N} \frac{\widehat{\tilde{f}^N}^c}{\hat{T^N}} \right.$$

$$\left. + \frac{\tilde{f}^{S^c}}{T^S} \frac{\widehat{\tilde{f}^S}^c}{\hat{T^S}} - \frac{\tilde{f}^{N^c}}{T^S} \frac{\widehat{\tilde{f}^N}^c}{\hat{T^S}} - \frac{\tilde{f}^{S^c}}{T^N} \frac{\widehat{\tilde{f}^S}^c}{\hat{T^N}} \right) > 0. \tag{K3}$$

In view of $\tilde{f^N}^c = \tilde{f^S}^c$ at the cooperative equilibrium, (K3) is

$$\Leftrightarrow \frac{\tilde{f^N}^c}{T^N}\frac{\tilde{f^S}^c}{T^S}\left(\frac{\widehat{\tilde{f^N}}^c}{\hat{T^N}}\frac{\widehat{\tilde{f^S}}^c}{\hat{T^S}} - \frac{\widehat{\tilde{f^N}}^c}{\hat{T^S}}\frac{\widehat{\tilde{f^S}}^c}{\hat{T^N}}\right) + 2\gamma\Phi''\tilde{f^N}^c\left(\equiv \tilde{f^S}^c\right)\left(\frac{\widehat{\tilde{f^N}}^c}{T^N\hat{T^N}} - \frac{\widehat{\tilde{f^S}}^c}{T^N\hat{T^N}} + \frac{\widehat{\tilde{f^S}}^c}{T^S\hat{T^S}} - \frac{\widehat{\tilde{f^N}}^c}{T^S\hat{T^S}}\right)$$

$$\Leftrightarrow \frac{\tilde{f^N}^c}{T^N}\frac{\tilde{f^S}^c}{T^S}(\tilde{w}.\tilde{x} - \tilde{y}\tilde{z}) + 2\gamma\Phi''\tilde{f^N}^c\frac{1}{T^S}\left(\frac{T^S}{T^N}(\tilde{w} - \tilde{z}) + (\tilde{x} - \tilde{y})\right) > 0, \tag{K4}$$

where we define $\tilde{w} \equiv \widehat{\tilde{f^N}}^c/\hat{T^N}$, $\tilde{x} \equiv \widehat{\tilde{f^S}}^c/\hat{T^S}$, $\tilde{y} \equiv \widehat{\tilde{f^N}}^c/\hat{T^S}$, and $\tilde{z} \equiv \widehat{\tilde{f^S}}^c/\hat{T^N}$ for notational brevity. It will be shown that $(\tilde{w}.\tilde{x} - \tilde{y}.\tilde{z}) > 0$ and $(\tilde{w} - \tilde{z})$ and $(\tilde{x} - \tilde{y})$ are both negative so that (K4) holds.

We begin with the notations and relations in (A4) and (A5) (except the ranking between natural resource and capital use between the two countries). Instead, as already derived in Appendix J,

$$T^{Nc} < T^{Sc}; \;\; K^{Nc} < K^{Sc}. \tag{K5}$$

We also need to utilize the following expressions

$$\hat{\eta} \;\; = \;\; \frac{\theta\eta(1-\eta)(\hat{T^N} - \hat{T^S})}{\eta}; \tag{K6}$$

$$dI = -\bar{K}d\eta \;\; = \;\; -\bar{K}\theta\eta(1-\eta)(\hat{T^N} - \hat{T^S}) \tag{K7}$$

We begin by proving (K1). By totally differentiating (5.53) we have

$$\widehat{\tilde{f^N}}^c \;\; = \;\; -\hat{T^N} + \hat{\eta} + \left(\widehat{\frac{\bar{K} + \alpha I}{K^N + \alpha I} - \frac{\alpha I}{K^S - \alpha I}}\right) \tag{K8}$$

$$\equiv \;\; -\hat{T^N} + \theta(1-\eta)(\hat{T^N} - \hat{T^S}) - \bar{K}\theta\eta(1-\eta)\frac{k^{Nc'}}{k^{Nc}}(\hat{T^N} - \hat{T^S}) \tag{K9}$$

by substituting for $\hat{\eta}$ and dI from (K6) and (K7) and defining $k^{Nc'} \equiv \frac{\bar{K}-\alpha\bar{K}^S}{(K^N+\alpha I)^2} - \frac{\alpha\bar{K}^S}{(K^S-\alpha I)^2}$.

Then,

$$\tilde{w}\left(\equiv \frac{\widehat{\tilde{f^N}}^c}{\hat{T^N}}\right) \;\; = \;\; -1 + \theta(1-\eta) - \bar{K}\theta\eta(1-\eta)\frac{k^{Nc'}}{k^{Nc}} < 0, \tag{K10}$$

if, given $\theta(1-\eta) < 1$, $k^{Nc'} > 0$. However, this may not hold unconditionally. In what follows, we derive the sufficient condition such that $k^{Nc'} > 0$.

Mathematically, we need to have

$$\frac{\bar{K} - \alpha\bar{K}^S}{(K^N + \alpha I)^2} > \frac{\alpha\bar{K}^S}{(K^S - \alpha I)^2} \tag{K11}$$

$$\Leftrightarrow \frac{\alpha\bar{K}^S}{\bar{K} - \alpha\bar{K}^S} < \left(\frac{\bar{K}^S}{\bar{K}^N}\right)^2 < \left(\frac{K^S - \alpha I}{K^N + \alpha I}\right)^2.$$

The last inequality follows from the fact that $\left(\frac{K^S - \alpha I}{K^N + \alpha I}\right) \equiv \left(\frac{\bar{K}^S + (1-\alpha)I}{\bar{K}^N - (1-\alpha)I}\right)$ is decreasing in α. In view of this, for (K11) to hold, it is sufficient that

$$\begin{aligned} \alpha\bar{K}^S\bar{K^N}^2 &< (\bar{K} - \alpha\bar{K}^S)\bar{K^S}^2 \Leftrightarrow \alpha(\bar{K^N}^2 + \bar{K^S}^2) < \bar{K}^S\bar{K} \\ \Leftrightarrow \alpha &< \frac{\bar{K}^N\bar{K}^S + \bar{K^S}^2}{\bar{K^N}^2 + \bar{K^S}^2}. \end{aligned}$$

We henceforth refer to this conditions as (R3) and assume that it is met.

We now return to (K8), which implies

$$\tilde{y}\left(\equiv \frac{\widehat{\tilde{f}^N}^c}{\hat{T}^S}\right) = -\theta(1-\eta) + \bar{K}\theta\eta(1-\eta)\frac{k^{N^{c\prime}}}{k^{N^c}} < 0 \tag{K12}$$

since $k^{N^{c\prime}} > 0$ assuming that (R3) holds. Hence, (K10) and (K12) respectively imply

$$\tilde{f}_N^{N^c} \equiv \partial\tilde{f}^{N^c}/\partial T^N < 0, \quad \tilde{f}_S^{N^c} \equiv \partial\tilde{f}^{N^c}/\partial T^S < 0, \tag{K13}$$

Next, turn to (5.54), which could be differentiated similarly to yield

$$\widehat{\tilde{f}^S}^c = -\hat{T}^S - \theta\eta(\hat{T}^N - \hat{T}^S) - \bar{K}\theta\eta(1-\eta)\frac{k^{S^{c\prime}}}{k^{S^c}}(\hat{T}^N - \hat{T}^S) \tag{K14}$$

where we define $k^{S^{c\prime}} \equiv \frac{-\bar{K} + \alpha\bar{K}^N}{(K^S - \alpha I)^2} + \frac{\alpha\bar{K}^N}{(K^N + \alpha I)^2}$. From this,

$$\tilde{x}\left(\equiv \frac{\widehat{\tilde{f}^S}^c}{\hat{T}^S}\right) = -1 + \theta\eta + \bar{K}\theta\eta(1-\eta)\frac{k^{S^{c\prime}}}{k^{S^c}}. \tag{K15}$$

In what follows it is shown that $\tilde{x} < 0$ irrespective of $k^{S^{c\prime}} \gtrless 0$. This is easy to see when $k^{S^{c\prime}} < 0$, given $\theta\eta < 1$. Else, if $k^{S'} > 0$, we need to show that

$$\theta\eta + \bar{K}\theta\eta(1-\eta)\frac{k^{S^{c\prime}}}{k^{S^c}} < 1,$$

for which it is sufficient that

$$\frac{k^{S^{c\prime}}}{k^{S^c}} < \frac{1}{K^N}\left(\equiv \frac{1}{\eta\bar{K}}\right). \tag{K16}$$

This is proved as follows. Since $K^S - \alpha I \equiv \bar{K} - (K^N + \alpha I))$,

$$\begin{aligned}
\frac{k^{S^{c\prime}}}{k^{S^c}} &= \frac{1}{k^{S^c}}\left(-\frac{\bar{K} - \alpha(K^N + I)}{(\bar{K} - (K^N + \alpha I))^2} + \frac{\alpha(K^N + I)}{(K^N + \alpha I)^2}\right) \\
&< \frac{\alpha(K^N + I) - \bar{K}}{(\bar{K} - (K^N + \alpha I))^2} + \frac{\alpha(K^N + I)}{(K^N + \alpha I)^2} \text{ (since, from } K^N + \alpha I > K^S - \alpha I,\ k^{S^c} > 1) \\
&< \frac{K^N + \alpha I - \bar{K}}{(\bar{K} - (K^N + \alpha I))^2} + \frac{(K^N + I)}{(K^N + \alpha I)^2} \equiv -\frac{1}{K^S - \alpha I} + \frac{1}{K^N + \alpha I} \\
&< \frac{1}{K^N + \alpha I} < \frac{1}{K^N}.
\end{aligned} \tag{K17}$$

Utilizing (K17) in (K15), we have

$$\begin{aligned}
\tilde{x} &< -1 + \theta\eta + \bar{K}\theta\eta(1-\eta)\frac{1}{K^N(\equiv \eta\bar{K})} \\
&< -1 + \theta\eta + \theta(1-\eta) = -1 + \theta < 0.
\end{aligned} \tag{K18}$$

Finally,

$$\tilde{z}\left(\equiv \frac{\widehat{\tilde{f}^{S}}^{c}}{\hat{T^N}}\right) = -\theta\eta - \bar{K}\theta\eta(1-\eta)\frac{k^{S^{c\prime}}}{k^{N^c}}. \tag{K19}$$

This would be negative for $k^{S^{c\prime}} < 0$ and could be greater or less than zero otherwise.

Thus,

$$\tilde{f}^{S^c}_S \equiv \partial\tilde{f}^{S^c}/\partial T^S < 0 \quad \text{and} \quad \tilde{f}^{S^c}_N \equiv \partial\tilde{f}^{S^c}/\partial T^N \gtrless 0. \tag{K20}$$

(K13) and (K20) together with $\Phi'' < 0$ imply that second-order conditions hold under the regularity condition (R3), and (a) is proved. Moreover, whilst T^S is a strategic substitute of T^N, T^N may turn out to be strategically complementary to T^S, which proves (b).

We next turn to proving (c), assuming (R3) holds.

Gathering the expressions for $\tilde{w}$, $\tilde{x}$, $\tilde{y}$ and $\tilde{z}$ from (K10), (K12), (K15) and (K19), we have

$$\begin{aligned}
\tilde{w}.\tilde{x} - \tilde{y}.\tilde{z} &= \left(-1 + \theta(1-\eta) - \bar{K}\theta\eta(1-\eta)\frac{k^{Nc\prime}}{k^{Nc}}\right)\left(-1 + \theta\eta + \bar{K}\theta\eta(1-\eta)\frac{k^{Sc\prime}}{k^{Sc}}\right) - \\
&\quad \left(-\theta(1-\eta) + \bar{K}\theta\eta(1-\eta)\frac{k^{Nc\prime}}{k^{Nc}}\right)\left(-\theta\eta - \bar{K}\theta\eta(1-\eta)\frac{k^{Sc\prime}}{k^{Sc}}\right) \\
&= [1 - \theta(1-\eta) - \theta\eta] + \bar{K}\theta\eta(1-\eta)\frac{k^{Nc\prime}}{k^{Nc}} - \bar{K}\theta\eta(1-\eta)\frac{k^{Sc\prime}}{k^{Sc}} \\
&= 1 - \theta + \bar{K}\theta\eta(1-\eta)\left(\frac{k^{Nc\prime}}{k^{Nc}} - \frac{k^{Sc\prime}}{k^{Sc}}\right). \qquad \text{(K21)}
\end{aligned}$$

The sign of (K21) is the same as the sign of $(k^{Nc\prime}/k^{Nc}) - (k^{Sc\prime}/k^{Sc})$. Observe that from (J1) we have

$$k^{Nc} < k^{Sc} \qquad \text{(K22)}$$

We now show that $k^{Nc\prime} > k^{Sc\prime}$. Recalling the definitions of $k^{Nc\prime}$ and $k^{Sc\prime}$, we have

$$\begin{aligned}
k^{Nc\prime} - k^{Sc\prime} &= \frac{\bar{K} - \alpha\bar{K}^S}{(K^N + \alpha I)^2} - \frac{\alpha\bar{K}^S}{(K^S - \alpha I)^2} - \frac{-\bar{K} + \alpha\bar{K}^N}{(K^S - \alpha I)^2} - \frac{\alpha\bar{K}^N}{(K^N + \alpha I)^2} \\
&= \frac{\bar{K} - \alpha\bar{K}^S - \alpha\bar{K}^N}{(K^N + \alpha I)^2} + \frac{\bar{K} - \alpha\bar{K}^S - \alpha\bar{K}^N}{(K^S - \alpha I)^2} > 0 \\
&\Rightarrow \; k^{Nc\prime} > k^{Sc\prime}. \qquad \text{(K23)}
\end{aligned}$$

Using (K22) and (K23) in (K21),

$$\tilde{w}.\tilde{x} - \tilde{y}.\tilde{z} > 0. \qquad \text{(K24)}$$

We now turn to determining the signs of $(\tilde{w} - \tilde{z})$ and $(\tilde{x} - \tilde{y})$. In explicit form,

$$\begin{aligned}
\tilde{w} - \tilde{z} &= \left(-1 + \theta(1-\eta) - \bar{K}\theta\eta(1-\eta)\frac{k^{Nc\prime}}{k^{Nc}}\right) + \left(\theta\eta + \bar{K}\theta\eta(1-\eta)\frac{k^{Sc\prime}}{k^{Sc}}\right) \\
&= -1 + \theta - \bar{K}\theta\eta(1-\eta)\left(\frac{k^{Nc\prime}}{k^{Nc}} - \frac{k^{Sc\prime}}{k^{Sc}}\right), \qquad \text{(K25)}
\end{aligned}$$

which is negative in view of (K22) and (K23). Similarly, it could be shown that

$$\tilde{x} - \tilde{y} < 0. \qquad \text{(K26)}$$

(K24), (K25) and (K26) together with $\Phi'' < 0$ imply that (K4) holds and (c) is proved.

Appendix L

In case of environment being a normal good, the effect of cooperation (in respect of environment policies) on the magnitude of FDI, and regional and global pollution is analyzed here.

Recalling the definitions of $p^N(\cdot)$ and $p^S(\cdot)$ in subsection (5.4.2), and denoting $\left(\frac{\alpha I}{K}\right) / \left(1 - \frac{\alpha I}{K^S}\right) \equiv q^N(I)$ and $\left(\frac{\alpha I}{K}\right) / \left(1 + \frac{\alpha I}{K^N}\right) \equiv q^S(I)$, equilibrium conditions (5.51) and (5.52) in the text could be expressed as

$$\tilde{f^N}^c \equiv \frac{\beta}{T^N}\left(p^N(\cdot) - \frac{Y^N}{Y^S}q^N(\cdot)\right) = \frac{2\gamma}{\bar{T} - T^W} \quad \text{(L1)}$$

$$\tilde{f^S}^c \equiv \frac{\beta}{T^S}\left(p^S(\cdot) + \frac{Y^S}{Y^N}q^S(\cdot)\right) = \frac{2\gamma}{\bar{T} - T^W} \quad \text{(L2)}$$

We first derive the change in the magnitude of FDI in moving from the non-cooperative (Nash) equilibrium to the cooperative equilibrium. This is done by introducing the parameter $\tilde{b}$, $\tilde{b} \in [0, 1]$ into the above conditions such that the pair of equations:

$$\frac{\beta}{T^N}\left(p^N(\cdot) - \tilde{b}\frac{Y^N}{Y^S}q^N(\cdot)\right) = \frac{(1+\tilde{b})\gamma}{\bar{T} - T^W}; \quad \text{(L3)}$$

$$\frac{\beta}{T^S}\left(p^S(\cdot) - \tilde{b}\frac{Y^S}{Y^N}q^N(\cdot)\right) = \frac{(1+\tilde{b})\gamma}{\bar{T} - T^W} \quad \text{(L4)}$$

represents the non-cooperative equilibrium at $\tilde{b} = 0$ and the cooperative equilibrium at $\tilde{b} = 1$.

Let $\rho \equiv K^N/K^S$ and $\Pi \equiv T^N/T^S$. Equating the l.h.s. of (L3) and (L4) the two equations could be collapsed into

$$p^N(\cdot) - b\rho^\alpha \Pi^\beta q^N(\cdot) = \Pi\left(p^S(\cdot) + bK^{-\alpha}\Pi^\beta q^S(\cdot)\right). \quad \text{(L5)}$$

Holding I constant at the non-cooperative equilibrium level, comparative statics with respect to $\tilde{b}$ yield

$$\frac{d\left(T^N/T^S\right)}{d\tilde{b}} \equiv \frac{d\Pi}{d\tilde{b}} = -\frac{\rho^\alpha \Pi^\beta q^N(\cdot) + \frac{\Pi}{\rho^\alpha \Pi^\beta} q^S(\cdot)}{p^S(\cdot) + \frac{\beta\tilde{b}}{\rho^\alpha \Pi^{1-\beta}} q^N(\cdot) + \frac{(1-\beta)\tilde{b}}{\rho^\alpha \Pi^\beta} q^S(\cdot)} < 0. \quad \text{(L6)}$$

This implies that pollution in the North relative to the South falls as countries move from non-cooperative to cooperative regime.

Moreover, with $I = \bar{K}^N - \eta\bar{K} = \bar{K}^N - \frac{(\Pi)^\theta}{\left(1+(\Pi)^\theta\right)}\bar{K}$ it is easy to check that

$$\frac{dI}{d\Pi} = -\frac{\theta\Pi^\theta}{\Pi(1+\Pi^\theta)^2} < 0 \tag{L7}$$

The signs of the derivatives in (L6) and (L7) together yield

$$\frac{dI}{d\bar{b}} = \frac{dI}{d\Pi}\frac{d\Pi}{d\bar{b}} > 0 \tag{L8}$$

Thus, FDI rises in moving from a non-cooperative to a cooperative equilibrium.

We now turn to the implications for regional pollution levels. In comparison with the Nash first-order conditions (5.45)-(5.46), with cooperation (characterized by (5.49)-(5.50)) three additional effects are observed:

1. From (L8) the level of FDI is higher than under non-cooperation.

2. In both the first-order conditions, (5.49) and (5.50), there is now an additional term in the benefit side, which is $\left(-\frac{I\frac{\partial r}{\partial T^N}}{Y^S - rI}\right)$ for the North and $\left(\frac{I\frac{\partial r}{\partial T^S}}{Y^N + rI}\right)$ for the South. This represents the internalization of the income-adjusted factor terms-of-trade effects of the *partner* country from a change in *own* pollution policy of the country – an implication of joint welfare maximization.

   Unlike in the neutral-environment good model, where these effects exactly offset each other, in the presence of income effects on the demand for environmental good, as the sizes of the national income/output vary between the countries, the factor terms-of-trade effects do not net out between the North and South. Further, T and K being complementary factor inputs, an increased use of one raises the marginal product of the other, that is, $\partial r^j/T^j > 0$. It is, therefore, intuitive that being a net energy exporter (importer) this effect is negative (positive) for the North (South).

3. On the cost side, international coordination of pollution policy implies that each country now takes into account the global costs of pollution, which are twice of those borne by the individual country (given that both the countries are identical in terms of population and preferences). This represents full internalization of the pure public good (or bad) nature of pollution. At the same time cooperation involves a change in global pollution, T^W.

All of these effects have implications for marginal benefits and marginal costs of pollution of both countries.

Ceteris paribus, on account of the first, i.e. a higher magnitude of FDI the marginal benefit schedule of the North shifts down whilst that of the South may shift up or down. Mathematically, this can be seen from

$$\frac{d}{dI}\left(\frac{1+\frac{\alpha I}{\bar{K}}}{1+\frac{\alpha I}{\bar{K}^N}}\right) = \frac{\alpha}{\bar{K}^N\bar{K}}\left((\bar{K}^N + \alpha I) - \frac{\bar{K}^N}{\bar{K}^N}(\bar{K} + \alpha I)\right) < 0$$

since $\bar{K}^N/\bar{K}^S > 1$, and

$$\frac{d}{dI}\left(\frac{1-\frac{\alpha I}{\bar{K}}}{1-\frac{\alpha I}{\bar{K}^S}}\right) = \frac{\alpha}{\bar{K}^S\bar{K}}\left(\frac{\bar{K}^S}{\bar{K}^S}(\bar{K} - \alpha I) - (\bar{K}^S - \alpha I)\right) \gtrless 0.$$

For small enough $\bar{K}^S$ this may be negative, entailing shifting down of South's marginal benefits.

The second effect (representing the inclusion of the factor terms-of-trade change of the partner country induced by a change in a country's own environment policy) leads to a loss (gain) for the North (South) through a downward (upward) shift in the benefit schedule.

The third manifests in an upward shift in the marginal cost schedule of both countries, which, by itself, would have a negative effect on pollution. But, depending upon the change in the level of aggregate global pollution, there would also be a movement along the marginal cost curve. A priori this may lead to an overall increase or decrease in regional pollution.

(Although, we shall find later in this appendix that global pollution falls in moving from non-cooperative to cooperative equilibrium). The impacts of the various effects are summarized in Table 1 below.

Table 1: Movement from Non-cooperation to cooperation

	Increase in FDI	FToTE of other country	Change in MC of pollution
T^N	↓	↓	↓
T^S	↓ or ↑	↑	↓
FToTE: Factor Terms-of-Trade Effect; MC: marginal cost			

Depending upon the strength of these individual effects *a priori* the implication of environment policy coordination on regional pollution levels is not clear.

Finally, it is found that global pollution falls even below the autarky level; the mathematical proof follows.

The first-order conditions (5.51) and (5.52) could be expressed as:

$$\frac{1}{2}\left(\frac{1+\frac{\alpha I^c}{K}}{1+\frac{\alpha I^c}{K^{N^c}}} - \frac{Y^N}{Y^S}\left(\frac{\frac{\alpha I^c}{K}}{1-\frac{\alpha I^c}{K^{S^c}}}\right)\right) = \frac{\gamma T^N}{\beta(\bar{T}-T^W)}$$

$$\frac{1}{2}\left(\frac{1-\frac{\alpha I^c}{K}}{1-\frac{\alpha I^c}{K^{S^c}}} + \frac{Y^S}{Y^N}\left(\frac{\frac{\alpha I^c}{K}}{1+\frac{\alpha I^c}{K^{N^c}}}\right)\right) = \frac{\gamma T^S}{\beta(\bar{T}-T^W)}$$

Adding up the two eqs. and utilizing the relationship $Y^N/Y^S = K^N/K^S = \eta/1-\eta$ (that holds for any capital mobility equilibrium), the above pair collapses to:

$$\frac{1}{2}\left(\frac{1+\frac{\alpha I^c}{K}}{1+\frac{\alpha I}{K^{N^c}}} - \frac{\eta}{1-\eta}\left(\frac{\frac{\alpha I^c}{K}}{1-\frac{\alpha I^c}{K^{S^c}}}\right) + \frac{1-\frac{\alpha I^c}{K}}{1-\frac{\alpha I^c}{K^{S^c}}} + \frac{1-\eta}{\eta}\left(\frac{\frac{\alpha I^c}{K}}{1+\frac{\alpha I^c}{K^{N^c}}}\right)\right) = \frac{\gamma T^W}{\beta(\bar{T}-T^W)} \equiv g(T^W). \tag{L9}$$

The r.h.s. of (L9) is the same function $g(T^W)$ as in eqs. (H2) and (H1) in Appendix H, which pertain to the autarky and non-cooperation equilibria respectively. Since $g(\cdot)$ is increasing in T^W, if the l.h.s. of eq. (L9) is less than the l.h.s. of eq. (H2), it is sufficient for T^W to fall below the autarky level. (This also implies global pollution at the cooperative equilibrium being lower than at the non-cooperative equilibrium, as the latter is higher than the autarky global pollution).

Focussing on the l.h.s. of (L9), indeed it turns out that

$$\frac{1}{2}\left(\frac{\eta(\bar{K}+\alpha I^c)}{\eta\bar{K}+\alpha I^c}-\frac{\eta\alpha I^c}{(1-\eta)\bar{K}-\alpha I^c}+\frac{(1-\eta)(\bar{K}-\alpha I^c)}{(1-\eta)\bar{K}-\alpha I^c}+\frac{(1-\eta)\alpha I^c}{\eta\bar{K}+\alpha I^c}\right)=\frac{1}{2}(1+1)=1<2.$$

which is the l.h.s. of (H2). Hence the result $T^{W^c} < T^{W^a} < T^{W^o}$.

Chapter 6

Further Extensions

In the first chapter the analytical framework and major findings of the three essays in chapters 3-5 covered by the thesis are summarized. These relate to selected topics under the trade and environment debate, namely, (a) links between trade flows and environment, (b) interactions between trade policy and environment policy in the presence of political economy, and (c) foreign investment flows and environmental effects. In this concluding chapter the intent is to highlight the possibilities of taking forward the work under each of these three topics.

Under topic (a), on linkages between goods trade and environment, an immediate extension will be the inclusion of non-prohibitive trade intervention along with environmental regulation. This would offer insights into the strategic effects of trade policy on the commodity terms-of-trade, in addition to the effect of environment policy on the terms-of-trade. Strategic manipulation of environment policy, e.g., "ecological dumping" from the viewpoint of competitiveness concerns is another interesting area of investigation. Discriminatory pollution taxes against the non-traded vis-a-vis the traded good sectors could "artificially" improve international competitiveness of the traded sectors. Characterizing ecological dumping and examining its sensitivity with respect to changes in the underlying parameters should be an interesting area of analysis.

Another potential extension of the model is to the issues of transboundary or global environmental implications, which would, in turn, warrant examination of international policy coordination. In this context, the inclusion of newly designed economic instruments such as tradeable emissions permits or emissions quotas could provide useful predictions.

The political economy analysis of chapter 4 is confined to a single-sector and a single-lobby. It will be worthwhile to extend it to a multi-sector and multi-lobby analysis, as in Grossman and Helpman (1994). Furthermore, an environmental lobby can be introduced, together with the industrial lobby. It is expected that, in the many-lobby framework, the relative bargaining strengths of the government and the different interest-groups will have a more direct bearing on the determination of equilibrium policies. Another extension will be to examine policy outcomes in the context of large open economies where strategic interaction between governments and lobbies across countries is likely to generate interesting predictions.

At least two extensions of the analysis of FDI and environment in chapter 5 are immediately appealing. First, the static model can be extended to a multi-period framework, wherein capital accumulation and growth could have a trade-off with static gains from FDI. The role of capital taxation as a deterrent to FDI flows could be examined in this context. Second, one can investigate the role of FDI as a conduit for transfer of environmentally-sound or superior technology from capital-rich North to capital-poor South.

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