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RENEWABLE RESOURCES, POLLUTION AND TRADE IN A SMALL OPEN ECONOMY

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ABSTRACT. Industrial pollution can have damaging effects on resource-based productive sectors. International trade creates opportunities for overexploitation of the open-access renewable resource but also for separating the sectors spatially. The paper shows that, depending on the relative damage inflicted by the two industries on the environment, it is possible that the production externality will persist and that specialization in the dirty good may not be the obvious choice from a welfare perspective. Also, the resource exporter does not necessarily have to lose from trade even when specializing incompletely, due to the partially offsetting external effects.

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1. INTRODUCTION

Around the world, mostly in developing countries, but by no means limited to them, open-access fishing areas are often located in the proximity of polluting manufacturing facilities. Examples range from the North Atlantic salmon fishery,¹ to the lobster fishery in the North Pacific, the collapsed walleye fishery in the Tittabawassee River in Michigan, the Baia Mare, Romania cyanide pollution of the rivers adjacent to gold mines and countless (less publicized) local problems in the less-developed world. As the more biology-oriented literature documents, for many species of fish, the nursery grounds are located in the coastal areas, which are also the more polluted ones, due to the toxic waste spilled directly into the sea, or carried by rivers from inland. Due in part to poor regulation of the environment, many developing countries experienced an accelerated depletion of their resources after opening up to international trade. The welfare effects of this form of tragedy of the commons amplified by trade are likely to be quite significant in poor, small, developing economies, where the resource sector has an important share both in exports and GDP. At the same time, the phenomenon of dirty-industry migration from North to South - as a possible effect of tightening up of standards in the developed world - may result in increased industrial pollution of the environment. Openness makes both scenarios theoretically plausible.

Renewable resources can be under two types of pressures: excessive harvesting, especially where there is no effective management, and pollution from other sectors. Previous work has looked at each of these pressures individually. Brander and Taylor (1997) show that a small open economy that exports an open access resource

Key words and phrases. renewable resources, pollution, production externalities, environment, international trade.

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¹ Among the chief causes cited as contributing to the collapse of North Atlantic fisheries were pollution and over-harvesting.

will suffer resource depletion and will incur a long run real income loss, whereas a country that imports the resource will gain from trade, because pressure is taken off the resource. Copeland and Taylor (1999) show that with a cross-sectoral pollution externality, trade tends to cause small countries to specialize. Severe resource depletion may occur. Also, in their model, a resource exporting country will gain from trade because it leads to a contraction of the polluting sector. However, many renewable resources are in reality concomitantly subject to *both* types of pressures.

The interaction between pollution and international trade has been extensively studied recently. The approach used in the recent book by Copeland and Taylor (2003) is to build a unified GE framework which allows them to clearly identify the various effects that characterize the interaction and to take into account the endogenous nature of environmental policy. Yet, as they acknowledge, for poor resource exporters, the evolution of the stock of natural resources with trade is likely to be more important than pollution for their welfare (Copeland and Taylor (2003), p. 362). The manufacturing sector is generally under-developed and so the effects of additional local pollution on the consumers are likely to be low. Then, a key mechanism identified by the authors as influencing the level of pollution with trade: namely the endogenous policy response - may not play as important a role.² However, the existence of a polluting sector and its external effects cannot be dismissed even in these economies. Some would argue it is likely to become even more of a problem, as production in the North moves towards cleaner service-based sectors while the South gets a higher share of world's manufacturing.

The literature documents many instances of habitat quality influencing population levels, harvesting, and having detrimental welfare effects. For instance, several examples are provided in Knowler (2002), in a review of bioeconomic models employed to estimate the welfare effects of environmental quality.³ Relying on the motivating examples discussed above, the basic question addressed in this paper is: what is the effect of trade when an un-managed renewable resource is subject to the two interacting problems: overharvesting and pollution? The present work builds on the baseline Brander and Taylor (1997) model and the subsequent Brander and Taylor (1998) and resembles the two in the fact that it deals with an open-access natural resource and the impact of international trade on its stock. It departs from the original Brander and Taylor framework in that it also assumes the existence of production externalities, as in Copeland and Taylor (1999). However, unlike the latter model, where the production in the clean sector is only a function of the "environmental capital" stock,⁴ in the present paper the production of the "clean" good also depletes the stock of the resource. It is argued that the fact that *both* sectors exert a differentiated pressure on the stock of the resource proves to be important in establishing the results.⁵

² Another reason may be that the democratic channels by which higher pollution triggers a policy response may not be functioning properly.

³ Some examples provided in Knowler (2002) include: the effect of changes in water salinity on shrimp catch in Pamlico Sound, North Carolina (Swallow (1994)), the impact of increased nutrient and sediment loads on aquatic vegetation in Chesapeake Bay (Kahn and Kemp 1985), the effect of increased nutrient concentration on the Black Sea anchovy fishery in Knowler and Barbier (2001). Even closer to the spirit of this paper, Loomis (1998) analyze the effect of logging on the downstream fisheries in the form of sediments and water temperature changes.

⁴ i.e. cleanliness of a river, soil and there is no harvesting of the renewable resource per se.

⁵ Thinking about other real-life examples: if sector H is tourism and sector M is a polluting manufacture, it is likely that both activities pollute the adjacent lake or river, although conceivably,

To briefly preview the results, the autarkic equilibrium in this economy is inefficient. Besides the open access problem, whose magnitude is a function of demand parameters, there is the uninternalized effect of pollution. However, opening up to trade allows the economy to potentially do better in the long run. Non-traditional gains from trade occur from spatially separating the conflicting sectors by focusing production on the area of comparative advantage. It is argued that - under certain conditions - specialization in the “dirty” good can be detrimental, while specialization in the resource good can be welfare-improving.⁶ The policy relevance of the paper may be framed in terms of the industrial planning challenges faced by a small resource-endowed developing economy that eventually becomes open to trade. Even when disutility costs to consumers are small, excessive industrialization imposes external costs via the environment-based sectors.

Starting with a small open economy, the analysis then moves further to endogenize the international price formation in a two-countries case. The analysis of welfare changes can give an indication as to what drives the results and will possibly suggest a direction for policy measures. If the only commodity that is traded once the economy opens up to trade is the manufacturing good, then spatial separation will likely reduce the stress on the resource and may bring welfare gains, provided that the country in question starts importing the industrial good. If the resource-based product (e.g. fish) is also tradable,⁷ then overdepletion makes the results ambiguous, and several cases may develop, based on the parameters of the system. The two externalities here have *partially offsetting effects*, which in autarchy could bring the economy closer to a first best optimum than in the simple over-harvesting fishery model. As can be expected, opening up to trade alters these effects. Whether the country stays diversified or completely specializes in one of the sectors with trade will play a role in deciding the welfare gains or losses from trade, as will the relative impact of the two sectors on the stock of the resource. Here the economy can in fact specialize in any of the sectors, and trade can bring a welfare improvement or a welfare decline. Increasing production in the relatively more harmful sector will have the effect of decreasing the stock under the autarkic steady state level, while (even incompletely) specializing in the relatively environmentally-friendly sector will raise the stock above it, likely influencing the comparative advantage of the country.

There are not many papers dealing explicitly with the issue of renewable resources management with pollution. However, a few papers deal with related issues. Knowler, Barbier and Strand (2002) look at the effect on the stock of a resource of nutrient concentration increase of water. However, here the polluting factor is exogenous and there is no trade-off between the resource sector and the polluting sector, which is captured in our model. McConnell and Strand (1989) analyze water quality impact on commercial fishing when consumer perception of better water quality shifts out demand, while the supply of fish increases as well with water quality. Here the open-access dimension is missing, and the focus is domestic. Also, a special issue of Environmental Resource Economics dedicated to the

to quite different degrees. Also, given the wide evidence documenting the damaging effect of aquaculture for the environment, M can be thought of as fish or shrimp farming, while H is the harvesting of the wild resource.

⁶ In a stylized way, this result runs contrary to the so-called Dutch Disease “symptoms” of the “Natural Resources Curse”.

⁷ And this is the less restrictive, more realistic case.

Economics of Non-convex Ecosystems⁸ contains papers that specifically deal with existence of competitive equilibria, multiple basins of attraction, threshold and positive feedback effects and the local aspect of many environmental externalities. The closest to this work is a recent paper by Smulders, van Soest and Withagen (2004) which focuses on habitat destruction by having a specific factors model with three sector, two of which are dependant on ‘land’ as a resource base (harvesting) or factor of production (agriculture). While the paper is similar in the sense that their model also includes both ‘within-industry’ and ‘between industry’ externalities, the driving force of their results is the interplay between the negative long-run stock effects and the positive short-run search costs reducing effect of a shrinking habitat size. Their work also reverses some of the results in Brander and Taylor papers, yet the model seems to only apply to terrestrial resources.⁹ In the present paper, inter-industry externalities are only negative: pollution reduces the stock size, diminishing productivity in the harvesting sector, and it also increases the implicit search costs, as sparsely distributed marine resources are harder to catch. To the best knowledge of the author, the exact focus of this paper, who better fits the pollution-marine life motivating example, has not been previously undertaken.

The rest of the paper is organized as follows. The next section analyzes the autarkic general equilibrium in the short run and then in the long run, introducing a non-convexity issue. The third section then looks at the open economy equilibrium, analyzing possible specialization avenues and their impact on the stock of the resource and on welfare. The last section concludes and points to possible future research directions.

2. THE AUTARKIC MODEL

Let the stock of the renewable resource S grow according to a natural growth rate $G(S)$, like in the original Gordon-Schäfer model.

$$(2.1) \quad \frac{dS}{dt} = G(S(t)) - H(t) - Z(t)$$

where H is the harvest level and Z is the detrimental effect of pollution on the resource growth and where we take the stock S to follow a logistic growth function that was shown to perform quite well empirically for some species of fish:¹⁰

$$G(S) = rS\left(1 - \frac{S}{K}\right)$$

where r , the intrinsic growth rate of the resource and K , the carrying capacity are known parameters.¹¹

⁸ ERE (December 2003, Volume 26 Issue 4), with papers from: Dasgupta and Mäler, Chave and Levin, Scholes, Brock and Starrett, Mäler, Xepapadeas, and de Zeeuw, Crepin, Arrow, Dasgupta and Mäler, which are concerned with topics such as the economics of savannas, pollution in shallow lakes, multiple species forests and sustainable development.

⁹ For marine resources it is harder to come up with activities that physically diminish the habitat.

¹⁰ Brander and Taylor (1997) list Pearl (1930) and Feller (1940) for empirical support of the logistic form of growth and Paterson and Wilen (1977) for empirical support of the choice of harvesting production function. See Brander and Taylor (1997), p. 531-532.

¹¹ Jinji endogenizes the carrying capacity. In his forestry model K depends linearly on the stock of the “base resource:” land. A number of comparative statics exercises can be performed when K is allowed to vary. See Jinji (2003), p. 6.

It can be seen from equation (2.1) that activity in both sectors of the economy influence the change of stock.¹² As shown in the original fishery model, under open access, extraction will occur at zero profit levels, due to free entry into the sector that has the effect of driving rents to zero. The added complication here is the negative externality imposed by the polluting sector.

2.1. Supply.

There are two productive sectors in this economy: harvesting of the renewable natural resource (H) and manufacturing (M). Both sectors are using one primary input: labour (L). In addition, H-production also depends on the stock of the resource according to a typical Schäfer yield function:

$$(2.2) \quad H = qSL_H,$$

while

$$(2.3) \quad M = L_M$$

that is, manufacturers use only labour and produce according to this very simple constant returns production function. However, this is a polluting activity. Pollution (Z) is generated at rate alpha in the process, so that

$$Z = \alpha M = \alpha L_M.$$

Assume pollution does not accumulate¹³, there is no abatement and no pollution policy¹⁴ and emissions intensity is α .

Let M be the numeraire commodity and so

$$p_M = 1.$$

From the zero-profit condition in the M-sector: $\Pi^M = M - wL_M = 0$ we obtain $w = 1$.

Because L is the only factor firms in the harvesting industry have to pay for under open access, profits will be:

$$\Pi^H = pH - wL_H = pqSL_H - wL_H$$

and the free entry/zero profit condition implies:

$$(2.4) \quad w = pqS \Rightarrow p = \frac{1}{qS}.$$

Therefore, if both sectors of the economy are active in autarky, the relative price of the harvesting good is determined by the stock level.

¹² To be accurate, due to the multiplicity of biological/natural and anthropogenic interactions existent in a marine environment, there is little conclusive evidence to date that ‘normal’ pollution actually kills fish, except for ‘ecological disasters.’ However, the scientific evidence that pollution leads to perturbations in the reproducing system of fish is available. Thus, the effect of the pollution externality on the stock of fish can also enter in a more complicated manner than here, namely via an intrinsic growth function $r(Z)$ that is decreasing in pollution: $dr/dZ < 0$. Yet, our specification is equivalent to one in which the ‘true’ intrinsic growth rate ρ is diminished by a properly-weighted pollution effect to yield the ‘actual’ intrinsic growth rate r as follows: $r = [\rho - \frac{Z}{S}(1 - \frac{S}{K})^{-1}]$.

¹³ Pollution just flows downstream if the pollutant and the clean sector are located along a river. Treating pollution as a stock might be more appropriate for lakes or oceans. This scenario is omitted here for simplicity.

¹⁴ there is no regulation that internalizes any of the two externalities: open-access or pollution.

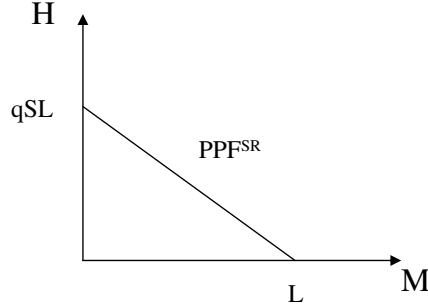


FIGURE 1

2.2. Demand.

On the demand side, there is a representative consumer with preferences described by a Cobb-Douglas utility function including both goods, and with $(1-\beta)$ the share of M, β the share of H in total spending.¹⁵ In the first best equilibrium there are resource rents. However, in our open-access framework, rents are dissipated and the only income accruing to the consumer is the wage. The consumer supplies inelastically one unit of labour and solves:

$$\underset{H,M}{Max} U = H^\beta M^{1-\beta} \text{ s.t. } pH + M = w.$$

Demands are then determined by their respective income shares, as usual:¹⁶

$$H = \frac{\beta w}{p}, M = \frac{(1-\beta)w}{1} \text{ and on aggregate } H = \frac{w\beta L}{p}, M = (1-\beta)wL,$$

where L is the total endowment of labour, which coincides here with total population. Then we get

$$(2.5) \quad p = \frac{\beta L}{H} \text{ for } w = 1.$$

2.3. The Short Run Autarkic Equilibrium.

Since there is only one primary factor L , the economy is Ricardian and the temporary PPF will be a straight line, as both firms and consumers' problems assume a fixed stock of the resource S . Notice the fact that in the short run the

¹⁵ The focus on production externalities developed here is particularly applicable to developing resources-based economies: their environments are still relatively pristine and the health consequences of industrial pollution may not be as severe, thereby making the assumption of no consumer-disutility of pollution more credible. Also, an endogenous policy response mechanism may not work, due to the fact that environmental-groups pressure is weak and/or the countries' democratic channels are not functioning properly.

¹⁶ Yet another assumption implicit in our model is that pollution or perceived water quality does not shift demand for fish, as in McConnel and Strand (1989), p. 285-287, where consumers use water quality as an indicator of fish quality. There, better water quality under open access may have the perverse effect of reducing social surplus.

negative production externality does not manifest itself.¹⁷ For a given stock of the resource S , $L_H = \frac{H}{qS}$, while $L_M = M$. The labour employment in the economy is divided between harvesting and manufacturing: $L = M + \frac{H}{qS}$ which implies that

$$H = qSL - qSM$$

describes the linear temporary PPF. The short-run equilibrium is found by equating expressions (2.4) and (2.5). This yields

$$(2.6) \quad H = q\beta LS \text{ and } M = (1 - \beta)L$$

as the short-run equilibrium outputs.

In autarky, the use of labour in manufacturing (and therefore the amount of pollution) does not depend on the use of labour for harvesting, due to fixed proportionality. Then, the evolution of the stock of resource in the short-run can be obtained by subtracting the effect Z of manufacturing on the change of stock S from the growth expression, and then interacting it with the harvest function to find the open-access level of stock S^0 .

In Figure 2, A would be the open-access extraction point in the absence of the manufacturing sector, or if there was no production externality. With pollution, we have:

$$Z(t) = \alpha(1 - \beta)L$$

which would be a straight line if represented in the space of Figure 2. Given the level of pollution Z , which is not a function of the stock S , the open-access stock equilibrium condition for the renewable resource is still that: $\frac{dS}{dt} = 0$, which implies

$$(2.7) \quad H(t) + Z(t) = G(S(t)).$$

As it is apparent from the picture, the harvest will take place at a lower level in the presence of pollution of the stock, as one would expect.

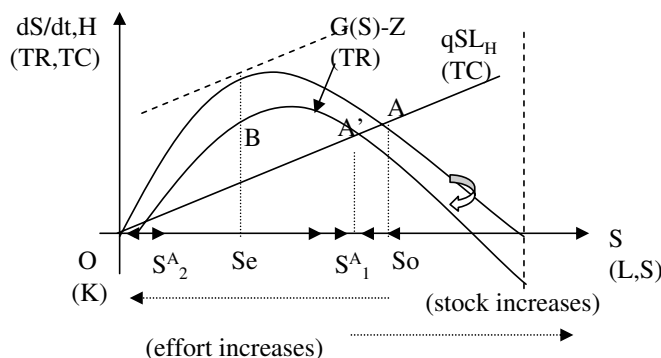


FIGURE 2

¹⁷ Therefore, the problem is so far similar to Brander and Taylor (1997).

Substituting the known expressions into (2.7) we get:

$$q\beta LS + \alpha(1 - \beta)L = rS\left(1 - \frac{S}{K}\right)$$

which is a quadratic equation yielding two possible steady states S_1^A and S_2^A as functions of the parameters.

Solving the quadratic equation:

$$\frac{r}{K}S^2 + (q\beta L - r)S + \alpha(1 - \beta)L = 0$$

yields as discriminant $\Delta = (q\beta L - r)^2 - \frac{4r}{K}\alpha(1 - \beta)L$ and the roots are:

$$S_{1,2} = \frac{r - q\beta L \pm \sqrt{\Delta}}{2r/K}.$$

When $\Delta > 0$, the roots are real and there exists a non-extinction steady-state (SS). If $\Delta < 0$, then, due to pollution and the given cost of harvesting, there is no interior solution: no feasible fishery due to excessive pollution. The condition for the existence of real roots is that

$$(2.8) \quad (q\beta L - r)^2 > \frac{4r}{K}\alpha(1 - \beta)L$$

which can be loosely translated as: high q (the productivity parameter in harvesting), high β (strong consumer preference for H), low intrinsic growth rate (r), high carrying capacity of the environment (K).

Denoting by S_1^A , S_2^A the two autarkic steady-state stock levels, notice from the graph in Figure 2 that S_1^A is stable, while S_2^A is not, where S_1^A is the lower root: $S_1 = \frac{r - q\beta L - \sqrt{\Delta}}{2r/K}$. This means that, regardless of the starting stock level S_0 , provided it is not to the left of S_2^A ,¹⁸ the stock level will move to S_1^A in the long run closed economy. Notice that the level of the stock in the long run under open access and with no pollution ($\alpha = 0$) is $S^A = K\left(1 - \frac{q\beta L}{r}\right)$.

Now plugging S_1^A into (2.4) and (2.6) we get $p^A = \frac{1}{qS_1^A}$ and $H^A = q\beta LS_1^A$, $M^A = (1 - \beta)L$, respectively.

Note by referring again to the graph, that provided the level of pollution Z is too high, which is the same as saying if α , $(1 - \beta)$, L are “too high,”¹⁹ we can get the case where no exploitation of the resource is possible, due to the strong externality that decreases the stock and raises the costs of extraction. Also, if the growth function of the stock would be depensatory (which may be the case for some species or circumstances) instead of taking the compensatory logistic form, then it may be relatively easy to get extinction and total collapse of the extraction sector, in which case M ceases to create an externality in production. However, we will abstract from such complications here and look instead at interior solutions, where the economy is diversified and the conditions necessary for $S_1^A > 0$ are met by the parameters.

¹⁸ The case of initial over-depletion of the renewable resource

¹⁹ which means, keeping the order, that: M is very pollution intensive, consumers have strong tastes for the manufacturing good or the country is very populous, respectively. Interpreting these conditions confirms the intuition for cases where no equilibrium with strictly positive stock of resources is possible.

2.4. Dynamics in Autarky and Non-Convexity.

We turn at this point to analyze the dynamic transition towards the steady state in this economy. Recall that the PPF in the short run, i.e. for a given stock level S , is a straight line. In the long run, production adjusts and will be influenced by the cross-sectoral production externalities, potentially yielding a convex PPF. Because in a dynamic setting, the manufacturing sector imposes costs to harvesting, the points on the static PPF will likely not be maintained, with the important exception of the intercepts. Depending on the parameters, the PPF can now be bowed-in and the problem can become non-convex due to production externalities, as shown in the seminal paper by Baumol and Bradford (1972). The basic argument is that producing the two goods jointly renders some convex combinations infeasible due to the negative external effect. Consequently, points on the linear short-run PPF become infeasible in the long-run. In their 1999 paper, Copeland and Taylor show that such non-convexities can create surprising specialization and trade effects.²⁰ As will be argued below, in our particular case, due to a combination of internal (intra-industry) and external (inter-industry) negative stock effects, the shape of the PPF turns out to be more complex.

However, before these specific results are derived, a discussion of the Baumol and Bradford (1972) result that production externalities are sufficient to cause non-convex production sets deserves a brief digression that hopefully helps build some intuition. Here we will just summarize the argument in diagrammatic form. Assume the M industry is polluting the environment, imposing a negative spillover effect on the industry that is sensitive to the quality of certain elements of the environment, A.²¹ If there is a preferred (low cost) location for both outputs, then the production possibility frontier PPF is convex (the production set is non-convex) and spatial separation can in fact act as a "palliative" to the problem, by expanding the feasible production set.

Starting with a concave PPF (no externality)²² and increasing the level of the negative externality between sectors, the production frontier will bend towards the origin, and eventually become convex. Key to the reasoning is the fact that the end points of the PPF, namely E and C will not move when the externality becomes more significant, as they represent cases of total specialization in production, and thus, cases where cross-sectoral spillovers are immaterial. The convex production possibilities frontier EFGC corresponds to joint production of both inputs in the same location. If A is moved to the higher cost location, BC will be the relevant PPF, while in the case when M is moved there, AD will be the PPF.²³

Thus, the production possibility set is non-convex provided the externality is strong enough. Moreover, spatial separation allows for higher total output, illustrated by the fact that the line segments AF and CG are situated above the respective arc/curve regions.

Returning to our specific model, we now move on to establish the curvature of the PPF in the long run autarky. We first state a somewhat surprising observation

²⁰ See Copeland and Taylor (1999), p. 139

²¹ M represents energy and A laundry producers in their example. Note the fact that the use of air pollution is avoided, as this would be unambiguously affecting consumers' utility and complicate the analysis.

²² suppose the polluting industry is just starting the dirty manufacturing

²³ Note that AD and BC do not have to be linear and can, in fact, be concave.

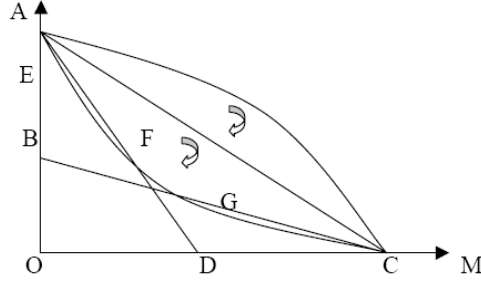


FIGURE 3

and postpone the analysis of its implications in an effort to keep the model as simple as possible.

Proposition 1. *Depending on parameter values, it is possible that the long-run optimum involves partial unemployment of the labour force.*

An algebraic derivation is suggested in Appendix D. Intuitively, the long-run stock of the resource is decreasing in the total labour applied to harvesting and manufacturing. It may then be optimal, given some parametric conditions, that total utility maximization involves leaving a fraction L_U of total population unemployed. This is easier to accept when a social planner solves the optimization problem. Here, however, we excluded any conscious planning or optimal management of the resources (S, L) whatsoever.²⁴ The introduction of another entirely ‘clean’ sector will allow getting around the unemployment issue. Here, keeping this first model manageable dictates the exclusion of these interesting possibilities.

Assuming from now on full employment in the steady state, recall the short run PPF²⁵ was $L = M + \frac{H}{qS}$. Also, from equation (2.1) one can write the change in the stock of the renewable natural resource as:

$$\frac{dS}{dt} = rS\left(1 - \frac{S}{K}\right) - qS(L - M) - \alpha M.$$

Hence, the steady-state level of stock has to satisfy:

$$(2.9) \quad rS\left(1 - \frac{S}{K}\right) - qS(L - M) - \alpha M = 0.$$

And the labour constraint can be written as:

$$(2.10) \quad L = M + \frac{H}{qS}$$

To find the long-run PPF, we need to solve (2.9) for S and plug it into the expression (2.10) above. Solving the quadratic equation and deriving the production possibilities frontier involves some uninformative algebra, and is relegated to Appendix A.

²⁴ Here, atomistic consumers do not realize that by increasing their effort the stock level is reduced and so will supply the full amount of labour in a Nash equilibrium.

²⁵ see section 2.3 above.

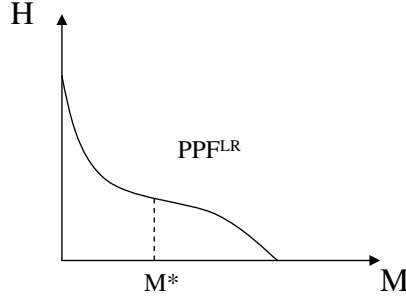


FIGURE 4

The autarkic stock S can be written as:

$$(2.11) \quad S^A = \frac{1}{2r} \{ \sqrt{[q(L-M) - r]^2 K^2 - 4r\alpha KM} - [q(L-M) - r]K \}$$

Plug this into (2.10) to obtain the steady-state PPF of the domestic economy:

$$(2.12) \quad H = \frac{q(L-M)}{2r} [\sqrt{K^2 q^2 (L-M)^2 + r^2 K^2 - 2qK^2(L-M) - 4\alpha rKM - Kq(L-M) + rK}]$$

As Appendix A details, convexity of the production possibility set reduces to the condition that a cubic in M be higher than zero, or the PPF^{LR} is convex for:

$$4K^2 q^4 (L-M)^3 - 3Kq^2(3Kq - 2\alpha r)(L-M)^2 - 12\alpha Kq^2 rM(L-M) + (3K^2 q^2 r^2 + 3K^2 q^2 + 4\alpha^2 r^2 - 8\alpha Kqr)(L-M) + 4\alpha r(Kq - 2\alpha r)M - Kr^2(Kq - 2\alpha r) > 0,$$

where α , K , q , r are parameters, L is the given population. As is apparent from this, the steady-state PPF is concave for some levels of M , given the parameters, and convex for others.

Proposition 2. *The long-run production possibilities frontier in M - H commodity space is convex-concave.*

Some further analysis implies that the cubic in M is positive for all values of M below a certain threshold M^* and negative for the others. In other words, the PPF^{LR} is concave ($\forall M > M^*$) and is convex ($\forall M < M^*$) for a certain limit level of M^* , a function of the parameters of the system. Then, given the single inflexion point M^* , the autarkic steady-state PPF will look like in Figure 4.²⁶

Notice that the PPF is convex in a neighbourhood of the H -axis, for values of M lower than the threshold M^* and concave in a neighbourhood of the M -axis, for values of M greater than M^* . The result concurs with the findings in Herberg and

²⁶ Allowing for the possibility that some workers are idle in equilibrium does not change this qualitative result.

Kemp (1969)²⁷ and Panagariya (1981),²⁸ which discuss the shape of the production possibilities curve when two sectors have different returns to scale.

In our case, the shape of the PPF could be explained intuitively as follows. When stock level is relatively high, the more damaging activity is harvesting. However, when stock decreases and harvesting becomes less efficient due to the implicit stock externality, manufacturing may become the more harmful activity.²⁹ For levels of M production lower than M^* , starting from the case where all the labour force is involved in harvesting and stock is relatively low, an extra worker shifted from H to M will have a decreasing opportunity cost, due to the fact that the shift to M impacts negatively on the productivity of labour in H. So, besides the direct level effect of reducing the labour applied to H, moving an extra worker to M production has a detrimental (negative but increasing) effect on the productivity of the remaining workers in H. However, beyond the threshold level M^* , manufacturing starts having a lower negative impact on productivity in H than harvesting itself.³⁰ In other words, when there is a lot of manufacturing, stock is relatively high and harvesting is the more damaging activity for the resource. Then we are in the concave part of the PPF, where shifting an extra worker from H to M has an increasing opportunity cost due to the additional productivity benefit in H.

Proposition 3. *The autarkic equilibrium is not efficient. It depends on the relative demand for the two commodities and on the relative strength of the externalities as sources of inefficiency.*

The shape of the PPF is important in deciding the pattern of specialization triggered by trade. Still looking at the closed economy, the autarkic equilibrium outputs determined in section 2.3 are: $H^A = q\beta LS^A$ which implies $\beta L = \frac{H^A}{qS^A} = H^A p$ and $L = \frac{M^A}{1-\beta}$, where p is the autarkic relative price. Then we have $\frac{\beta}{1-\beta} M^A = H^A p$ and $\frac{dH}{dM} = \frac{1}{p} \cdot \frac{\beta}{1-\beta} - \frac{M^A}{p^2} \cdot \frac{\beta}{1-\beta} \frac{dp}{dM}$, where $\frac{1}{p}$ is in fact the relative price line in Figure 4 above. Then we can compare the slope of the PPF at the equilibrium with the slope of the relative price. The condition that the slope of the PPF is higher than the slope of the price line reduces to:

$$\frac{2\beta - 1}{1 - \beta} > \frac{L}{p} \frac{dp}{dM}.$$

Notice that for $\beta > \frac{1}{2}$, i.e. when domestic taste for H is strong and the equilibrium occurs in the convex part of the PPF, the price line can be flatter than the PPF slope. Similarly, if $\beta < \frac{1}{2}$, i.e. when domestic taste for M is strong the price line tends to be steeper than the PPF at the autarkic equilibrium.

In the first case, with more general preferences, two equilibria can emerge, one in the convex, one in the concave part of the PPF, while in the second case the

²⁷ See p. 414. Note that for the shape of the PPF around $H = 0$ in Fig.4 it suffices that we have DRS in H.

²⁸ The result is also discussed in Ethier (1982), p. 1263.

²⁹ The condition for M to be less harmful than H in autarky is $S > \frac{\alpha(1-\beta)}{q\beta}$ and is more likely to hold the higher the stock level. This condition makes intuitive sense if we recall that it is harder to catch the resource when it is sparse, whereas the marginal damage from pollution is stock-independent. To make things interesting, we assume this condition can hold given our parameters.

³⁰ As derived in Appendix B, stock is not a monotonic function of M. In particular, $\frac{\partial S^A}{\partial M} < 0$ for $M < \underline{M}$ and $\frac{\partial S^A}{\partial M} > 0$ for $M > \underline{M}$.

internal equilibrium is unique. It is argued in Appendix C that in a static setting, opening up to trade from such an autarkic equilibrium can bring about any pattern of specialization/diversification, as international trade acts as a vent for the internal inter-sectoral tensions existing in the autarkic economy. We will return to use the results in the next section of the paper.

Therefore, the autarkic equilibrium is likely to be situated at a point where the price line is not tangent to the PPF, due to the external effects. If the domestic price line is steeper than the PPF at equilibrium, the market undervalues the true cost of the harvesting good H. Expanding production of M generates a negative externality on H, the “private” exceeds the “social” marginal productivity of labour in M and so there is overemployment of labour in M compared to what is efficient. If, on the contrary, the domestic price line is flatter than the slope of the PPF at equilibrium, the market undervalues the true cost of M due to the open-access externality. The following discussion of the effects of trade will assume the first scenario: there is a relatively strong domestic demand for M, the autarkic price line steeper than the slope of the production frontier and a unique autarkic equilibrium.³¹

Proposition 4. *The supply of manufacturing is not monotonic over the feasible price: there exists a critical point where the slope of supply of M changes sign.*

In order to study the stability properties of the autarkic equilibrium, plug the expression for the stock derived in (2.11) into the relation between the relative price and the stock found in (2.4) to get the inverse supply function:

$$(2.13) \quad p = \frac{1}{qS^A} = \frac{2r/q}{\sqrt{[q(L-M) - r]^2 K^2 - 4r\alpha KM - [q(L-M) - r]K}}$$

The sign of the first derivative of S^A with respect to M is not unambiguous.³² We get the sufficient condition that the supply of M is upward sloping for:

$$(2.14) \quad M > L - \frac{r}{q} + \frac{2r\alpha}{q^2 K}$$

While this is not a necessary condition³³ and so it does not allow by exclusion the identification of a complementary inequality that makes the supply upward sloping, it shows that supply can be downward sloping over a range.

The intuition behind Figure 5 is the following: Initially, higher M yields lower stock level S and lower productivity in H, which causes labour to shift from H to M and lowers the price necessary for firms in M to break even, as $\frac{1}{p} = qS$. This is a result commonly obtained in the increasing returns to scale trade models.³⁴ Increasing production of manufacturing goods beyond \underline{M} requires a higher price due to the fact that production moves along the PPF in the concave section, where the opportunity cost of producing more manufactures is increasing. Notice from equation (2.12) that the relationship between M-production and the relative price is not monotonic, and so the price increases after supply of M reaches a threshold value.

As Copeland and Taylor (1999) note,³⁵ generally, multiplicity of equilibria is - even in closed economies - a feature of the IRS models. Here, due to our utility

³¹ See Eaton and Panagariya (1979), p. 590, for a similar discussion.

³² See appendix B for derivation.

³³ Such a condition has a much more complicated expression. See Appendix B for details.

³⁴ E.g. Ethier (1982).

³⁵ See argument on p. 145, Copeland and Taylor (1999).

assumption, demand for M is $M^D = (1 - \beta)L$ a vertical line in the (M, p) space like in Figure 5, and the autarkic equilibrium is at E or E'. In autarky the economy will stay diversified due to the fact that both goods are essential for consumers. When opening up to trade, the small open economy takes world price p^w as given and three possible equilibria emerge. The IRS literature result is that a diversified equilibrium with trade becomes problematic (it is unstable) and specialization becomes possible. However, as we argued before, all this is valid here only for a range of M values (lower than \underline{M}). For the other possible levels of manufacturing good production we can have a diversified equilibrium even under free trade.³⁶

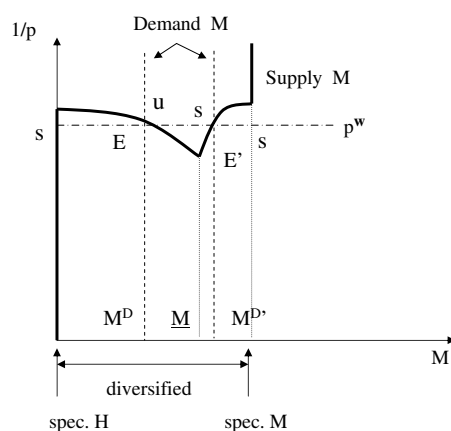


FIGURE 5

Thus, as can be seen in Figure 5, there are stable trading equilibria both when the economy is specialized and when diversified. Trade opportunities create an infinitely elastic demand for the goods produced domestically. If domestic demand for M under autarky is at $M^D < \underline{M}$, trading (at domestic prices) will make the autarkic equilibrium unstable. A small perturbation that increases production of the manufacturing good will be self-reinforcing and push for specialization in M. If domestic demand is at $M^{D'} > \underline{M}$, the autarkic equilibrium will still be stable and so no specialization is induced if trade begins at autarkic prices. The analysis is simpler when considering trade at international prices that differ from the pre-trade domestic price. For world prices ($1/p^w$) low enough the economy will completely specialize in H, while for prices high enough, the economy will specialize in M, as is apparent from the graph.

³⁶ Note that by altering the structure of the problem we may eliminate some of the cases and make the results clearer. Yet, one of the purposes of the paper is to show that under the conditions specified in the model, any specialization / diversification outcome is possible once the economy opens up to trade. This is a source of the different results from the literature.

3. THE OPEN ECONOMY EQUILIBRIUM

In the Brander and Taylor (1997) model, a country that exports the manufacturing good must gain from trade, and a country that has a comparative advantage in the resource good but fails to fully specialize in it necessarily loses from trade. In the present model this need not happen, as increased pollution caused by specialization in the dirty good hurts the resource.³⁷ Partially specializing in M increases the pollution pressure on the stock of the resource if M is more damaging than H. Full specialization in H may make the small open economy better off. From here one can learn that a successful industrialization process in a resource-abundant developing-country must take pollution into account.

The analysis of the welfare changes brought about by trade in our small economy looks first at the short-run impact and then the long-run effects are derived. In the short-run, the PPF is linear. When opening up to trade, the small economy takes as given the international price p^w . If we denote by p the autarky steady-state price, there are three possible cases: $p < p^w$, $p > p^w$ or $p = p^w$. If $p > p^w$, the country has a comparative advantage in M, will start by specializing in M (if the world demand for M is strong enough, which we assume here for the small economy case). Then $M = L$ and the stock will evolve to S^M . Depending on the parameters, we may get extinction of the stock if S^M becomes zero.

If $p < p^w$, the country has a comparative advantage in H, will specialize in H (again, given world demand for H is “large”). There will be more harvesting in the economy, so the overexploitation problem worsens, but there is no pollution-related negative impact on the stock. In a second case, if $p = p^w$, the international price is exactly equal to the autarkic opportunity cost of producing H, and so there are no areas of comparative advantage. However, if the autarky-inherited equilibrium is perturbed by increasing the M production, then productivity in the H-sector declines if the stock decreases - i.e. $S^T < S^A$ - as a result of the perturbation.³⁸ If the autarkic equilibrium were at a point like E in Figure 5, this is a self-reinforcing process, leading to specialization in M, and so the initial autarkic diversified equilibrium is unstable. If at E' in autarky, the pre-trade equilibrium is stable and there will be no welfare changes taking place. If, on the contrary, $S^T > S^A$, meaning that the M sector is relatively *less* harmful to the natural resource than harvesting, then productivity in H improves and the economy will return to a diversified production state.

The effect of trade on welfare can be seen in a simple setting that depicts the short-run responses of the PPF and PPC.

³⁷ A similar conclusion is reached by Hannesson (2000). He takes the Brander and Taylor model (which assumes constant returns to scale in the production of the other goods) and introduces decreasing returns in the other (non-resource) sector. The outcome is the inverse of the Brander and Taylor result: the country that partially specializes in the resource sector can gain from trade, as the losses of increasing production in the diminishing returns alternative sector can be limited through imports. Our setup differs from his in that it explicitly considers the production externality and the returns are constant in the manufacturing sector and could be decreasing in the resource sector. So, while he obtains a hump-shaped steady-state PPF, ours looks like in Figure 4.

³⁸ Like in Copeland and Taylor (1999), p. 147.

3.1. Comparative advantage in the resource good.

For Case 1, $p < p^w$ leads to comparative advantage in the resource good and specialization in H in the small open economy. If H specialization is more harmful than diversified autarkic production, then the stock of resource decreases and so does the feasible level of H. Then the PPF rotates downward as in Figure 6, bringing the PPC down with it. In the short run (SR) there are welfare gains, as the feasible budget set is now the upper price line in Figure 6, while the PPF is still the autarkic one. However, overexploitation of the resource dominates the beneficial pollution reduction as far as the stock is concerned and so the autarkic equilibrium becomes unfeasible. In the long run (LR) the stock S is lower and welfare (W) is lower because the feasible consumption set shrinks, and we eventually get diversification in production in the long run.³⁹

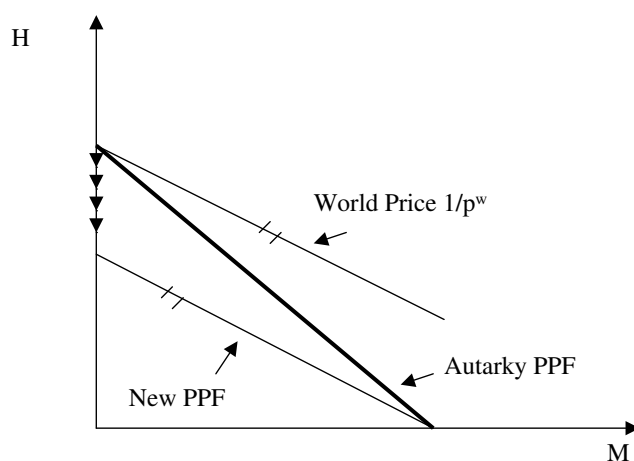


FIGURE 6

If, on the contrary, $S^A < S^H$ and the specialization in H allows the stock to actually rebound, the PPF rotates upward and the country experiences short-run gains from trade, as can be seen in Figure 7. Here, unlike in Brander and Taylor (1997), initial specialization in H may make the country better off. This result is obtained due to the beneficial result of spatial separation of industries. If the manufacturing is relatively more damaging to the resource, trade allows for an avenue to decrease the tensions created by the pollution externality. Like in Copeland and Taylor (1999), this non-traditional source of gains from trade can - for some values of the parameters - offset the fact that the other source of inefficiency, namely the open access problem, inevitably worsens.

3.2. No areas of comparative advantage for the small open economy.

For the relatively more complicated Case 2, $p = p^w$ does not confer any clear comparative advantage to the country opening up to trade. If we assume a perturbation by slightly increasing M-production, then H-production decreases as a result of the externality. If M is relatively more damaging, then S falls, production of H

³⁹ This is confirmed in Appendix C, where Figure C1 depicts the movement from the autarkic to trade production along the long-run PPF.

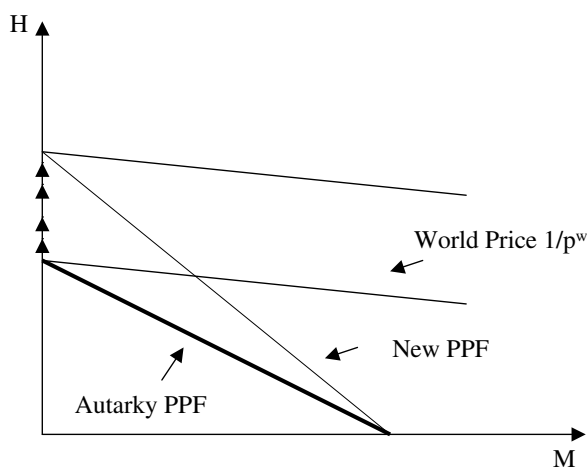


FIGURE 7

falls more in the longer run, like in Figure 8.⁴⁰ In the extreme case of complete specialization in M, the economy does not experience a welfare loss from trade in the long-run, as the pre-trade bundle is still feasible because the PPC stays unchanged at the world price line.⁴¹

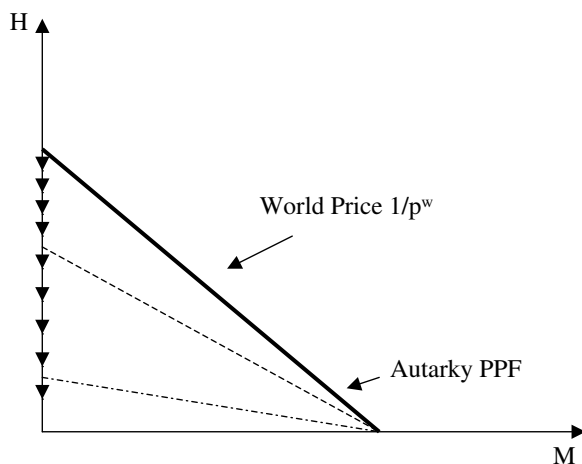


FIGURE 8

If M is relatively less damaging, S rises, H-production rises and the PPF rotates up like in Figure 9. Therefore, the stock increases and also welfare increases. However, as labour productivity is higher in H, there will be a shift of workers from M to H and the PPF can rotate back to be again coincidental with the international price line and a diversified equilibrium obtains again in the long run. The overall welfare effect is positive.

⁴⁰ Here we can potentially get extinction of the stock due to the self-reinforcing pattern of comparative advantage in M.

⁴¹ This result parallels one obtained in Brander and Taylor (1997).

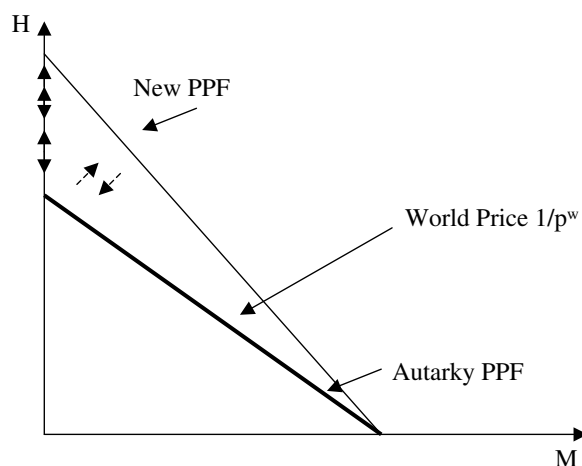


FIGURE 9

If, however, the perturbation of the diversified equilibrium is done by positively shocking H-production, then if H is relatively more damaging we can get the situation in Figure 6 above. Starting at E in Figure 5, the diversified equilibrium is unstable and it yields lower S and lower W. Yet, starting at E', there will be no welfare effect in the long run for the diversified economy, as the production point will return to the pre-trade position. If H is relatively less damaging, then we get a situation similar to the one illustrated in Figure 7 above, the diversified equilibrium is unstable and we can get higher S and W. Note here how trade arises as a means to spatially separate the two industries even in the absence of a price-dictated comparative advantage.⁴²

Thus, to summarize the discussion of these two cases, we can state the following result:

Proposition 5. *Specialization in the resource sector can be welfare improving in the long run, provided that harvesting is relatively less damaging to the growth of the resource.*

3.3. Comparative advantage in the manufactured good.

In a third case, $p > p^w$ the country has a comparative advantage in the manufacturing good production and can increase M-production. Again, given the relative harm inflicted by the two sectors on the stock of renewable resource, the economy may lose from trade. In Figure 9, if H is relatively more damaging for the stock, specializing in M reduces the pressure on the resource and allows the PPF to rotate upwards, increasing the productivity in harvesting. When the PPF becomes coincidental with the world price line $1/p^w$, a diversified equilibrium is possible where the economy can experience a long run welfare gain, even though the PPF can actually rotate back, depending on the production mix. However, if the manufacturing sector is relatively more damaging, the economy will behave similarly to what we already described in Figure 6 above. Here the economy experiences net losses in welfare terms in all cases except the long-run full specialization in M case. Thus:

⁴² This is one of the defining features of the Copeland and Taylor (1999) model.

Proposition 6. *Specialization in the manufacturing sector can be welfare reducing in the long run, provided that harvesting is relatively less damaging to the growth of the resource.*

Intuitively, the tradeoffs at play here are the following: If $p^A < p^w$, then H can expand and M can contract and so adding to the usual gains from trade, the overdepletion problem worsens, while the pollution problem improves. If $p^A > p^w$, M can expand and H can contract and the economy experiences less overdepletion, but more pollution to add to the gains from trade. Note that while even partial spatial separation of the two sectors allowed by trade adds to welfare, the persisting externality acts in the opposite direction. This leads to net results that are less categorical than those in the baseline models. To summarize the results above, taking our preferred case whereby manufacturing sector is inflicting relatively more damage on the stock (per unit of effort) than the harvesting per se,⁴³ we can say that opening up to trade seems to benefit the small open economy if it specializes in the traditional/environment-based sector. A resource exporter benefits from trade, taking advantage of the separation of the two industries, while a resource importer can in fact do worse than in autarky, as pollution problem worsens. This result is largely due to the fact that here the production externality dominates the overaccess problem. The results are changing dramatically if the relative harmfulness of the two sectors is inverted: If harvesting is more damaging for the resource, exporting H is welfare reducing, while specializing in M is welfare improving in this case. Here the overaccess externality dominates pollution in its negative effects and the economy does better by industrializing.

4. CONCLUSION

To conclude, our model is different in its predictions from the two models that were used as benchmarks. In Copeland and Taylor (1999), free trade was welfare improving for the small economy. In Brander and Taylor (1997) free trade was dominated by autarky from a welfare perspective. In our model with renewable resource and negative production externality, if the small open economy specializes in the sector that is less damaging for the stock of resource, trade can be welfare improving. We have shown that in our model, unlike Brander and Taylor (1997), specialization is possible in both sectors,⁴⁴ and that the small resource-abundant and exporting open economy does not necessarily have to lose from trade, if there exists the collateral beneficial separation effect of the two industries. Trade exacerbates the open-access over-harvesting. Yet, by the industry separation permitted by openness, the negative production externality declines in importance as a source of inefficiency. Moreover, complete specialization in the resource good is not needed in order to gain from trade. If H is relatively harmless for the resource stock, there will be gains. Unlike the Copeland and Taylor (1999) model, free trade may be welfare reducing, even when there is initial specialization in production, if specialization takes place in the relatively more environmentally-harmful sector.

⁴³ This could be rationalized by the fact that harvesting affects only a fraction of the stock, while pollution has a broader and longer-lasting impact on the resource.

⁴⁴ In their model only specialization in the production of the manufacturing good is possible.

The central message of the paper is that pollution can have non-negligible welfare effects *even* when there are no significant negative repercussions for consumers (possibly due to a relatively clean overall environment in a developing economy). Environmental Kuznets Curve (EKC) literature-inspired advice that income-augmenting development eventually brings cleaner environment may be misguided due to the existence of negative production spillovers. It is argued that the country may lose in welfare terms even when exporting the dirty good. This occurs because of the negative resource stock effect of the dirty good manufacturing and the repercussions on the “traditional” or environment-intensive sector. Under this scenario, even though overexploitation of the open-access resource is not a problem exacerbated by trade openness, pollution depletes the resource and brings down productivity in the resource-intensive sector. To the extent that the negative effect dominates, the country as a whole loses from trade. On the other hand, it appears that if the small open economy specializes in the resource good, even incompletely, it may stand to gain from trade. In short, a possible policy lesson for a developing renewable resource-rich economy is that industrializing at the expense of traditional sectors may in fact lead to welfare losses, while specialization in the resource-based sectors may lead to gains.

The paper looks at open access resources in a small open economy. Possible extensions, that include endogenizing the international trading price formation in a two-country setting, allowing for environmental policy in the form of taxes, or establishment of property rights, together with are candidate subjects for future study.

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This appendix derives the steady-state production possibilities frontier for the autarkic economy and provides the conditions for the local concavity and convexity of this PPF.

From the steady-state condition for the stock S we obtain the expression in equation (2.9) in the text:

$$(1) \quad rS\left(1 - \frac{S}{K}\right) - qS(L - M) - \alpha M = 0.$$

which, together with the short-run PPF (or the labour constraint)

$$(2) \quad L = M + \frac{H}{qS}$$

give the desired result.

Solving the quadratic equation in (1) yields as positive solution:¹

$$S^A = \frac{\sqrt{[q(L - M) - r]^2 K^2 - 4r\alpha KM} - [q(L - M) - r]K}{2r}.$$

Plugging this into (2) we get the desired PPF as:

$$(3) \quad H = \frac{q(L - M)}{2r} [\sqrt{K^2 q^2 (L - M)^2 + r^2 K^2 - 2qK^2(L - M) - 4\alpha rKM} - Kq(L - M) + rK].$$

Take first and second order derivatives to analyze the convexity properties of this long-run PPF:

$$(4) \quad 2r \cdot \frac{\partial H}{\partial M} = -q[\sqrt{K^2 q^2 (L - M)^2 + r^2 K^2 - 2qK^2(L - M) - 4\alpha rKM} - Kq(L - M) + rK] + q(L - M) \left[\frac{qK^2 - K^2 q^2 (L - M) - 2\alpha rK}{\sqrt{K^2 q^2 (L - M)^2 + r^2 K^2 - 2qK^2(L - M) - 4\alpha rKM}} + Kq \right].$$

$$(5) \quad 2r \cdot \frac{\partial^2 H}{\partial M^2} = qK \left[\frac{Kq^2(L - M) - qK + 2\alpha r}{\sqrt{K^2 q^2 (L - M)^2 + r^2 K^2 - 2qK^2(L - M) - 4\alpha rKM}} + q \right] - q \left[\frac{qK^2 - K^2 q^2 (L - M) - 2\alpha rK}{\sqrt{K^2 q^2 (L - M)^2 + r^2 K^2 - 2qK^2(L - M) - 4\alpha rKM}} + Kq \right] - q(L - M)K \cdot \frac{-Kq^2 \sqrt{K^2 q^2 (L - M)^2 + r^2 K^2 - 2qK^2(L - M) - 4\alpha rKM}}{K^2 q^2 (L - M)^2 + r^2 K^2 - 2qK^2(L - M) - 4\alpha rKM} - [Kq^2(L - M) - qK + 2\alpha r] \cdot \frac{(\sqrt{K^2 q^2 (L - M)^2 + r^2 K^2 - 2qK^2(L - M) - 4\alpha rKM})'}{K^2 q^2 (L - M)^2 + r^2 K^2 - 2qK^2(L - M) - 4\alpha rKM}$$

To obtain the conditions under which this expression is positive, drop some positive factors that do not influence the sign and get:

$$(6) \quad \frac{\partial^2 H}{\partial M^2} > 0 \Leftrightarrow [3Kq^2(L - M) - qK + 2\alpha r] \cdot [q^2 K(L - M)^2 + r^2 K - 2qK(L - M) - 4\alpha rM] + (L - M)[Kq^2(L - M) - qK + 2\alpha r]^2 > 0.$$

¹under the usual parametric conditions for the existence of roots in \mathbb{R} .

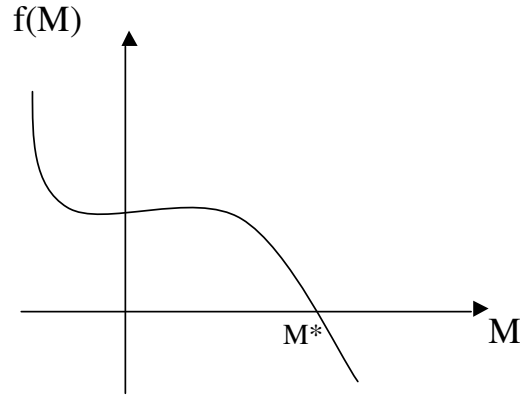


Fig. App.A

After further manipulation, this simplifies to the condition that a cubic in M be positive:

$$4K^2q^4(L - M)^3 - 3Kq^2(3Kq - 2\alpha r)(L - M)^2 - 12\alpha Kq^2rM(L - M) + (3K^2q^2r^2 + 3K^2q^2 + 4\alpha^2r^2 - 8\alpha Kqr)(L - M) + 4\alpha r(Kq - 2\alpha r)M - Kr^2(Kq - 2\alpha r) > 0$$

As it appears, we need to derive the conditions under which this cubic function of M with a negative M^3 coefficient is above the M -axis. The function looks somewhat like in the figure above.

Notice that the function is positive for M below a certain level M^* , and so this is also the condition for the long-run PPF of the autarkic economy to be convex. For $M > M^*$ the PPF is concave.

This appendix derives the supply of M in autarky as a function of the relative price p and provides the conditions for obtaining a downward sloping section on the inverse supply function.

Plugging the expression for the stock derived in (2.11) into the relation between the relative price and the stock found in (2.4), we get the inverse supply function:

$$(1) \quad p = \frac{1}{qS^A} = \frac{2r/q}{\sqrt{[q(L-M) - r]^2 K^2 - 4r\alpha KM} - [q(L-M) - r]K}$$

where p is a function of the inverse of the stock level S^A . Note that the inverse supply function for M should have the form $\frac{1}{p}(M)$, and therefore the partial derivatives of p and S with respect to M have the same sign. Taking the derivative of S^A with respect to M gives the following expression:

$$(2) \quad \frac{2r}{K} \cdot \frac{\partial S^A}{\partial M} = \frac{2q[r - q(L - M)] - 4r\alpha/K}{\sqrt{[q(L - M) - r]^2 - 4r\alpha M/K}} + q.$$

By quick inspection of equation (2) it can be noticed that a *sufficient* condition for the partial derivative to be positive, which is also the condition for the supply of M to be upward sloping, is that the numerator of the fraction be positive, which translates into:

$$q[r - q(L - M)] - 2r\alpha/K > 0$$

or

$$(3) \quad M > L - \frac{r}{q} + \frac{2r\alpha}{q^2 K}.$$

The less restrictive *necessary* condition for the supply of M to be upward sloping is:

$$2q[r - q(L - M)] - 4r\alpha/K + q\sqrt{[q(L - M) - r]^2 - 4r\alpha M/K} > 0$$

condition which is satisfied for all M above a critical level which is going to be less than the sufficient condition in (3) above.

Then the inverse supply of M is actually downward sloping for $M < \underline{M}$ and upward sloping for $M > \underline{M}$.

Hence, depending on the parameter values, there may be a range of feasible M values for which the supply is negatively sloped, leading to greater specialization in M and a self-reinforcing comparative advantage dynamics as obtained in the IRS trade literature. Yet for some values of M outside this range, supply of M is actually upward sloping and the tendency towards complete specialization found in Copeland and Taylor 1999 is countered.¹

¹ The critical value M_2 above which the supply of M is necessarily upward sloping is called \underline{M} in the paper.

This appendix shows how opening up to trade can influence the production and specialization patterns, starting from autarkic equilibrium points like A^1 (in the concave region) or A^2 (in the convex region) when there are *no inter-temporal* considerations, i.e. when the stock of resources is at its steady state level. For simplicity, suppose that the autarkic equilibrium is situated in the concave to the origin part of the long-run PPF.¹ Also, following the discussion of the efficiency of the autarkic equilibrium in the text, assume that, due to the externalities involved, the autarkic price line is steeper than the slope of the PPF at the equilibrium.

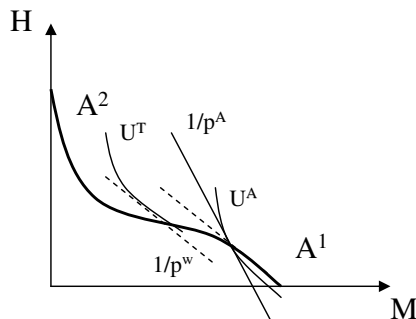


Fig. App.C1

Let $\frac{1}{p^w}$ be the international price that the small economy takes as given. Then if this is lower than the previous autarkic price, i.e. if $\frac{1}{p^w} < \frac{1}{p^A}$, the economy will move to produce more H as this is its area of comparative advantage. It can be seen from the first graph above that in this case the autarkic equilibrium dominates the trading one from a welfare perspective, as U^T is below U^A . The explanation is that moving to the new equilibrium point along the PPF shifts labour from M to the less productive/lower returns to scale sector, H.² The economy experiences a long run welfare loss, as it moves labour to the externality-ridden sector H.

If, on the contrary, $\frac{1}{p^w} > \frac{1}{p^A}$, as in the second graph, then the economy tends to move towards producing more M, where it has a comparative advantage. Full specialization in M is possible. Also, following specialization in M the economy can experience a long run gain in welfare.

¹ Eaton and Panagariya argue that equilibria in the convex part are unstable, due to the perverse supply behavior with respect to price changes.

² See Choi and Yu, op. cit., p. 984.

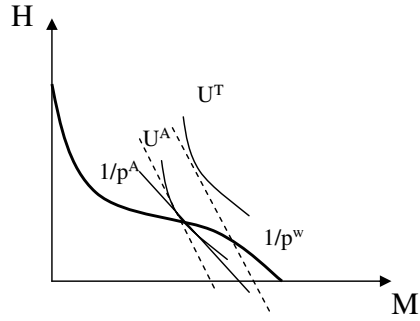


Fig. App.C2

Notice that any pattern of specialization or diversification is possible. Unlike Brander and Taylor, specialization in H is possible. Unlike Copeland and Taylor, it may yield losses for the small open economy. Also, specialization in the manufacturing good can yield long run gains.

This appendix explains how to determine whether in the steady state some labour will be left idle.

If the consumer takes the stock of the resource S as given, chooses the amount of labour to be allocated to H , M (and leaves some fraction unemployed) and solves:

$$\underset{L_H, L_M}{Max} \quad U = H^\beta M^{1-\beta} = (qSL_H)^\beta \cdot L_M^{(1-\beta)} \quad s.t. \quad L = L_H + L_M + L_U.$$

The solution to this static optimization problem is: $L_H = \frac{\beta(L-L_U)}{\beta+(1-\beta)qS}$ and $L_M = \frac{(1-\beta)qS(L-L_U)}{\beta+(1-\beta)qS}$.

In a first best scenario, a planner realizes that the stock is a function of total labour utilized in production. In the specification above, the consumer practically internalizes the negative externality imposed by working in any sector on productivity in the H sector and may chose to work less ($L_U > 0$). The implicit coordination issues are resolved when a social planner solves the optimization problem. If $U_{S(L)} < U_{S(L-L_U)}$ then some workers should be left idle in a first-best equilibrium. This is equivalent to $(1 - \frac{L_U}{L})^{\frac{1}{2-\beta}} < \frac{S(L-L_U)}{S(L)}$, where the value of the stock as a function of labour endowment is as determined in Appendix A. Notice that if S is monotonically decreasing in the total labour endowment, $S(L-L_U) > S(L)$ and so the validity of the inequality above is not unambiguous. There exists a cutoff value L_U^* that makes it true.

The possibility of leaving workers idle in autarky would raise the interesting question of the impact of trade on this optimal labour allocation.