Renewable Resources, Pollution and Trade in a Small Open Economy

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Abstract

Industrial pollution often exerts negative spillovers on resource-based productive sectors. International trade creates conditions for the overexploitation of an open-access renewable resource, but also provides opportunities for separating the productive sectors spatially. The existing literature suggests that a diversified exporter of the renewable resource good tends to lose from trade due to over-depletion, while the exporter of the non-resource good gains. This 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 manufacturing/dirty good may not be the optimal choice from a welfare perspective. In addition, the resource exporter does not necessarily have to lose from trade even when specializing incompletely, due to the partially offsetting external effects.

JEL: Q27, Q22, Q53

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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. According to a recent UN study, up to 80% of the ocean pollution is derived from industrial or residential land-based activities, in the form of 'excess nutrients (fertilizers, sewage, other nitrogenous compounds), persistent organic pollutants (POPs) (halogenated hydrocarbons, PCBs, and dioxins), radioactive substances'.[2] High profile examples of pollution-resource interaction issues range from the North Atlantic salmon fishery,[3] 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 similar cases in the developing world.

As the biology 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 experience an accelerated depletion of their resources after opening up to international trade. Indeed, it is not surprising that under a quasi-open access resource exploitation regime, expanding the size of the potential market leads to increased over-exploitation. The welfare effects of this form of tragedy of the commons amplified by trade are potentially very 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 foreseeable effect of tightening up of standards in the developed world - may result in increased industrial pollution of the environment: the so-called *pollution haven* effect.[4] This need not only apply

[2] See Sale et al. (2008), p. 16.

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

[4] Copeland and Taylor (2004), Ederington, Levinson and Minier (2005), and Grether, Mathys and de

to local pollutants, but to global pollutants as well, as carbon-intensity reductions agreed under any plausible post-Kyoto international climate change agreement are likely going to be non-uniform among developed and developing countries. Increasing trade and investment openness makes both over-depletion and pollution-haven 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 will suffer resource depletion and may incur a long run real income loss, whereas a country that exports the alternative non-resource good will gain from trade, as 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. In their model, a resource exporting country will gain from trade because specialization leads to a contraction of the polluting sector. However, many renewable resources are in reality concomitantly subject to *both* types of pressures.

This paper investigates the effect of trade when an un-managed renewable resource is subject to two interacting problems: overharvesting and pollution. The present work builds on the baseline Brander and Taylor (1997) model as well as 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 their framework in that it also assumes the existence of production externalities, like 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,[5] in the present paper the production of the 'clean' good also

Melo (2009) contain some of the most important discussions of the pollution haven effect. The last paper identifies an inverse trend in the pollution haven effect for local pollutants as production technologies became greener. For global pollutants, the inverse might still become the case once differentiated climate change carbon-reductions are implemented.

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

depletes the stock of the resource. The fact that *both* sectors exert a differentiated pressure on the stock of the resource proves to be important in establishing the results. Thinking about real-life examples: if one sector is tourism and another is a polluting manufacture, it is likely that both activities pollute an adjacent lake or river, although conceivably, to quite different degrees. Alternatively, given the emerging evidence documenting the damaging effect of aquaculture for the environment, one can be thought of as fish or shrimp farming, while another is the harvesting of the wild resource etc.

The resource economics literature illustrates many instances of habitat quality influencing population levels, harvesting, and having detrimental welfare effects. Knowler (2002), in a review of bioeconomic models employed to estimate the welfare effects of environmental quality provides several such examples: 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). Closer to the spirit of this paper, Loomis (1998) analyzes the effect of logging on the downstream fisheries in the form of sediments and water temperature changes.

The interaction between pollution and international trade has also been extensively studied recently. The approach used in Copeland and Taylor (2003) is to build a unified general equilibrium framework which allows them to clearly identify the various effects characterizing 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). If the manufacturing sector is relatively less important, the effects of additional local pollution on the consumers are likely to be low. Under these conditions, 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.[6] However, the

[6] Another reason may be that the democratic channels by which higher pollution triggers a policy response

existence of a polluting sector and its external effects cannot be dismissed even in these economies. One can 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.

To preview the main findings, 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. Opening up to trade allows the economy to potentially do better in welfare terms 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 turns out that - under certain conditions - specialization in the 'dirty' manufacturing good can be detrimental, while specialization in the resource good can be welfare-improving, despite the worsening overdepletion.[7] 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 becomes increasingly open to trade. Even when pollution disutility costs to consumers are small, excessive industrialization may imposes significant external costs to the environment-based sectors.

The analysis of welfare changes can give an indication as to what drives the results and will suggest a direction for possible policy measures. If the only commodity 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 produced elsewhere. If the resource-based product (e.g. fish) is also tradable,[8] then overdepletion makes the results ambiguous, and several cases develop, based on the parameters of the system. It is important to point out that

may not be functioning properly.

[7] In a stylized way, this result runs contrary to the so-called Dutch Disease 'symptoms' of the 'Natural Resources Curse,' which is, of course, driven by our assumptions about manufacturing as having exclusively negative externalities in the wider economy.

[8] And this is the less restrictive and perhaps more realistic case.

the two externalities here have *partially offsetting effects*, which in autarchy could actually bring the economy closer to a first best optimum than in the simple over-harvesting of a renewable resource 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 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 below the autarkic steady state level, while (even incompletely) specializing in the relatively environmentally-friendly sector will raise the stock above it, likely influencing in turn the comparative advantage of the country.

There are not many studies focusing explicitly on 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, 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 demand, while the supply of fish increases as well with water quality. Here the open-access dimension is missing, and the focus is domestic. A special issue of *Environmental & Resource Economics* dedicated to the Economics of Non-convex Ecosystems[9] 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 relatively recent paper by Smulders,

[9] 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.

van Soest and Withagen (2004) which focuses on habitat destruction by having a specific factors model with three sectors, two of which are dependent on 'land' as a resource base or factor of production. 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 only applies to terrestrial resources, where habitat size can be increased or decreased by the expansion of agriculture.[10] In the present paper, inter-industry externalities are exclusively negative: pollution reduces the stock size, diminishing productivity in the harvesting sector by increasing the implicit search costs, as sparsely distributed marine resources are harder to catch. To the best knowledge of the author, the focus of this paper on pollution and marine resources has not been previously undertaken.

The rest of this work is organized as follows. The next section analyzes the autarkic general equilibrium in the short run and in the long run, introducing the 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 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.

$$\frac{dS}{dt} = \dot{S} = G(S(t)) - H(t) - Z(t) \qquad (1)$$

where H is the harvest level and Z is the detrimental effect of pollution on the resource growth. We assume the resource stock S follows a logistic growth function that was shown to perform

[10] For marine resources it is more difficult to imagine activities that physically diminish the habitat.

quite well empirically for several fish species:[11]

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

with r the intrinsic growth rate of the resource, and K the carrying capacity as known parameters.[12]

It can be seen from equation (1) that activity in both sectors of the economy influence the change of stock. For the sake of accuracy, 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, 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 could also enter in a more complicated manner than here, namely via an intrinsic growth function $r(Z)$ that is decreasing in pollution: $dr/dZ < 0$. However it is straightforward to show that our simple specification is equivalent to one in which a 'true' intrinsic growth rate ρ is diminished by a properly-weighted pollution effect to yield the 'actual' intrinsic growth rate r as follows: $r = [\rho - \frac{Z}{S}(1 - \frac{S}{K})^{-1}]$. As shown in the original fishery model, under open access, resource extraction will occur at zero profit levels, due to free entry into the sector driving rents to zero. The added complication here is the negative externality imposed by the polluting sector, which combines with the typical stock externality of extraction.

2.1. Supply

There are two productive sectors in this Ricardian economy: harvesting of the renewable natural resource (H) and manufacturing (M). Both sectors are using one primary input: labour

[11] 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.

[12] Jinji endogenizes the carrying capacity. In his forestry model K depends linearly on the stock of the 'base resource:' land. A number of useful comparative statics exercises can be performed when K is allowed to vary. See Jinji (2007), p. 796.

(L). In addition, production of H depends on the stock of the resource according to a typical Schäfer yield function with productivity q:

$$H = qSL_H, \tag{2}$$

while manufacturers use only labour and produce according to the simplest constant returns production function:

$$M = L_M, \tag{3}$$

where L_H and L_M are, respectively, the shares of labour allocated to harvesting and manufacturing. However, the latter is a polluting activity. Pollution (Z) is generated at rate α in the manufacturing process, so that

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

Assume pollution does not accumulate[13], there is no abatement and no environmental policy[14] and emissions intensity α is given.

Let M be the numeraire commodity so that $p_M = 1$. From the zero-profit condition in the manufacturing sector: $\Pi^M = M - wL_M = 0$ we obtain that $w = 1$. 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 together with the unitary wage for the homogeneous labour from above implies:

$$w = pqS \Rightarrow p = \frac{1}{qS}. \tag{4}$$

Therefore, if both sectors of the economy are active in autarky, the relative price of the resource good is determined by the stock level and extraction technology: the autarkic price

[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 closed systems such as lakes. This scenario is omitted here for simplicity.

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

increases as the resource becomes more scarce and decreases if the harvesting productivity improves.

2.2. Demand

On the demand side, there is a representative consumer with preferences described by a Cobb-Douglas utility function of both goods, and with (1-β) the share of M, β the share of H in total spending.[15] In the first best harvesting equilibrium there would be 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:

$$\underset{H,M}{Max} \quad \{U = H^{\beta} M^{1-\beta}\}$$

subject to the budget constraint $pH + M = w$.

Demands are then determined by their respective income shares, as usual:[16] $\frac{\beta w}{p}$ for the resource good and $(1-\beta)w$ for the manufactured good. On aggregate, the market demands with unitary wages are:

$$H = \frac{\beta L}{p}, M = (1-\beta)L, \qquad (5)$$

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

2.3. The Short Run Autarkic Equilibrium

Since there is only one primary factor L, the economy is Ricardian and the temporary production possibilities frontier will be a straight line, as both firms' and consumers' problems

[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] 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.

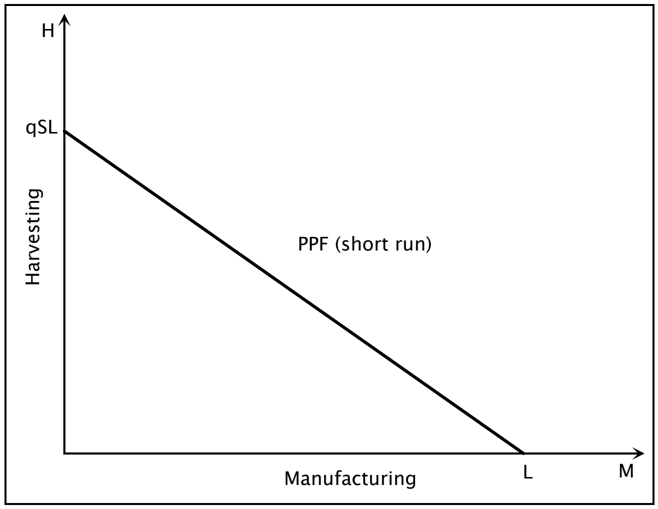

Figure 1: Autarky

assume a fixed stock of the resource S. Notice the fact that in the short run the 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 production possibilities frontier represented in Figure 1. The short-run equilibrium is found from expressions (4) and (5) above, which yield:

$$H = q\beta LS \text{ and } M = (1-\beta)L \tag{6}$$

as the short-run equilibrium outputs.

In autarky, due to fixed proportionality, the amount of labour used in manufacturing is pre-determined, and therefore the amount of pollution is also pinned down. The evolution of the resource stock in the short-run can then be obtained by simply subtracting the effect of manufacturing pollution on the change of stock in the growth equation, and interacting it with the harvest function to find the open-access level of stock S^O.

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

Figure 2 depicts the classical Gordon-Schäfer model of optimal renewable resource harvesting, modified to allow for the cross-sectoral externality. Point A would be the open-access extraction point in the absence of the manufacturing sector, or if there was no production externality: $\alpha = 0$. TC and TR stand for total costs and total revenues, respectively, where costs are linear in effort, since harvesters only pay the labour they hire the market wage, and where the total revenues mimic the growth rate of the resource in a sustained harvesting scenario. 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

$$H(t) + Z(t) = G(S(t)). \tag{7}$$

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.

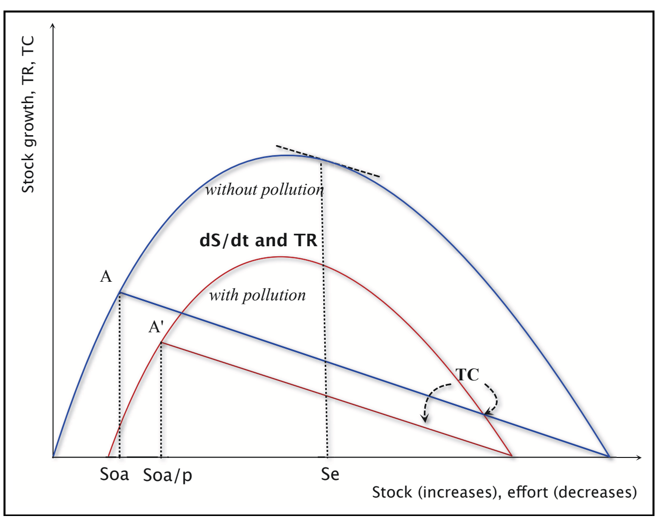

Figure 2: Effects of pollution on stock growth and open-access harvesting

Substituting the known expressions into (7) we get:

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

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:

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

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

$$(q\beta L - r)^2 > \frac{4r}{K}\alpha(1-\beta)L \tag{8}$$

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) and low population level (L).

The no-pollution steady state level of the resource stock under open access can be easily determined as $S_{oa} = \frac{K}{r}(r - q\beta L)$, thus the larger of the two roots calculated above corresponds with the steady-state level of the resource stock in autarky with pollution: $S_{oa/p} = \frac{r-q\beta L+\sqrt{\Delta}}{2r/K}$. The result is summarized by the following:

Lemma: *The uninternalized effect of pollution brings the autarkic economy closer to the first best optimum.*

This is obvious from the graph above, where $S_{oa/p}$ is closer to the efficient stock level S_e than the open-access, no-pollution level S_{oa}. Intuitively this can be understood due to the fact that the two externalities have offsetting effects: pollution reduces the profitability of harvesting, thereby reducing the scope for overharvesting. Now plugging $S_{oa/p}$ into (4) and

(6) we obtain as equilibrium solution $p^A = \frac{1}{qS_{oa/p}}$ and $H^A = q\beta LS_{oa/p}$, $M^A = (1-\beta)L$, 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,"[18] 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 supposedly 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.

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

[18] 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.

such non-convexities can create surprising specialization and trade effects.[19] 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 will hopefully help build some intuition. Here we simply summarize the argument in diagrammatic form. Assume the M industry is polluting the environment, imposing a negative spillover effect on the H industry, which is sensitive to the quality of certain elements of the environment.[20] 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 spillover)[21] 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.[22]

Thus, provided the externality is strong enough, the production possibility set is non-convex. 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.

[19] See Copeland and Taylor (1999), p. 139

[20] M represents energy and H 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.

[21] suppose the polluting industry is just starting the dirty manufacturing

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

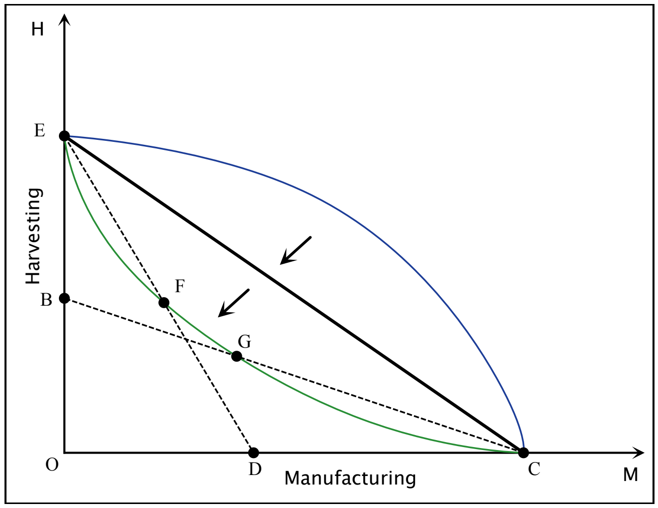

Figure 3: Non-convexity in the production set

Returning to our model, we now move on to establish the curvature of the PPF in the long run autarky. Using equation (1), the steady-state level of stock has to satisfy:

$$rS(1-\frac{S}{K})-qS(L-M)-\alpha M=0, \tag{9}$$

while the labour constraint can be written as:

$$L=M+\frac{H}{qS} \tag{10}$$

To find the long-run PPF, we need to solve (9) for S and plug it into the expression (10) above. The autarkic stock S can be written as:

$$S^A=\frac{1}{2r}\{\sqrt{[q(L-M)-r]^2K^2-4r\alpha KM}-[q(L-M)-r]K\} \tag{11}$$

and thus the (long-run) steady-state PPF of the domestic economy in autarky is:

$$H=\frac{q(L-M)}{2r}[\sqrt{K^2q^2(L-M)^2+r^2K^2-2rqK^2(L-M)-4\alpha rKM}- \\ -Kq(L-M)+rK]. \tag{12}$$

As the Appendix section A details, the condition for 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 some levels of M and convex for others, given the environmental and production parameters α, K, q, r and L the given population.

Proposition 1. *The long-run production possibilities frontier in M-H commodity space is convex-concave.*

Further analysis implies that the cubic expression in M is positive for all values of M below a certain threshold M^* and negative for the others (see Appendix). 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.[23] Then, given the single inflexion point M^*, the autarkic steady-state PPF will look like in Figure 4. Notice that the PPF is convex

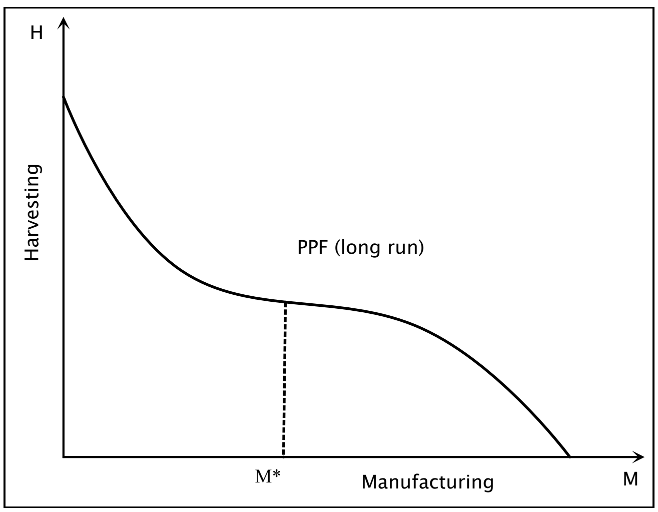

Figure 4: Convex-concave PPF

in a neighbourhood of the H-axis intercept, for values of M lower than the threshold M^* and concave in a neighbourhood of the M-axis intercept, for values of M greater than M^*. The result concurs with the findings in Herberg and Kemp (1969)[24] and Panagariya (1981),[25] which discuss the shape of the production possibilities curve when two sectors have different returns to scale.

[23] The implicit assumption here is that parameters are such that $M^* < L$.
[24] 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.
[25] The result is also discussed in Ethier (1982), p. 1263.

In our case, the shape of the long-run production possibilities frontier could be explained intuitively as follows. When the stock level is relatively high, the more damaging activity for the resource is harvesting. When the resource level decreases, harvesting becomes less efficient due to the implicit stock externality and manufacturing may become the more harmful activity.[26] This makes intuitive sense if we recall that it is costlier to harvest the resource when it is sparse, whereas the marginal resource damage from pollution is stock-independent. For levels of M production lower than M*, starting from the case where the whole labour force is employed in harvesting and the 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 remaining labour in H, via the pollution effect. Therefore, besides the direct 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.[27] In other words, when there is a lot of manufacturing, resource 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 2. *The autarkic equilibrium is inefficient, as a result of the pollution and stock externalities.*

The shape of the production possibilities frontier is important in deciding the pattern of specialization triggered by trade. Still looking at the closed economy, the autarkic equilibrium

[26] The condition for the manufacturing activity overall to be less stock-reducing than harvesting in autarky is $S > \frac{\alpha(1-\beta)}{q\beta}$ and is more likely to hold the higher the stock level. For one unit of effort, the condition is: $S > \frac{\alpha}{q}$. The first condition is the more restrictive one when consumer preferences are M-biased, and less restrictive when preferences are H-biased.

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

outputs determined above 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 of H. 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 the relative price of M in figure 4 above. Then we can compare the slope of the PPF at this autarkic 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:

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

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 general preferences, two equilibria can emerge, one in the convex, one in the concave part of the PPF, while in the second case the 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 following scenario: the autarkic price line is steeper than the slope of the production frontier and a unique autarkic equilibrium exists.[28]

Proposition 3. *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 (11) into the relation between the relative price and the stock found in (4) to get the inverse supply function:

$$p = \frac{1}{qS^A} = \frac{2r/q}{\sqrt{[q(L-M)-r]^2K^2 - 4r\alpha KM} - [q(L-M)-r]K} \tag{13}$$

The sign of the first derivative of S^A with respect to M is not unambiguous, as argued in Appendix B. We obtain the sufficient condition that the supply of M is upward sloping for:

$$M > L - \frac{r}{q} + \frac{2r\alpha}{q^2K} \tag{14}$$

While this is not a necessary condition[29] and so it does not allow by exclusion the identification of a complementary condition for an upward sloping supply, it does show the relative supply of M to 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 [30] and it appears in Copeland and Taylor (1999)as well. Increasing production of manufacturing goods beyond $\underline{M}$ however, 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, and this is different from the previous papers. Notice from equation (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.

[28] See Eaton and Panagariya (1979), p. 590, for a similar discussion.

[29] Such a condition has a much more complicated expression. See Appendix B for details.

[30] E.g. Ethier (1982).

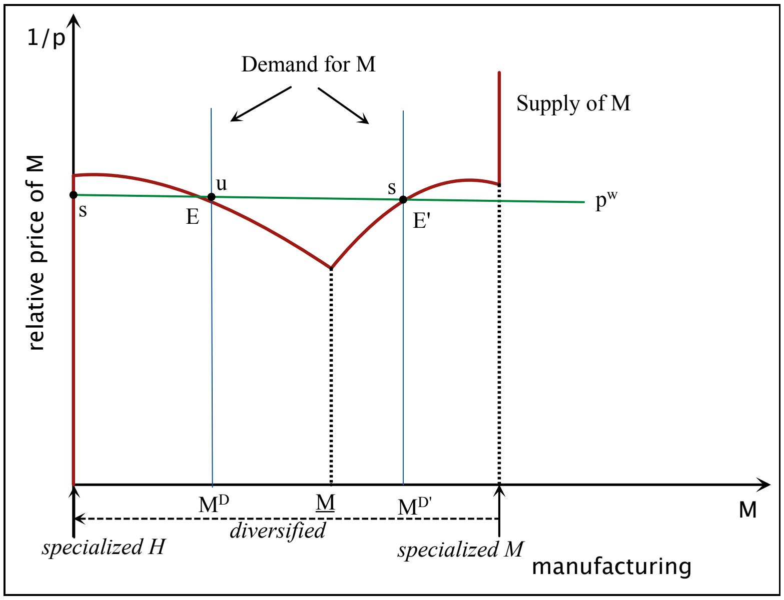

Figure 5: Possible equilibria

Generally, multiplicity of equilibria is - even in closed economies - a feature of the increasing returns to scale (IRS) models.[31] Here, according to our the assumption on utility, demand for M is either M^D or $M^{D'} = (1-\beta)L$, a vertical line in the $(M, \frac{1}{p})$ space represented 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 the world price p^w as given and three possible equilibria emerge. The typical increasing returns to scale literature result is that a diversified equilibrium with trade becomes problematic (it is unstable) and Ricardian-like complete specialization becomes possible. However, as we argued before, 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.[32]

[31] See argument on p. 145, Copeland and Taylor (1999).

[32] 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

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 lead to further specialization in M. If domestic demand is at $M^{D'} > \underline{M}$, the autarkic equilibrium will still be stable and no specialization is induced if trade begins at autarkic prices. The analysis is more straightforward 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.

3. The Open Economy Equilibrium

One of the main aims set in the introduction was to explore differences with the benchmark models. In Brander and Taylor (1997), a country that exports the manufacturing good must gain from trade, and a country that has a comparative advantage in the resource good yet fails to fully specialize, necessarily losses from trade. In the present framework this need not happen, as increased pollution caused by specialization in the dirty good hurts the resource.[33] Partially specializing in M increases the pollution pressure on the stock of the resource if M

source of the different results from the literature.

[33] 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 is convex-concave.

is more damaging than H. Specialization in H may make the small open economy better off.

The analysis of the welfare changes brought about by trade in our small economy focuses first at the short-run impact and then amends the equilibrium to take the long-run effects into account. 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 towards a level S^M. Depending on the parameters, extinction of the resource is possible. If $p < p^w$, the country has a comparative advantage in H, will specialize in H (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. 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.[34] If the autarkic equilibrium were at a point like E in Figure 5, the initialautarkic diversified equilibrium is unstable and a self-reinforcing process leads to increased specialization in M. 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 depicting the short and long-run responses of the production possibilities (PPF) and consumption possibilities frontiers (CPF). The size of the autarkic resource stock as a function of the harvesting productivity parameter q and pollution intensity α determines which activity is more damaging to the resource, and leads

[34] Like in Copeland and Taylor (1999), p. 147.

to different welfare effects.[35]

3.1. Comparative Advantage in the Resource Good

In Case 1: $p < p^w$ leads to comparative advantage in the resource good and the specialization in H of the small open economy. If this specialization is more harmful than diversified autarkic production, then the stock of resource decreases and so does the feasible level of H production. Then the PPF rotates downward as in Figure 6(a), bringing the CPF down with it. In the short run there are welfare gains, as the feasible budget set is now the upper price line in Figure 6(a), while the PPF is still the autarkic one. However, overexploitation of the resource dominates the beneficial pollution reduction as far as the stock level is concerned and so the autarkic equilibrium becomes unfeasible. In the long run 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.[36]

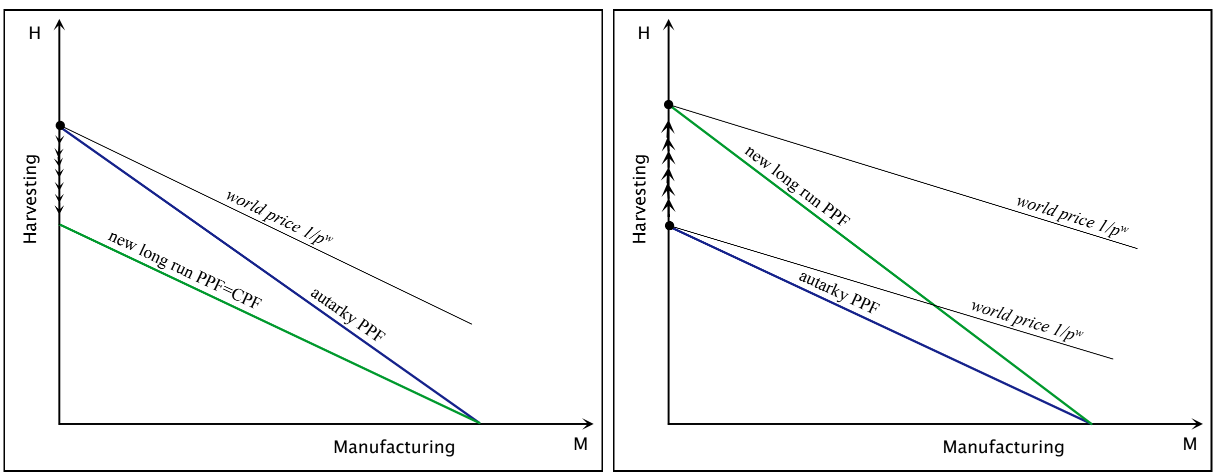

Figure 6: Comparative advantage in harvesting:
(a)(left) Overdepletion due to trade decreases productivity; (b)(right) Harvesting is relatively less damaging.

[35] As shown above, H is the more damaging sector for unit of labour employed if the stock is relatively large: $S > \frac{\alpha}{q}$.

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

If, on the contrary, $S^A < S^H$ and the specialization in H actually allows the stock to rebound from the autarkic level, the PPF rotates upward and the country experiences short-run gains from trade, as can be seen in Figure 6(b). 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. When 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 autarkic stock levels below the critical level $\frac{\alpha}{q}$ - offset the fact that the other source of inefficiency, namely the open access problem, inevitably worsens. The small open economy gains in welfare terms in this case.

3.2. No Areas of Comparative Advantage for the Small Open Economy

In a 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-productivity decreases as a result of the externality. If M is relatively more damaging, then S falls, production of H falls more in the longer run, like in Figure 7(a).[37] 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 consumption bundle is still feasible because the CPF stays unchanged at the world price line.[38]

If M is relatively less damaging, the stock recovers, H-productivity rises and the PPF rotates up like in Figure 6(b). Therefore, the stock increases and also welfare increases initially. However, since 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 long-run welfare effect is positive.

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

[38] This result parallels one obtained in Brander and Taylor (1997).

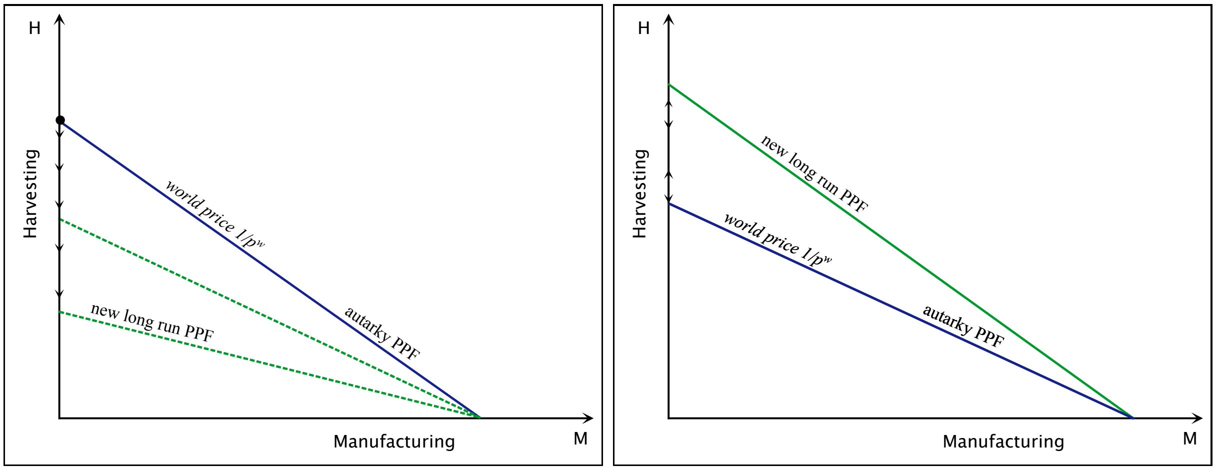

Figure 7: (a)(left) Harvesting is relatively more damaging; (b)(right) Comparative advantage in M.

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 depicted in Figure 6(a) above. When starting at E in Figure 5, the diversified equilibrium is unstable and it yields lower resource stock and lower welfare. When 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 6(b) above, the diversified equilibrium is unstable and we can get higher resource stock and higher welfare. Note here how trade still arises even in the absence of a price-dictated comparative advantage, as a means to spatially separate the two industries.[39] To summarize the discussion of these two cases, we can state the following result:

Proposition 4. *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 and can increase manufacturing production when opening up to trade. Again, given the

[39] This is one of the defining features of the Copeland and Taylor (1999) model.

relative harm inflicted by the two sectors on the stock of renewable resource, the economy may lose from trade. In Figure 7(b), when harvesting 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 eventually 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(a) above. Here the economy experiences net loses in welfare terms in all cases except the long-run full specialization in M case.

Proposition 5. *Incomplete specialization in the manufacturing sector can be welfare reducing in the long run, provided that manufacturing is relatively more 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,[40] 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

[40] 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.

problem worsens. This result is largely due to the fact that here the production externality dominates the open-access problem. The results are changing dramatically if the relative harmfulness of the two sectors is inversed: 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 open-access externality dominates pollution in its negative effects and the economy does better by industrializing.

4. Conclusion

To conclude, while sharing several premises, our model is different in some of 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 for a diversified resource exporter. 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. 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 the harvesting sector 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.

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 industrial 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, 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 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, which constitute subjects for future study.

APPENDIX:

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

Equation (12) in the text provides the expression for the PPF as:

$$H = \frac{q(L-M)}{2r}[\sqrt{K^2q^2(L-M)^2 + r^2K^2 - 2rqK^2(L-M) - 4\alpha rKM} - \\ -Kq(L-M) + rK]. \tag{15}$$

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

$$2r \cdot \frac{\partial H}{\partial M} = -q[\sqrt{K^2q^2(L-M)^2 + r^2K^2 - 2qrK^2(L-M) - 4\alpha rKM} - \\ -Kq(L-M) + rK] + \\ +q(L-M)[\frac{qrK^2 - K^2q^2(L-M) - 2\alpha rK}{\sqrt{K^2q^2(L-M)^2 + r^2K^2 - 2rqK^2(L-M) - 4\alpha rKM}} + Kq]. \tag{16}$$

$$2r \cdot \frac{\partial^2 H}{\partial M^2} = qK[\frac{Kq^2(L-M) - qrK + 2\alpha r}{\sqrt{K^2q^2(L-M)^2 + r^2K^2 - 2qrK^2(L-M) - 4\alpha rKM}} + q] - \tag{17}$$

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

$$-q(L-M)K \cdot \frac{-Kq^2\sqrt{K^2q^2(L-M)^2 + r^2K^2 - 2qrK^2(L-M) - 4\alpha rKM}}{K^2q^2(L-M)^2 + r^2K^2 - 2qrK^2(L-M) - 4\alpha rKM} -$$

$$-[Kq^2(L-M) - qrK + 2\alpha r] \cdot \frac{(\sqrt{K^2q^2(L-M)^2 + r^2K^2 - 2qrK^2(L-M) - 4\alpha rKM})'}{K^2q^2(L-M)^2 + r^2K^2 - 2qrK^2(L-M) - 4\alpha rKM}.$$

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

$$\frac{\partial^2 H}{\partial M^2} > 0 \Leftrightarrow [3Kq^2(L-M) - qrK + 2\alpha r] \cdot [q^2K(L-M)^2 + r^2K - 2qrK(L-M) - \\ -4\alpha rM] + (L-M)[Kq^2(L-M) - qrK + 2\alpha r]^2 > 0. \tag{18}$$

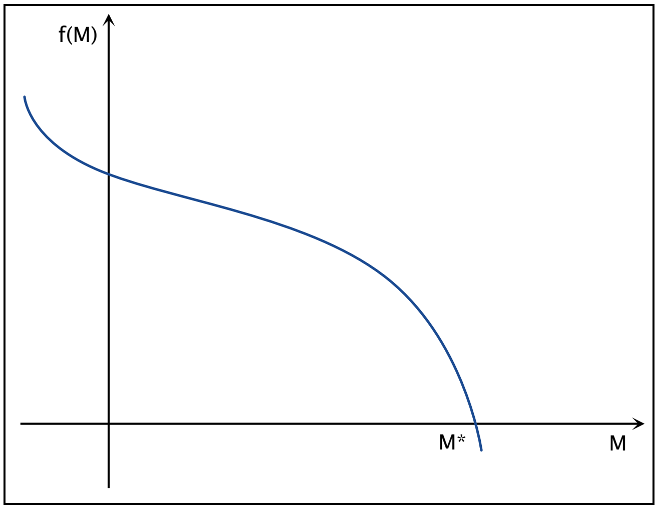

Figure A

After further manipulation, this simplifies to the condition that a cubic in M (denoted f(M) in the figure) be positive. 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 horizontal 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.[41]

B. This section 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 (11) into the relation between the relative price and the stock found in (4), we get the inverse supply function:

$$p = \frac{1}{qS^A} = \frac{2r/q}{\sqrt{[q(L-M)-r]^2K^2 - 4r\alpha KM} - [q(L-M)-r]K} \tag{19}$$

where p is a function of the inverse of the stock level S^A. Note that the inverse supply function

[41] We have assumed that parameter values are such that M^*¡L, or the inflection point on the PPF is 'interior.'

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:

$$\frac{2r}{K} \cdot \frac{\partial S^A}{\partial M} = \frac{2q[r - q(L-M)] - 4r\alpha/K}{\sqrt{[q(L-M)-r]^2 - 4r\alpha M/K}} + q. \tag{20}$$

A quick inspection of this equation reveals 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

$$M > L - \frac{r}{q} + \frac{2r\alpha}{q^2 K}. \tag{21}$$

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 lower than the sufficient condition above.

Then the inverse supply of M is 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 increasing returns to scale and 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.[42]

C. This section 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). For simplicity, suppose that the autarkic equilibrium is situated in the concave to the origin part

[42] The critical value beyond which the supply of M is necessarily upward sloping is called $\underline{\text{M}}$ in the paper.

of the long-run PPF.[43] Following the discussion of the efficiency of the autarkic equilibrium in the text, we also assume that, due to the externalities involved, the autarkic price line is steeper than the slope of the PPF at the equilibrium A^1: the market overvalues M-production compared to what is socially efficient.

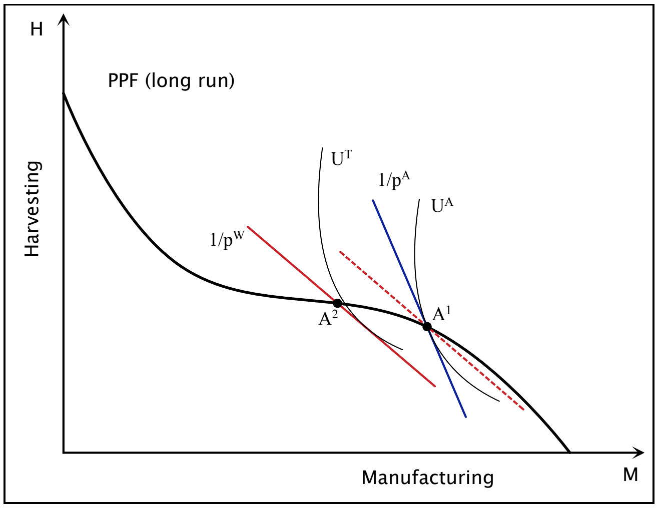

Figure C_1

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 A^2 to produce more H, 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 sector which is less productive, given the cross-sectoral externalities, i.e. H.[44] 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

[43] Note that equilibria in the convex part are unstable, due to the perverse supply behaviour with respect to price changes.

[44] See Choi and Yu, op. cit., p. 984 for a similar argument in a variable returns to scale context.

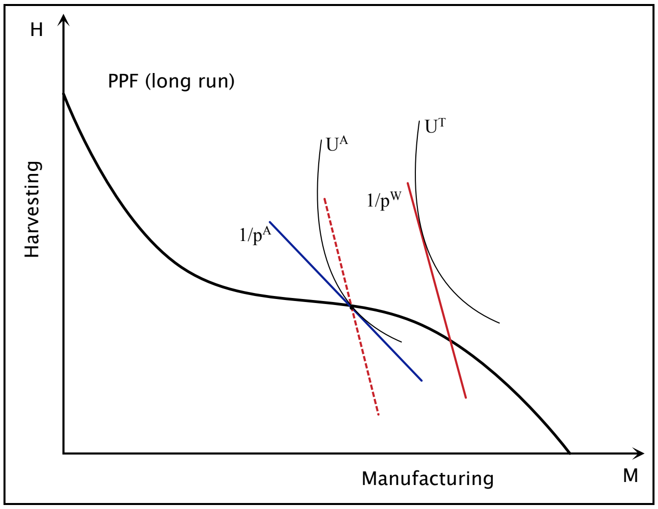

Figure C_2

is possible. Also, following specialization in M the economy can experience a long run gain in welfare.

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.

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