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**Sustainable Economic Development: On the
coexistence of Resource-Dependent and
Resource-Impacting Industries**

by

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Sustainable Economic Development: On the coexistence of Resource-Dependent and Resource-Impacting Industries

By

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Abstract. This paper studies the interactions between harvesters that depend on the renewable resource as a vital factor of production (i.e., fisheries) and industries that can have important impacts on the renewable resource but whose production does not depend on it (i.e., off-shore oil extraction) in the context of a growing economy. We examine these issues in the context of a closed economy focusing on how the co-existence between these two sectors affects the potential for sustainable development and how the well-being of the poor, i.e., the harvesters, is affected. We identify conditions under which existence and expansion of a resource-impacting sector may make sustainable development more likely. However, if these conditions are not met growth of the resource-impacting sector leads to resource depletion or even complete extinction and thus to the disappearance of the harvesting activity over the long run.

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Sustainable Economic Development: On the coexistence of Resource-Dependent and Resource-Impacting Industries

Many developing countries obtain a large share of their income from the harvesting of common-property or open access renewable natural resources, including fisheries, forests, grazing grounds, and water resources. The literature, originated in Gordon Scott's (1954) classical paper, has emphasized the effect of these activities on the renewable natural resources which in turn are a key factor of production. The issue is that these harvesting activities are not only resource-impacting but, most importantly, also highly resource-dependent. When the number of producers using open access resources is large there is overexploitation and excessive degradation of such resources that in the end makes producers poorer (the so-called "tragedy of the commons").

However, as this literature emphasizes, even in the complete open access case there are automatic mechanisms that place limits to the extent of resource degradation. The main reason for this is the high dependence of harvesting on the renewable resources; as the natural resource deteriorates productivity of the harvesting effort falls which in turn reduces the incentives to spend efforts in the harvesting of such resource. In the end there may be a long run equilibrium in which the level of harvesting of the resource is equal to the regeneration of the renewable resource and the value of the average product of effort in exploiting the resource is equal to the (opportunity) cost of such effort in alternative activities. At this point no further deterioration of the resource or of the income of the producers occurs. To emphasize the importance of the feedback productivity effects associated with the degradation of renewable resources as a stabilizing mechanism we call these activities "resource-dependent" sectors (or, at times, simply "harvesting" sectors).

The automatic resource stabilizing effect as considered in the standard literature implicitly assumes that the alternative activities that dictate the opportunity cost of effort do not rely on the renewable natural resource as a factor of production. Moreover, it must also be the case that the non-harvest production activities are not resource-impacting

either. In reality however many of the most important alternative production activities especially in developing countries, while not dependent on the renewable resources as a factor of production, do impact on them. Most industrial production as well as the extraction of exhaustible resources and energy production impact upon the renewable natural resources despite that the renewable resource is not a factor of production for these activities¹. Mining, coal extraction, hydroelectric power generation, various manufacturing activities as well as oil and gas extraction have led to the depletion of water supplies, water and soil contamination, flooding of large areas often formerly used by small producers, deforestation, destruction of fisheries, and more. Henceforth we call these industries “resource-impacting” sectors (or at times simply “industrial” sectors).

Since the resource-impacting sectors do not use the renewable resource as a factor of production the automatic equilibrating mechanism prevailing in the standard case of resource degradation by harvesters of such resources are in principle absent. The degradation of the renewable resource may not discourage the expansion of the resource-impacting activities. So even if there were a third sector that was neither resource dependent nor impacting there is no inherent mechanism that would limit production-induced damages upon the renewable resources caused by these sectors. Thus, the potential environmental destruction and consequent impoverishment of the resource harvesters could be much more serious in this case compared to the standard one. In the absence of regulation mitigating the impact effect of the resource-impacting sectors on the renewable resources the extent of the resource destruction could be much more intense and in principle even boundless. However, using a formal model we show below that the above intuition is not always right but we ascertain the specific conditions required for it to be in fact correct.

Another significant difference between resource-dependent and resource-impacting activities is that the former tend to involve very large numbers of mostly self-employed

¹ Some of these activities are dependent on the availability of underground exhaustible resources. Since the focus of this paper is on the renewable resources we assume that the availability exhaustible resources are plentiful. This assumption is consistent with recent findings suggesting that the potential limits to growth are not so much given by the availability of underground exhaustible resources but by the increasing scarcity of the (above-ground) renewable resources (Simpson, Toman, and Ayres, 2005).

and poor producers relying mainly on labor-intensive technologies while the latter are comprised of relatively few large firms that tend to be capital intensive. This is an important issue that the ensuing theoretical model highlights.

In general most resources of great economic importance are inherently open access.

The fact that the resource-dependent sector is composed of so many small producers renders almost impossible to regulate them. Also, as Partha Dasgupta has often emphasized the fact that most natural resources such as animals, insects, rivers, ground water, fish resources and the atmosphere are frequently mobile renders almost impossible to establish or enforce property rights (Dasgupta 2005)². The idea of setting property rights on these resources is a chimera and so is that concerning “optimal” taxes or regulations that could have a chance of effective enforcement.

By contrast, the fact that the resource-impacting sector is comprised of relatively few, large and highly visible firms would in principle facilitate regulating them, for example as some countries try it, by requiring environmental impact assessments as requisites to approve investment projects. Paradoxically, however, the very fact that these firms are large makes them economically and politically powerful which itself becomes an obstacle for their effective regulation. This is true for developing countries and even for a country as advanced as the U.S.A. as none other than President Obama has recently recognized in connection with the oil disaster in the Gulf of Mexico: “For too long ... there has been a cozy relationship between the industry and the [regulators] that permit them to drill...” (Washington Post, May 15, 2010). Similar remarks have been often made concerning other major disasters caused by other resource-impacting industries including coal mining. The regulators often sleep with the regulated. For these reasons we make no

² Two studies in Sub-Saharan Africa have empirically shown that even in cases where resources are not mobile (such as forests and woodlands) and are used by a restricted number of producers the management of these resources appear to reflect a negligible fraction of its true economic value (López 1997 and 1998). That is, property rights or community self-regulation appear to be mostly absent even under relatively favorable conditions regarding lack of mobility of the resource and limited access implying a common property but not open access resource. Common property in these cases is undistinguishable from open access from the point of view of resource management.

apologies for the assumption of open resource access made throughout the theoretical model³.

There is increasing empirical evidence regarding the importance of the non-harvesting yet renewable resource-impacting activities as a source of destruction of such resources (Engel and López, 2008). Documented cases include oil and gas extraction in the Amazon, Indonesia and Sub-Sahara Africa affecting forest and water resources seriously impairing the livelihood of local communities; mining in the arid deserts of Chile (mineral extraction and processing being highly intensive in the most scarce renewable resource, water) resulting in ground water depletion hurting hundreds of thousands of indigenous people that have been forced to migrate; oil and gas exploration in forests of Ecuador hurting renewable resource-dependent local communities for many years; gold extraction in the North of Chile and Argentina threatening a large glacier which is a vital source of irrigation and drinking water; coal extraction especially using mountain top removal which causes enormous negative impacts on forests and water resources⁴.

The impacts of oil spills on marine and other renewable natural resources are by now legendary. According to reports every year on average oil extraction in Nigeria causes one disaster as large as the Exxon Valdez one (Nwilo and Badejo, 2006). Some 230,000 cubic meters of oil -- from at least 300 spills -- contaminate the Niger Delta region annually (Moffat and Linden 1995). In Mexico, unregulated oil extraction has forced massive relocations and led to hazardous living conditions including the release of toxic substances and disruption of water supplies damaging crops and depleting fish populations (Chelala, 1998). In Ecuador, extremely high levels of water pollution affecting the livelihood of hundreds of thousand of people depending on harvesting

³ The case for using an assumption such as open access that is both a good approximation of reality and at the same time helps simplifying the theory is obviously highly compelling. By contrast, assuming instead fantasies such as “perfect property rights” or “optimal” regulation would not only further remove the model from reality but also render the analysis exceedingly more complicated thus contributing to obscure certain key mechanisms at work.

⁴ The impact of extractive activities on renewable resources are likely to be considerable, given that for example nearly one third of all active mines and exploration sites are located within areas of what are considered fragile ecosystems (Miranda et. al., 2003).

activities have been attributed to contamination from unlined waste pits created by Texaco's involvement in the Ecuadorian forests (Kane, 1996; Brooke, 1994)⁵.

Despite the empirical importance and potential conceptual ramifications of the existence of resource-impacting industrial or extractive sectors on the renewable resources and on the income of often poor harvesters, the modeling efforts have mostly ignored the interactions between resource-dependent and resource-impacting sectors. Some authors look at the management of the commons by harvesters in isolation from the rest of the economy and concentrate on factors that affect the management efficiency of the commons (Ostrom, 1990; Ostrom et.al. 1994; Baland and Platteau, 1997 and 1998). Other studies do consider general equilibrium interactions of the harvester sector with the "rest of the economy" but studies have often used models based in Brander and Taylor (1997) where the alternative sectors are "clean", i.e., they do not impact the resource stock (Brander and Taylor, 1998; Copeland and Taylor, 2009; and many others)⁶.

Moreover, this literature regards the "other" sector (in our case the resource-impacting sector) as static. It simply plays the role of competing for labor with the resource-dependent sector and thus dictating a fixed opportunity cost to the harvesters. By contrast, in our analysis the "rest of the economy" plays a much more fundamental role having its own endogenous dynamics, in turn triggered by the incentives to save and capital accumulation arising from the market equilibrium conditions. This endogenous dynamics plays a vital role as a source of economic development and in determining the sustainability characteristics of such development. The reason why we do this is because our focus is on characterizing the process of economic development rather than on static trade patterns as this literature does.

⁵ And certainly the most recent massive oil disaster in the Gulf of Mexico affecting fisheries and many other renewable resources in the USA serves as a reminder that the issue in which this paper focuses is important not just for developing countries but even for advanced economies which are often assumed to have "fixed" their property right problem.

⁶ Jinji (2006) who allows agriculture to compete for land with the forest sector in a small open economy may in certain respects be regarded as an exception within this literature. Smulders, et al. (2004) also allows for sectors competing for land. However, in both studies the competing sectors are "clean" in the sense that their production processes have no direct impact on the resource stock. In addition, the models do not allow for capital accumulation and economic growth.

This paper studies the interactions between harvesters that depend on the renewable resource as a vital factor of production and industries that can have important impacts on the renewable resource but whose production does not depend on it. We examine these issues in the context of a closed economy focusing on how the co-existence between these two sectors affects the potential for sustainable development and how the well-being of the poor, i.e., the harvesters, is affected. The industrial resource-impacting sectors recruit their work force from the large number of harvesters and invest in physical capital. The expansion of the industrial sector directly impact on the resource causing its degradation. This in turn may reduce the productivity of harvesters and in principle make it possible for the industrial sector to pay lower wages. On the other hand, the fact that the industrial sector pulls labor out of the harvesting sector has the opposite effect on the natural resource by decreasing harvesting pressures. A third aspect to consider in the analysis is the fact that the expansion of the industrial sector also causes the price of the harvested good to increase in a closed economy or in an open economy able to influence world prices. The price effect makes recruitment of harvesters a bit more expensive to the industrial firms and at least partly mitigates the possible income losses that harvesters could suffer as a consequence of the degradation of the natural resource.

The production sectors

We consider two production sectors, a resource-dependent or harvesting sector and the resource-impacting or industrial sector. The natural resource is under open access regime. To emphasize the differences in capital intensity between the two sectors we assume that the resource-dependent sector uses only labor and the natural resource as factors of production while production of the resource-impacting sector uses both labor and capital. We assume that harvesting of the renewable resource is carried out according to the standard production function originally proposed by Schaefer (1957) and subsequently used by many other authors (i.e., Copeland and Taylor, 2009; Brander and Taylor, 1998; Clark, 1990, and many others),

$$(1) \quad H = ANL_E,$$

where N is the stock of natural resource, L_E is the level of employment in the sector and A is a fixed productivity factor.

The resource-impacting sector is capital intensive so its production uses capital in addition to labor. We assume a Leontief production function for this sector⁷,

$$(2) \quad M = D \min \left\{ K, \frac{L_M}{\psi} \right\},$$

where M is output level, K is the stock of capital used by the resource-impacting sector, L_M is labor, D is a productivity parameter and ψ is the labor-to-output ratio. Given that we have normalized the capital-output ratio to one (one over D indeed), ψ is also the labor to capital ratio. That is,

$$(3) \quad (i) \quad M = DK ; \quad (ii) \quad L_M = \psi K$$

The total labor endowment of the economy is fixed at L so that the employment level in the resource sector is $L_E = L - L_M$. The resource-dependent sector picks up whatever labor is not employed by the industrial sector. Using (3ii) we have that

$$(4) \quad L_E = L - \psi K$$

The natural resource stock is subject to the following dynamics,

$$(5) \quad \dot{N} = g(N) - H - \phi M$$

Where N is the stock of renewable resources is, $g(N)$ is a function representing the natural renewable of the resource, and the parameter ϕ represents the *resource impact factor* of the industrial sector production. The most important difference between this

⁷ The Leontief production function restricts the labor-capital production flexibility but since the capital-labor substitution is not the focus of this paper we use this specification because it allows us to minimize unnecessary algebraic clutter and, more importantly, it allows us to present the results using fairly simple phase diagrams. The reader may however verify that all the qualitative results remain intact if we use a more conventional production function such as a Cobb-Douglas one.

formulation and the standard one is that (5) allows for the industrial sector to impact on the renewable natural resource stock despite that its production does not depend on it.

We specify the standard logistic model for natural resource renewal function, $g(N) = rN(1 - N/\bar{N})$, where r is the intrinsic growth rate of the natural resource and \bar{N} is the maximum carrying capacity of the natural system (Clark, 1990). Using (1), (3), and (4) in (5) we obtain an explicit representation of the resource dynamics,

$$(6) \quad \dot{N} = rN(1 - N/\bar{N}) - AN(L - \psi K) - \phi DK$$

The consumption sector

We assume that the representative consumer has the following indirect utility function,

$$(7) \quad U = \ln(\tilde{C}/e(p_1, p_2)),$$

where \tilde{C} is the total nominal consumption expenditure, p_1 and p_2 are the prices of the industrial good and resource good, respectively, and $e(p_1, p_2)$ is the (indirect) unit expenditure function or cost-of-living index (so that $\tilde{C}/e(p_1, p_2)$ is the real level of consumption). Preferences are assumed to be Cob-Douglas which means that the unit expenditure function is also Cob-Douglas,

$$(8) \quad e = p_1^\beta p_2^{1-\beta},$$

where β is the fixed expenditure share of the industrial good and $1 - \beta$ is the share of the resource good in the consumer budget.

Using Royce identity we can derive the consumer demands for the two goods,

$$(9) \quad M^D = -\frac{\partial U / \partial p_1}{\partial U / \partial \tilde{C}} = \beta C$$

$$(10) \quad H^D = -\frac{\partial U / \partial p_2}{\partial U / \partial \tilde{C}} = (1 - \beta)C / p$$

In (9) and (10) we have normalized by the price of the industrial good so that $C \equiv \tilde{C} / p_1$ is the total consumption expenditure in units of the industrial good and $p \equiv p_2 / p_1$ is the relative price of the resource good.

Market equilibrium conditions

Since the two sectors compete for labor we have that both sectors have to pay the competitive wage rate which is equal to the average value product of labor in the resource sector. That is, w , the wage rate (in units of the industrial good) is

$$(11) \quad w = pAN ,$$

The market clearing condition for the resource-dependent or harvested good requires that,

$$(12) \quad (1 - \beta)C / p = ANL_E$$

The industrial good is assumed to provide the material goods for new capital investments as well as for consumer good. Hence, production of the resource-impacting or industrial good must be equal to the consumer demand for the good plus the capital investment.

Thus, using (3i) and (9) we have,

$$(13) \quad \beta C + I = DK ,$$

where I is gross investment in new capital.

Finally, the level of investment demand is assumed to be determined by the level of profits in the industrial sector, where profits $\pi = DK - wL_M$. Thus we have,

$$(14) \quad I^D = s[DK - wL_M] ,$$

where $1 > s > 0$ is a fixed parameter that can be interpreted as the rate of savings out of profits. That is, we are assuming that the economy is poor so that workers whether in the resource-dependent or in the resource-impacting sector do not save. Only capitalists save part of their profits⁸.

⁸ The reader may verify that the ensuing qualitative results would not change if we allowed workers to also save and if we allow for the rate of savings (s) to be endogenous. These assumptions allow us to focus on the key implications of the analysis saving unnecessary complications.

Equilibrium in the industrial good sector implies that $I = I^D$, which using (13) and (14) imply that,

$$(15) \quad (1-s)DK + swL_M = \beta C$$

Finally, the change of the stock of capital over time is,

$$(16) \quad \dot{K} = I - \delta K,$$

where δ is the rate of depreciation of the stock of capital.

Solving the temporary equilibrium

The equilibrium conditions (11) to (15) in conjunction with the labor market equilibrium condition given by (4) solve for the temporary equilibrium values of the six endogenous variables, w, C, p, L_E, L_M, I . This is a temporary equilibrium solution in the sense that the solution values are all conditional on the initial levels of the stocks of capital and natural resources, K and N . The subsequent dynamics of these stocks in turn is determined by the temporary equilibrium values of the above-mentioned endogenous variables.

Using (11) and (12) in (13), we obtain,

$$(17) \quad I = DK - \frac{\beta}{(1-\beta)} pANL_E.$$

Combining (4), (17) and (14) we solve for the equilibrium level of the wage rate, pAN ,

$$(18) \quad pAN = \frac{(1-\beta)(1-s)DK}{\beta(L - (1-s)\psi K)}$$

Thus, as expected, the equilibrium level of the wage rate is increasing in K and decreasing in the size of the labor force, L . Equation (18) also implies the reasonable result that p is decreasing in N and L and increasing in K .

We use (3i), (3ii), (11) and (18) to obtain the equilibrium level of profits,

$$(19) \quad \pi = \frac{\beta L - (1-s)\psi K}{\beta[L - (1-s)\psi K]} DK$$

An important result emanating from (18) is that the per capita income of workers engage in harvesting activities (equal to pAN) is increasing in K . This is true regardless of the

impact of K on the stock of natural resources. Even if the expansion of the industrial sector associated with a higher level of K causes the natural resources to contract, the income of the harvesters increases. The reason for this is that any fall in N would be compensated by a more than proportional rise of the price of the harvested good that a higher K causes. What happens is that the increase in K has both a cost push and a demand effect that magnify the impact on p .

The dynamics of the stock of capital

Using (14), (16) and (18) (noting that $w = pAN$) we obtain the capital accumulation equation,

$$(20) \quad \dot{K} = \frac{s(\beta L - (1-s)\psi K)}{\beta(L - (1-s)\psi K)} DK - \delta K,$$

or, equivalently, the rate of capital accumulation, $\hat{K} \equiv \dot{K} / K$, is,

$$(20i) \quad \hat{K} = \frac{s(\beta L - (1-s)\psi K)}{\beta(L - (1-s)\psi K)} D - \delta$$

Equations (20) or (20i) characterize the dynamics of the capital stock. From (20i) it follows that there is a unique level of K at which $\dot{K} = 0$,

$$(21) \quad K^* = \frac{(sD - \delta)\beta L}{(sD - \beta\delta)(1-s)\psi}$$

In (21) the long run the equilibrium level K^* is positive as long as $sD - \delta > 0$; that is, if the rate of savings per unit of capital is greater than the rate of depreciation of capital. Moreover, from (20) it is easy to see that $\dot{K} > 0$ if $K < K^*$ and $\dot{K} < 0$ if $K > K^*$. That is, the dynamics of the capital stock is quite straightforward: There is a unique level of K at which capital becomes constant and the stock of capital will globally converge to such equilibrium level. We now turn to the characterization of the dynamics of the stock of natural resource.

The natural resource dynamics

Long run equilibrium in the resource sector implies that $\dot{N} = 0$. Hence using (6) we have,

$$(22) \quad rN(1 - N/\bar{N}) - AN(L - \psi K) - \phi DK = 0$$

Define, the level of N that would prevail if $K=0$ as \tilde{N} ,

$$(23) \quad \tilde{N} = \frac{r - AL}{r} \bar{N}.$$

Then we can rewrite (22) as follows,

$$(24) \quad (\tilde{N} - N) \frac{r}{\bar{N}} = (\phi D - \psi AN) \frac{K}{N}$$

The key implication of (24) is the following: Suppose that $\phi D - \psi A\tilde{N} > 0$ in which case it must also be true for any $N \leq \tilde{N}$. Then for positive values of K and N it must be the case that in fact $N \leq \tilde{N}$. The opposite happens if $\phi D - \psi A\tilde{N} < 0$; now it must be that $N \geq \tilde{N}$. From (24) it follows that along the $\dot{N} = 0$ schedule we have that

$$(25) \quad K = \frac{(\tilde{N} - N)rN}{(\phi D - \psi AN)\bar{N}}$$

Thus we have: (i) However, if $\psi A\tilde{N} < \phi D$ then the $\dot{N} = 0$ schedule would require that $K < 0$ for any $N \geq \tilde{N}$. Hence, in this case we need that $N \leq \tilde{N}$. In this case the $\dot{N} = 0$ schedule has a segment that is downward-sloping and another one that is upward-sloping. (ii) If $\psi A\tilde{N} > \phi D$ then the $\dot{N} = 0$ schedule is consistent with $K > 0$ only if $N \geq \tilde{N}$. In this case the $\dot{N} = 0$ schedule is upward sloping. Below we characterize the $\dot{N} = 0$ schedule for each case.

The economic meaning of all this can be made clear by the following experiment: Suppose that initially $K = \varepsilon$ where ε is an arbitrary small number as close to zero as possible (but not quite zero because in a closed economy we need a positive level of both outputs). Then \tilde{N} is an approximation to the equilibrium level of N that prevails when the resource-impacting or industrial sector is minimal and almost all the labor force is employed in the resource-dependent or harvesting sector. The term $\phi D - \psi A\tilde{N}$ represents the net marginal effect of expanding the industrial sector (i.e., of increasing K) on the natural resource at this point. It is comprised of the direct impact effect (ϕD)

which is always positive and the indirect impact $(-\psi AN)$ caused by the fact that an expansion of the industrial sector causes a reduction in the level of employment in the harvesting sector which in turn reduces pressure on the natural resource. Cases (i) and (ii) above represent the cases when the net impact of K on N is negative and positive, respectively. So in case (i) capital accumulation starting when $N \approx \tilde{N}$ causes N to fall while the opposite happens in case (ii).

1. Case (i): the net impact of the industrial sector is to increase resource pressure ($\psi A\tilde{N} < \phi D$).

If the net effect of the industrial sector is to increase resource pressure then the $\dot{N} = 0$ schedule as shown in (25) must lie completely on the left of \tilde{N} for positive levels of K ; that is, it is defined only for $N \leq \tilde{N}$. From (25) it follows that along the $\dot{N} = 0$ schedule we have that $K=0$ if either $N = \tilde{N}$ or $N=0$. Also, the slope of the $\dot{N} = 0$ curve is negative when evaluated at $N = \tilde{N}$ and it is positive when evaluated at $N=0$. Finally as we show below the $\dot{N} = 0$ curve reaches a maximum at a unique level of N , which means that this curve has an inverted U shape. The $\dot{N} = 0$ curve in Figures 1A and 1B is drawn consistent with this characterization.

Figure 1A shows the case when sustainable development is possible. Importantly, in this Figure K^* is below the maximum height of the $\dot{N} = 0$ curve. The long run equilibrium of the system is shown in Figure 1A by the coordinates labeled N^* and K^* which simultaneously satisfy the conditions $\dot{K} = 0$ and $\dot{N} = 0$. There is another level of the resource that also satisfies this condition but it can be easily seen that such equilibrium is unstable. The arrows show the motion of the system outside steady state. As can be seen in Figure 1A, for levels of K above those required by the $\dot{N} = 0$ condition the stock of the resource declines and it increases for levels of K below the $\dot{N} = 0$ curve. This can be easily seen by inspecting (22) and is due to the fact that in this case $\psi A\tilde{N} < \phi D$. Also, as discussed in the previous section the dynamics of the stock of capital as shown by (20)

implies that K increases (decreases) if $K < K^*$ ($K > K^*$) regardless of the level of N . Thus, the $\dot{K} = 0$ schedule is a horizontal line in the $K - N$ space as drawn in the Figures.

We now turn to determine the maximum height of the $\dot{N} = 0$ curve. Differentiating (25) and making the derivative expression equal to zero we find the critical level of N at which this curve reaches its maximum height is,

$$(26) \quad N^C = \frac{\phi D}{\psi A} \left[1 - \sqrt{1 - \frac{\psi A \tilde{N}}{\phi D}} \right]$$

We note that the solution is real because Case (i) implies that $\frac{\psi A \tilde{N}}{\phi D} < 1$. Also consistent

with this case we have chosen the negative root solution because $N^C < \tilde{N} < \frac{\phi D}{\psi A}$.

The maximum level of K consistent with the $\dot{N} = 0$ condition is obtained by using (26) in equation (25),

$$(27) \quad K^C = \frac{(\tilde{N} - N^C) r N^C}{(\phi D - \psi A N^C) \tilde{N}}$$

The key issue is whether K^* as defined by (21) is above or below K^C . If $K^* < K^C$ as in Figure 1A sustainable development is possible; that is, $\lim_{t \rightarrow \infty} N(t) = N^* > 0$. However, if $K^* > K^C$, then sustainable development is not possible; that is, in this case $\lim_{t \rightarrow \infty} N(t) = 0$.

The level of the resource continuously fall (and p continuously increases) over time.

Figure 1B shows the case where when $K^* < K^C$. Now (unlike the case drawn in Figure 1A) the system cannot achieve sustainable equilibrium over the long run. The arrow line ZK^* represents a possible (unsustainable) pathway for an economy that starts with a low level of capital and a relatively high endowment of N . Comparing (21) and (27) (using (26)) it can be appreciated that the likelihood of unsustainable development is increasing with the economy's saving rate (s), with the share of the industrial good in the consumer budget (β), and with the gross or direct resource impact effect of K (ϕD), and

decreasing in ψA . Also, the population size (L) increases the risks of unsustainable development because L increases K^* and reduces K^C through its effect on \tilde{N} .

2. *Case (ii): the net impact of the industrial sector is to reduce resource pressure* ($\psi A \tilde{N} > \phi D$).

Figure 2 depicts this case. The $\dot{N} = 0$ schedule is now upward-sloping for all $\tilde{N} \leq N \leq \bar{N}$ ⁹. Hence, as shown in the Figure 2 in this case development is always sustainable. If the K^* is sufficiently large then $\lim_{t \rightarrow \infty} N(t) = \bar{N}$. In this figure the long run equilibrium is shown at K^* and N^* . The motion outside the steady state is shown by the arrows. The most important difference with figures 1A and 1B is that unlike Case (i) now the stock of the resource is increasing for levels of K greater than those required by the $\dot{N} = 0$ condition. This is very important: Now, in contrast with Case (i), the dynamics of the natural resource implies that accumulation of capital causes the resource stock to expand rather than fall. If the economy emerges from near zero capital stock (and from $N \approx \tilde{N}$), its accumulation leads to increase the stock of natural resource. A condition that remains in place for all $N \geq \tilde{N}$.

Importantly, in the cases represented by both Figures 1A or Figure 2 the convergence toward sustainable long run equilibrium may not be monotonic. Various types of approaches could occur including convergent cyclical paths.

Summary of the main results

The main findings of this paper are the following:

1. The expansion of the resource-impacting or industrial sector does not necessarily reduce the equilibrium stock of renewable natural resources and does not

⁹ The critical, $N^C = \frac{\phi D}{\psi A} \left[1 + \sqrt{1 - \frac{\psi A \tilde{N}}{\phi D}} \right]$, is in this case imaginary; this means that for any real-valued

number within the $\tilde{N} \leq N \leq \bar{N}$ interval the $\dot{N} = 0$ curve has to be increasing.

necessarily threatens sustainable development even under conditions of non-existing property rights on the natural resources as we assume in this paper.

2. We have elucidated the precise condition that determines whether the industrial sector expansion reduces or increases the equilibrium level of the natural resource: If $\psi A \tilde{N} \equiv \psi A(r - AL)\bar{N} / r > \phi D$ then the industrial sector expansion is consistent with an improvement of the natural resources. That is, capital and the natural resource are complements. However, if such inequality is reversed then the long run equilibrium level of the resource stock falls with the degree of industrial development. Capital and natural resources in the latter case are substitutes at least within the economically relevant ranges.
3. However, if $\psi A(r - AL)\bar{N} / r < \phi D$ not only is the long run level of the natural resource lower but it is also likely that the industrial sector may threaten the sustainability of economic development.
4. The likelihood of unsustainable development decreases with the resiliency of the natural resource represented by its intrinsic natural growth rate (r) and maximum carrying capacity (\bar{N}), and increases with the size of the labor force (L), with the productivity of the industrial sector (D) and with its marginal environmental impact effect (ϕ).
5. Whether the expansion of the industrial sector hurts or benefits the renewable resources the per capita income of the harvesters whose output directly depends on the natural resource necessarily rises with the industrial expansion.

Thus, the analysis yields some surprising results. In particular the fact that the existence and expansion of a resource-impacting sector may under certain conditions make sustainable development more, not less likely is a surprising finding. Also, note that even if the direct resource impact effect of the industrial sector is in fact large (that is, if ϕD is large) the net effect of such sector on the natural resource can still be positive as long as the labor/capital ratio (ψ) is sufficiently high. However, if the net impact condition is reversed, which may happen when the gross resource impact effect of the industrial sector is very large and/or if the productivity (A) of the harvesters is very low, or if the

industrial sector is very capital intensive, then the expansion of the industrial sector will not only further degrade the natural resources over the long run but it may even threaten the very sustainability of economic development.

All this can happen while the income of the harvesters grows along the industrial development process. This by itself is not surprising. What is surprising is that this is true regardless of the gravity of the impact of the industrial sector upon the renewable resource stock. This result holds even if the industrial development causes unsustainable economic development.

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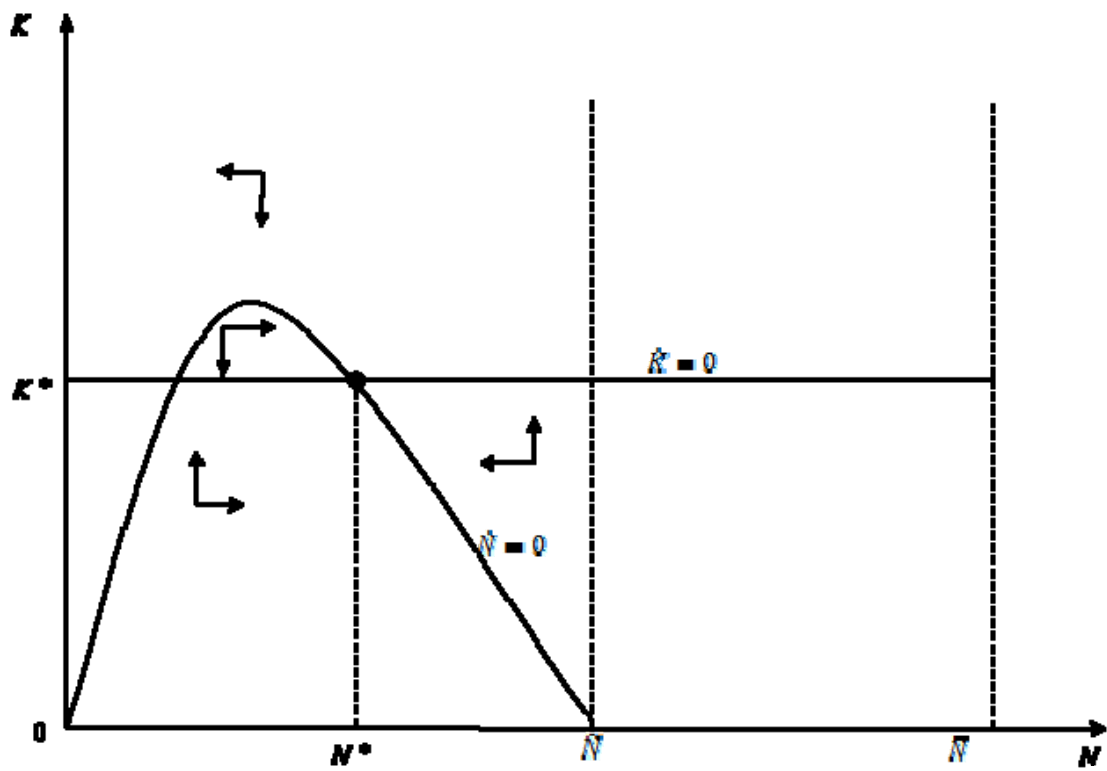


FIGURE 1A
Case 1: $A\psi\tilde{N} < \phi D$ with sustainable long-run equilibrium

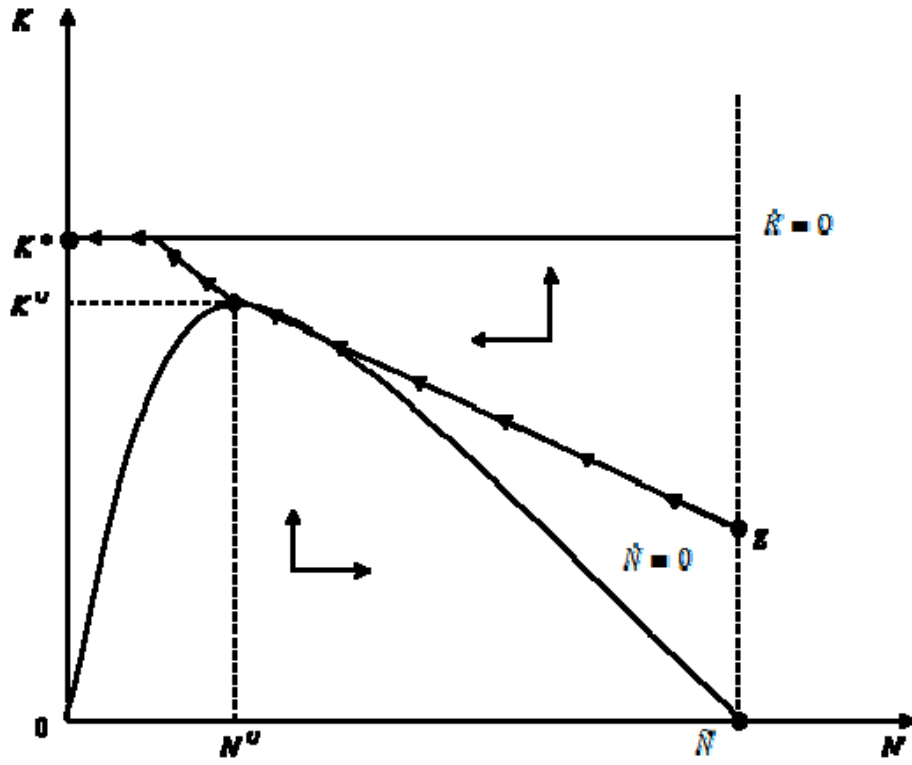


FIGURE 1B

Case 1: $A\psi\tilde{N} < \phi D$ with unsustainable long-run equilibrium

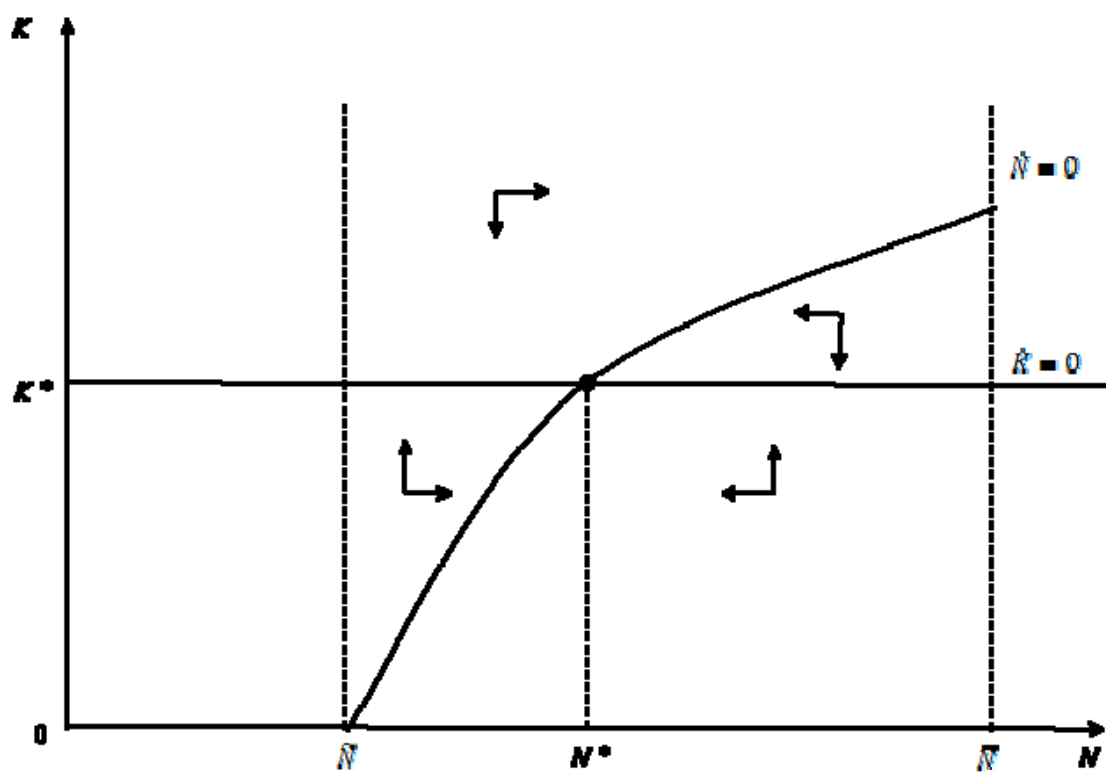


FIGURE 3
Case 2: $A\psi\tilde{N} > \phi D$. Sustainable long-run equilibrium.