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ABSTRACT

Trade and Migration with Renewable Natural Resources: Out-of-Steady-State Dynamics*

Commodity price increases associated with the entry of China, India and other countries into the world economy has led to increased pressure on common-property renewable natural resources (*NR*). The problem is particularly worrisome for economies that obtain a large share of their income from the exploitation of *NR* in the production of an exportable commodity. This paper contributes to the analysis by examining the issue in the framework of a general equilibrium dynamic model and by solving for both the steady state *and* the transition dynamics. We show that i) a resource-rich, capital-poor economy is more likely to be subject to a "natural resource curse" and complete (irreversible) *NR* depletion; ii) the latter's likelihood rises with the relative commodity price and labor inflow; iii) a labor inflow under internal equilibrium results in a *higher* steady-state capital-labor ratio and manufacturing output, and unchanged *NR* and commodity output; iv) import and export taxes result in a larger steady-state *NR* and commodity output and a smaller capital stock and manufacturing output, and may prevent complete *NR* depletion; and v) the latter may also be prevented through capital inflows (foreign aid) and labor outflow (openness by the North), improved regulation, technical change and a production tax.

JEL Classification: F22, O13, O15, Q17, Q27

Keywords: renewable natural resources, depletion, transition dynamics, steady state, trade, migration, capital flows

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I. Introduction

Many developing countries obtain a large share of their income from the exploitation of common-property renewable natural resources, including fisheries, forests, grazing grounds, and water resources. Their degradation has typically been caused by activities such as logging, agriculture, commercial fishing, and other.[1] It has also been associated with the extraction of exhaustible resources. For instance, mining and oil extraction has led to the depletion of water supplies, water contamination, deforestation, and more.[2]

As is well known, a lack of property rights for natural resources results in their excessive exploitation compared to the social optimum and thus in a higher rate of depletion and a smaller long-run (steady-state) stock. López (1998) estimates the losses from non-cooperative behavior on common-property lands and lack of internalization of the external costs of biomass use in land allocation decisions in Côte d'Ivoire to be as high as 14 percent of total village income. He finds that the degree of internalization of the negative externalities is less than 30 percent and declines with community size. López (1997) obtains similar estimates for the income loss in Ghana. These and other studies make it clear that the problem of imperfect property rights is of crucial importance for many countries and may even result in total depletion of the natural resource and disappearance of poor communities.

A large number of studies have examined communities that had been stable for long periods but then started a process of impoverishment that worsened over time (see the forthcoming paper by López for a review of such studies). These communities typically experienced important changes over time – such as an increase in population or in market size which resulted in increased pressure on the natural resource and a decline in the degree of internalization of the negative externalities – but failed to develop adequate institutions to deal with them.

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[1] The classic case of natural resource depletion is that of fisheries which has affected a large number of countries over the years and was the focus of early natural resource depletion studies (e.g., Gordon 1954, Scott 1955). An example is that of Peruvian anchovies whose world price increased dramatically in the late 1970s and early 1980s. This raised the incentive to invest in fishing boats, an investment subsidized by the government when a tax would have been optimal. The higher prices and subsidies led to a dramatic increase in the fishing fleet and the stock of anchovies disappeared for several years, leading to a decline in the use of these boats and thus in fishing. This enabled the anchovy stock to replenish over time.

[2] It is estimated that nearly one third of all active mines and exploration sites are located within areas of ecosystems with high conservation value (Miranda et. al., 2003).

Often located in tropical areas, land quality in such communities has typically been of poor quality, with natural resource depletion impeding regeneration of soil fertility and leading to further decline in their quality by hampering nutrients deeper in the soil to rise to the surface. The ensuing deforestation has, in extreme cases, led to the disappearance of entire communities. A well-known such case is that of Easter Island where excessive logging led to the disappearance of its population. A more recent one is the deforestation in low-lying areas in the Philippines, with some four million people moving from low-lying to high-lying areas in recent years to (Washington Post, February 23, 2009, pp. 1-2). Similarly, excessive pressure on natural resources has led to the advance of the Sahara and Gobi deserts.

This paper examines the welfare consequences of commodity production under a lack of property rights for natural resources. Unlike most previous studies that are based on static and partial equilibrium analysis, we focus on the dynamics of the economy's adjustment to changing conditions and policies, and explicitly account for general equilibrium interactions. We consider a two-sector economy where one of the productive sectors, the primary commodity-producing sector, is directly dependent on renewable natural resources. The economy uses three factors, labor, capital and natural resources. The first two are allocated competitively across the two sectors while the natural resource stock is exclusively used in the commodity-producing sector. The economy can save and invest its savings in expanding the stock of capital. The natural resource and capital stocks are determined endogenously and in turn determine the evolution of the economy.

An issue that has become a matter of increasing concern in recent years is the link between trade and the environment.[3] A common argument is that international trade has resulted in greater environmental degradation in developing countries. Existing studies have focused on long-run equilibrium effects but have not examined the adjustment dynamics to changes in the trade regime. This is likely to be a significant problem, particularly since shocks typically occur frequently and the economy rarely has time to reach its long-run equilibrium but rather tends to adjust to the various shocks while being in a disequilibrium situation. Moreover, introducing this type of analysis is critical as it allows for alternative long-run equilibria – such as the total depletion of natural resources

[3] For a good review and analysis of trade's environmental impact, see Copeland and Gulati (2004).

– that are not generated by models that focus exclusively on static or steady-state analysis.

This paper is a first effort to fill this important gap in the literature. We examine out-of-steady-state adjustments to changes in policy and other conditions, as well as their impact on the steady state. Policies considered include those affecting the international movement of goods and factors – including in- and out-migration and foreign aid – as well as regulation of natural resource use and technology designed to reduce the natural-resource intensity of commodity production. Changes in terms of trade are analyzed as well.

This issue is particularly relevant in the context of China, India and other countries' recent integration into the world market and the resulting boom in commodity prices and increased pressure on natural resources. The importance of this boom is illustrated by the fact that it affected a larger share of important commodities for the Latin America and Caribbean region than ever recorded in the past (World Bank, forthcoming). This phenomenon is expected to continue in the future due, first, to these countries' high expected growth rates and, second, to the associated massive internal (rural-urban) migration in a part of the world where over a third of the world's population resides together with the fact that per-capita commodity demand is substantially higher in urban than in rural areas.[4]

An analysis that emphasizes conditions outside long-run equilibrium in a context of two state variables (physical capital and natural resource) in a general equilibrium framework can be exceedingly complex. In order to keep the problem tractable, we provide a basic dynamic model with sufficient complexity needed to yield important insights on the behavior of the economy when subjected to a variety of shocks.

The remainder of the paper is organized as follows. Part II presents the benchmark model, Part III examines the transition path of a resource-rich, capital-poor economy, and Part IV examines the impact of trade policy, factor movement policy and other ones. Part V looks at the situation of environmental collapse and Part VI concludes.

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[4] Higher commodity demand implies higher derived demand for both renewable natural resources (for consumption, e.g., agricultural and fish products, and for production, e.g., wood and cellulose) and exhaustible resources (for production, housing, infrastructure, etc).

II. The benchmark model

The small open economy consists of two sectors, a resource-dependent commodity sector *C* and a manufacturing sector *S* that does not depend on the natural resource as an input. Each sector uses labor (*l*) and capital (*k*). The commodity sector also uses a renewable natural resource input, *n*, in addition to capital and labor. The production functions are:

(1) $$y_s = Ak_s^{\alpha} l_s^{1-\alpha}$$

(2) $$y_c = nDk_c^{\beta} l_c^{1-\beta}$$

where y_s and y_c are the output levels of the manufacturing and commodity goods, respectively ($0<\alpha<1,\ 0<\beta<1$) and *A* and *D* are fixed parameters. The natural resource enters the production of the commodity (equation (2)) in the way it is conventionally done in the literature (Gordon 1954, Schaefer 1957, Copeland and Taylor 1994, and many others).

The manufacturing (commodity) sector represents the modern urban (traditional rural) sector. We assume the modern sector is more capital intensive than the traditional one, i.e., we assume $\alpha > \beta$. The dynamics of the natural resource stock is given by

(3) $$\dot{n} = g(n) - \phi nDk_c^{\beta} l_c^{1-\beta}$$

The term $g(n)$ is the intrinsic growth function of the renewable natural resource. The second term represents the reduction of the natural resource stock due to production of the commodity good *C*. The parameter $0<\phi<1$ measures the intensity of the environmental demands per unit of *C*. We follow the literature and assume that the intrinsic growth of the natural resource takes the quadratic form

(4) $$g(n) = \gamma n(1-(n/\bar{n}),$$

where $\bar{n}$ is the maximum carrying capacity and $\gamma > y_c / n$[5] is a parameter.

The aggregate stock of physical capital grows according to:

(5) $$\dot{K} = Ak_s^{\alpha} l_s^{1-\alpha} + pnDk_c^{\beta} l_c^{1-\beta} - \delta K - c$$

[5] The condition $\gamma > y_c / n$ ensures a positive value for n in steady state, i.e., $n^* > 0$.

where p is the commodity market price (the manufacturing good price is normalized to 1), δ is the rate of capital depreciation, and $c \equiv c_s + pc_c$ is the total real consumption expenditures measured in units of the manufacturing good. The sum of the first two terms on the right-hand-side of equation (5) is the total real income of the economy, y, measured in units of the manufacturing good, with gross capital accumulation equal to savings y - c.[6]

Labor and capital markets are assumed perfectly competitive so that at any moment in time, the economy is in full employment and the stock of physical capital is fully utilized. We assume the total labor force L is fixed:

(6) $$l_c + l_s = L ,$$

(7) $$k_c + k_s = K .$$

As is well known, the behavior of a competitive economy can be replicated by a constrained optimum for the economy that maximizes the present value of welfare, subject to the parameters and institutional constraints. Among the institutional constraints, we assume that property rights on the natural resource are non-existent. That is, condition (3) above does not enter directly into the inter-temporal optimization process. However, it does show the evolution of the natural resource stock, an evolution which itself plays a central role in the dynamics and steady state of the economy.

We assume that the economy's indirect utility function is,

(8) $$u = u(c / e(1, p)) ,$$

where $e(1, p)$ is the unit expenditure function. The indirect utility function in (8) implies that the underlying direct utility function is homothetic. Also, u is assumed to be increasing and strictly concave in c. The indirect utility function implies that the consumer has already solved the static consumer problem by picking the optimal combination of c_s and c_c conditional on the price, p, and on a level of total consumption

[6] Equation (5) also represents the budget constraint of the economy. It reflects, in the context of an open economy, the trade balance equilibrium or, equivalently, the situation where the total value of domestic output is equal to the value of expenditures in consumption of the two goods plus investment, with differences between commodity (manufacturing) production and consumption exported (imported) at a fixed price.

expenditure, c [7]. The optimal level of c (and hence of capital accumulation) is determined by the inter-temporal optimization.

A competitive economy behaves "as if" it maximizes the present discounted value of the utility function, $\int_0^\infty u(c/e(1,p))\{\exp \rho t\}dt$ (ρ is the time discount rate), subject to the relevant economic and institutional constraints. It does so by choosing the levels of $c,\ l_c, l_s, k_c, k_s$ and investment $I \equiv \dot{K} + \delta K$ at each point in time subject to equations (5), (6) and (7), and subject to the given initial conditions $K(0) = K_0$ and $n(0) = n_0$. As a consequence of the institutional failure, the economy ignores the impact of its choices on the environmental dynamic represented by (3). However, the above choices do impinge upon the dynamics of the natural resource according to equation (3), which in turn carries implications for future choices. Thus, despite the assumption of competitive markets the existence of the institutional constraint associated with imperfect property rights on the natural resource implies that the solution to the optimization problem should be interpreted as the best path possible *given* the institutional imperfection.

This problem can be solved by maximizing the current value Hamiltonian

(9) $$H = u\left(c/e(1,p)\right) + \lambda\left[Ak_s^{\alpha} l_s^{1-\alpha} + pnDk_c^{\beta} l_c^{1-\beta} - \delta K - c\right]$$

where λ is the co-state variable of the capital stock. Assuming interior solutions, the first order conditions are:

(10) $$u_c(c/e(1,p)) = \lambda$$

(11) $$pnD(1-\beta)(k_c/l_c)^{\beta} = A(1-\alpha)(k_s/l_s)^{\alpha} \equiv w$$

(12) $$pnD\beta\left(k_c/l_c\right)^{\beta-1} = A\alpha\left(k_s/l_s\right)^{\alpha-1} \equiv r$$

(13) $$\dot{\lambda} = \lambda\left(\rho + \delta - A\alpha\left(k_s/l_s\right)^{\alpha-1}\right)$$

(14) $$\lim_{t\to\infty} e^{-\rho t}\lambda K = 0$$

where w and r are the market wage rate (in units of the manufacturing good) and the rental price of capital or interest rate, respectively[8]. Equations (11) and (12) indicate that

[7] In fact, by Roy's identity, one can retrieve the optimal conditional consumption bundle from the indirect utility function.

factor returns in competitive markets are equal to their respective marginal value products and, given factor mobility, such returns are equalized across the sectors. Equation (10) shows the equalization between the marginal utility of current consumption and the shadow price of capital (or the present value of the utility derived from an extra unit of capital created by reducing current consumption). Equation (13) is the classical no-arbitrage condition reflecting temporary competitive equilibrium in the asset market. It states that the expected returns to holding one unit of capital (the interest rate, r, plus the expected capital gain, $\dot{\lambda}/\lambda$) must be equal to the marginal cost of holding one unit of capital (the capital depreciation rate, δ, plus the opportunity cost, ρ).

Dividing (11) by (12), we obtain:

$$\frac{k_c}{l_c} = \frac{\beta(1-\alpha)}{\alpha(1-\beta)}\frac{k_s}{l_s} \equiv \Psi \frac{k_s}{l_s}. \tag{15}$$

Given the assumption that $\alpha > \beta$, it follows that $\psi < 1$. Substituting equation (15) in equation (12), we can obtain an expression for the capital/labor ratio in the commodity sector as a function of the stock of natural resources and various parameters, i.e.:

$$\frac{k_c}{l_c} = \left[\left(\frac{1-\beta}{1-\alpha}\right)^{1-\alpha}\left(\frac{\beta}{\alpha}\right)^{\alpha}\frac{D}{A}\right]^{\frac{1}{\alpha-\beta}}(pn)^{\frac{1}{\alpha-\beta}} \tag{16}$$

Thus, equations (15) and (16) solve for the capital-labor ratios in each industry as a function of the relative commodity price, fixed parameters, and the natural resource stock, n. The fact that the two capital-labor ratios are functions of $n(t)$ determines their evolution over time. The capital-labor ratios are increasing in *n*, the commodity price *p* and total factor productivity (TFP) in the commodity sector (*D*), and decreasing in TFP in the manufacturing sector (*A*). Note that these ratios depend on the product *pn*, i.e., they are invariant to changes in *p* and *n* that keep *pn* unchanged.

The reason the capital-labor ratios are increasing in *n* is as follows. An increase in the natural resource stock raises the economy's demand for labor more than for capital

[8] An optimal path with perfect property rights on the natural resource would require that the selection of the control variables incorporate their effect on the changes of the natural resource stock (valued at its shadow price) in the optimization problem. An unrestricted optimum would thus need to consider an additional term, $\mu\dot{n}$ (where μ is the optimal shadow value of the stock of natural resources), in (9). Lack of property rights on the resource means that the economy behaves myopically with respect to the natural resource stock, i.e., as if μ = 0.

because the commodity sector is labor-intensive relative to the manufacturing sector ($\alpha > \beta$). This causes the wage rate to increase relative to the rental rate of capital and leads producers to select more capital-intensive techniques.[9]

With the definitions of factor prices w and r given in equations (11) and (12), and using equations (15) and (16), we obtain explicit expressions for the factor prices:

(17) $$w = (1-\alpha)A^{-\frac{\beta}{\alpha-\beta}}\left[\left(\frac{1-\beta}{1-\alpha}\right)^{1-\alpha}\left(\frac{\beta}{\alpha}\right)^{\alpha}\right]^{\frac{\alpha}{\alpha-\beta}}(Dpn)^{\frac{\alpha}{\alpha-\beta}}$$

(18) $$r = \alpha\psi^{1-\alpha}A^{\frac{1-\beta}{\alpha-\beta}}\left[\left(\frac{1-\beta}{1-\alpha}\right)^{1-\alpha}\left(\frac{\beta}{\alpha}\right)^{\alpha}\right]^{\frac{\alpha-1}{\alpha-\beta}}(Dpn)^{\frac{\alpha-1}{\alpha-\beta}}$$

More succinctly, we can write the factor prices as

(19) (i) $w = w(Dpn, A)$, (ii) $r = r(Dpn, A)$,

with $w_1(Dpn, A) > 0$, $w_2 < 0$ and $r_1(Dpn, A) < 0$, $r_2 > 0$ (where subscripts denote first derivatives). Factor prices also follow a dynamic path over time as they are functions of the evolution of the *NR* stock. Thus, since $\alpha > \beta$, it follows that the wage rate (interest rate) is increasing (decreasing) in $n(t)$, p and *D*, and decreasing (increasing) in A.

As is well known, the total level of income in the economy (in units of the manufacturing output) can be expressed in terms of the value of output ($y = y_s + py_c$) or, equivalently, of the total factor returns. Thus, using (19), it follows that total economy's income (y) is

(20) $$y(pn, K; L) = w(Dpn, A)L + r(Dpn, A)K$$

where the income or (dual) revenue function y is increasing in K and L. Moreover, the dual revenue function must be increasing and convex in p, and the first derivative of the income function with respect to p is equal to the commodity output level, by the so-called Hotelling's lemma (Diewert, 1981); that is, $\partial y / \partial p \equiv y_1(pn, K : L)n = y_c$. This means that the net effect of p on national income must be positive, which in turn also

[9] Despite unchanged quantities of labor and capital (in the short run), capital-labor intensities can increase in both sectors due to a change in output composition, with competitive forces leading to the contraction of the capital-intensive manufacturing sector and the expansion of the labor-intensive commodity sector.

means that the national income function is increasing in n (that is, the positive wage effect associated with a higher level of n dominates the negative capital price effect). Moreover, the convexity of the national income function in the commodity price means that $\partial y_c / \partial p > 0$, i.e., commodity output increases in its price. This also means that y_c is increasing in n. Specifically, we can write y_c as the first derivative of (20) with respect to p, i.e.:

(21) $$y_c(p,n,K;L) = w_1(Dpn,A)DnL + r_1(Dpn,A)DnK .$$

Since $w_1 > 0$ and $r_1 < 0$, it follows that y_c *increases* in L and *decreases* in *K*. The following lemma summarizes these results.

Lemma 1. *Assume the manufacturing sector is more capital intensive than the commodity sector. Then: (i) the economy's wage rate increases in the stock of natural resources and in the commodity price while the interest rate falls in the same variables, and (ii) production of primary commodities (manufacturing) is increasing (decreasing) in the resource stock and in the labor force and decreasing (increasing) in the stock of capital.*

Since both capital and resource stocks change endogenously over time, it follows that both factor prices and the level and composition of national income must also adjust over time. Before analyzing the dynamics of the system, it is convenient to consider its long run equilibrium or steady state.

1. <u>Steady State</u>

Let's re-write equation (13) using (19.ii),

(13') $$\dot{\lambda} = \lambda\left(\rho + \delta - r(Dpn,A)\right),$$

and the equation of motion of the natural resource, equation (4) as,

(4') $$\dot{n} = g(n) - \phi y_c(p,n,K;L)$$

We define the steady state using these two conditions: the interest rate (r) must be equal to the opportunity cost of capital ($\rho + \delta$) and the stock of natural resources must be constant, i.e., $\dot{\lambda} = \dot{n} = 0$. The first equality means that

(22) $$r(Dpn^*,A) = \rho + \delta$$

That is, there is a unique level of the natural resource stock, n^*, for which the rate of return on capital is equal to its opportunity cost. Setting $\dot{n} = 0$, we can solve equation (4') for the steady state level of capital, K^*:

(23) $$y_c(p, n^*, K^*; L) = g(n^*)/\phi$$

Equations (22) and (23) uniquely determine the steady-state levels of capital and natural resources K^* and n^*. It is clear that there is no net investment in steady state since, by (22), the rate of interest is just equal to the opportunity cost of capital, and by (23) the consumption of natural resources is just equal to its natural renewal.

Substituting (18) in (22), we can derive an explicit solution for n^*, namely:

(24) $$n^* = \frac{1}{Dzp}\left[\frac{\alpha\psi^{1-\alpha}}{\rho+\delta}\right]^{\frac{\alpha-\beta}{1-\alpha}} A^{\frac{1-\beta}{1-\alpha}},$$

where $z \equiv \left(\frac{1-\beta}{1-\alpha}\right)^{1-\alpha}\left(\frac{\beta}{\alpha}\right)^{\alpha}$. Based on (24), we have:

Lemma 2*. The steady state level of the stock of natural resources n^* under internal equilibrium is decreasing in the commodity price p, the discount rate ρ, the depreciation rate of capital δ and the commodity sector TFP, and is increasing in the manufacturing sector TFP. Interestingly, it is not affected by the size of the labor force L.*

Substituting (24) into (17), we obtain an explicit solution for the steady state level of the wage rate:

(25) $$w^* = (1-\alpha)\psi^{\alpha}\left[\frac{\alpha}{\rho+\delta}\right]^{\frac{\alpha}{1-\alpha}} A^{\frac{1}{1-\alpha}}$$

Thus, the steady state level of the wage rate is increasing in the manufacturing sector TFP and decreasing in the discount and depreciation rates but is unaffected by the commodity sector TFP. The reason for the latter is that $r^* = \rho + \delta$ is given in steady state, and since p is given as well, w^* is fully determined by the implicit zero profit condition of the manufacturing sector (needed for that sector to have a positive production level) and must therefore be independent of *D*. However, when *A* increases, since $r = r^*$ is given, w^* must increase.

2. Dynamics

Rewriting equations (3), (5) and (13), and using some of the results in Lemma 1, we have:

(26) $$\dot{n} = g\left(n\right) - \phi y_c(p, n, K; L)$$

(27) $$\dot{K} = y(pn, K; L) - \delta K - c(\lambda)$$

(28) $$\dot{\lambda} = \lambda\left(\rho + \delta - r(Dpn, A)\right)$$

We thus have two possible out-of-steady state conditions for the initial stock of natural resources *n*:

(i) If $n > n^*$, it follows from (22) and (28) that $r < \rho + \delta$, which implies that the economy has no incentive to invest in capital and hence $\dot{K} = -\delta K < 0$. And since there is no investment and therefore no savings, it follows that $c = Y(pn, K, \bar{L})$. The rate of growth of consumption is: $\dot{c}/c = -(1/a)\dot{\lambda}/\lambda = (1/a)[r(Dpn, A) - (\rho + \delta)] < 0$, where $a \equiv -cu_{cc}/u_c > 0$ is the elasticity of marginal utility, which is assumed constant;

(ii) If $n < n^* \Leftrightarrow r > \rho + \delta \Leftrightarrow \dot{K} > 0$. In addition, the rate of growth of consumption in this case is positive.

III. Transition path of a resource-rich, capital-poor economy

We now turn to the case of a prototype developing economy that is rich in natural resources and poor in capital, and examine the transition dynamics outside the steady state. The importance of the out-of-steady-state situation depends on the length of time an economy finds itself in such a situation – which is a function of the size and frequency of shocks to which the economy is subjected and on its speed of adjustment – as well as on the likelihood that the economy converges to a permanently inferior equilibrium.

The top panel of Figure 1 depicts the relationship between the rate of return on capital (or interest rate) *r* and the stock of natural resources *n*. The second panel in Figure 1 is a phase diagram depicting the dynamics of the system in the $\{K, n\}$ space. The third panel shows the dynamics of the adjustment in the $\{y_c, n\}$ space.

Consider the case of an economy that is initially rich in natural resources ($n(0) > n^*$) and poor in capital ($K(0) < K^*$), as illustrated by point M in the three panels of Figure 1. Since $n(0) > n^*$, it follows that $r(0) < \delta + \rho$ (equation 18). This implies that initially there is no investment in capital and $\dot{K} < 0$. Initial commodity output $y_c(0)$ must be above its steady-state level because $K(0) < K^*$ and $n(0) > n^*$, as shown by point M in the bottom panel.[10] The adjustment process goes through the following phases:

Phase I: The "Resource Curse"

The economy disinvests in capital (which falls at the rate of depreciation) and allows the natural resource endowment to degrade (see panel 2 in Figure 1). Hence, both output and consumption – which, in the absence of investment, is equal to output – fall. How long the economy will remain in such a situation will depend on the speed with which it adjusts when it is not in steady-state equilibrium.

Phase II: Economic Growth with Resource Degradation

The natural resource continues to degrade and the capital stock starts increasing. In this phase, $\dot{\lambda}$ is negative which, by (10), implies that consumption starts growing from a low initial level. As the economy is poor in capital, accumulation may be very slow and the adjustment path may be so flat that it never crosses the $\dot{n} = 0$ schedule. In this case, the economy follows a non-sustainable path that eventually leads to a total (and irreversible) depletion of the natural resource stock.

The likelihood of this outcome is enhanced if the $\dot{n} = 0$ schedule, the commodity price and the discount rate are higher, and if the economy is initially poorer (i.e., its level of capital is lower). These points are summarized in the following proposition:

***Proposition 1**. An economy is more likely to fall into a total and irreversible resource depletion trap the higher the commodity's environmental impact (ϕ), the discount rate and the relative commodity price (p), and the lower its capital stock and the intrinsic growth rate parameter (γ) of the natural resource.*

[10] Recall that y_c is increasing in n, and decreasing in K.

Proof: From (26), it follows that for a given level of n, the $\dot{n} = 0$ schedule requires a larger capital stock K – i.e., it is higher in Figure 1 – if ϕ and p are higher (because y_c increases with p and decreases with K). Also, the likelihood of reaching the resource depletion trap falls with the size of the initial capital stock. There are two reasons for this: first, the economy is more likely to be in or close to Phase III (see Figure 1) and, second, the adjustment path in Phase II is flatter for higher values of p and ϕ (the proof is available from the authors). $\otimes$

An important implication of Proposition 1 is that an economy in Phase II runs the risk of total and irreversible resource depletion. While this risk depends on initial conditions $n(0)$ and $K(0)$ and on technical conditions (i.e., on ϕ and γ) that are difficult to affect in the short run, it depends as well on conditions (e.g., the relative commodity price, p) that policy can impact directly. This is examined in Parts IV and V below.

Phase III: Economic Growth with Resource Recovery

Phase III in Figure 1 is characterized by growth of both the capital and natural resource stock, with consumption also growing in this phase. The capital stock is sufficiently large and commodity output is sufficiently small for the natural resource stock to start recovering. The system may converge directly to the steady state equilibrium; however, as shown in Figure 1, the capital stock and the natural resource stock may overshoot before convergence to the steady state is achieved.

IV. Trade and migration

We now proceed to examine the impact of a number of trade and factor movement policies on the economy's transition dynamics and steady state. Section 1 looks at the impact of an outflow of labor from the country under analysis to another developing country and Section 2 examines changes in trade policy.

1. South-South migration

Assume two small developing neighbors that are open to trade and are identical, except for TFP in the manufacturing sector (A) which is higher in the home (H) than in the foreign (F) country. Assume an internal equilibrium (the case of total depletion of the natural resource is examined below). Then, as shown by (24) and (25), the steady-state natural resource stock and wage rate are higher in H than in F, providing an incentive to emigrate from F to H. Suppose now that H opens its door to a fixed number of immigrants.

Long run effects

Neither the wage rate nor the natural resource stock is affected by immigration in the long run (see (24) and (25)) under an internal solution (an alternative solution is examined below). Since the steady-state level of the natural resource, n^*, is identical to the level prior to the inflow of immigrants, it follows that commodity output is the same as well since there is a unique level of output that can be supported by n^*.[11] Rewriting (23) and evaluating it at the steady state, we have:

(23') $$y_c(p, n^*, K; L) = L[w_1(Dpn^*, A)Dn^* + r_1(Dpn^*, A)Dn^*(K/L)]$$

As immigration causes an increase in the labor force *L*, the long-run level of commodity output can only remain constant if the capital-labor ratio of the economy increases. Since $w_1(Dpn^*, A) > 0$, an increase in *L* raises the level of y_c and, given that $r_1(Dpn^*, A) < 0$, *K/L* must increase to restore y_c to its original level, i.e., the economy must invest sufficient resources along the adjustment path to raise the long-run level of capital proportionately more than labor.[12]

Using (20), the total level of per capita income is

(20') $$y(pn^*, K; L)/L = w(Dpn^*, A) + r(Dpn^*, A)(K/L).$$

Since immigration raises the *K/L* ratio, it follows from (20') that it raises per capita income in the long run.

According to the Rybczynski Theorem, the labor-(capital-) intensive commodity sector expands (contracts) as the labor force increases. The reason we obtain different results is that the commodity sector uses a third factor of production, the natural resource,

[11] A lower (higher) level of output implies a positive (negative) natural resource growth rate.

[12] If *K* increases in the same proportion as *L*, so do y_c and y_s. From Rybczynski's Theorem, an increase in *K* lowers y_c and raises y_s. Thus, *K* must increase by a greater proportion than *L* (*K/L* must increase) in order to keep y_c unchanged.

which imposes a long-run constraint on the level of output of the commodity sector but not the manufacturing sector.

The following proposition summarizes immigration's long run effects.

Proposition 2. *The long-run effects of allowing entry by a limited number of workers into a small open economy under an internal solution are: (i) the stock of natural resources, the labor-intensive commodity sector output and the wage rate are unaffected; (ii) the capital/labor ratio, per-capita income and the capital-intensive manufacturing sector output increase.*

The economy may also converge to another long-run equilibrium. This is examined in (ii) below.

The adjustment process

The economy may follow one of two divergent paths in response to the labor inflow: (i) convergence to a new steady state with a positive stock of natural resources, or (ii) destruction of the natural resource. The transitional dynamics caused by the one-time influx of immigrants are depicted in Figures 2 and 3.

(i) *Internal steady-state equilibrium*: The economy is at a point such as *M* in Figure 2. Immigration raises commodity output y_c and reduces per capita output *y/L* (see (20')), and shifts the $\dot{n}=0$ schedule upwards. The natural resource stock falls, causing the rate of return to capital *r* to rise above its opportunity cost ($\rho+\delta$) and stimulating capital accumulation. Thus, the system moves up and to the left of *M* (Figure 2). The capital stock continues to grow, y_c starts declining (both because of the increase in *K* and decline in *n*) from the high level caused by immigration, and n continues to decline until the new $\dot{n}'=0$ schedule is reached. At that point, the higher capital stock has lowered y_c to the point where *n* starts recovering. At the new steady state (point *N*), the capital stock is equal to K_1^* and, since $r=\rho+\delta$, there is no further incentive to increase it.

(ii) *Natural resource depletion trap*: The fact that the $\dot{n}=0$ schedule shifts upwards means that migration raises the likelihood of an irreversible collapse of the natural resource (see Proposition 1). Thus, an economy in Phase II and on a sustainable path such as MN in Figure 3 may shift to an unsustainable path such as MF following the inflow of immigrants. Thus, analysis of the out-of-steady-state adjustment dynamics reveals a potential for bifurcation: depending on initial conditions, immigration will lead to different long-run equilibria, one of which is characterized by an irreversible depletion of the natural resource and no long-run commodity output.

These results are collected in the following proposition.

Proposition 3*. The effect of a one-time increase in the number of immigrants induces the economy to take one of two alternative adjustment paths, depending on initial conditions at the time migration takes place:(i) convergence to a new steady state characterized by a greater stock of capital and an unchanged natural resource stock (as in Proposition 2); or (ii) convergence towards a steady state characterized by an irreversible resource depletion if the capital stock is sufficiently small. Note that immigration reduces per capita output in the short-run but raises it in the long run.*

2. Trade policy

Assume the type of trade policy observed in many resource-rich low-income countries: protection for the import-competing manufacturing sector and/or export taxes on the primary or commodity sector.[13] A decrease in import tariffs or export taxes causes the relative commodity price p to increase, which, from (17) and (18), reduces the interest rate and raises the wage rate. Manufacturing output falls and commodity output increases, causing the natural resource stock to decline. As the interest rate is below capital's opportunity cost, investment is nil and the capital stock falls. That is, the increase in p moves the economy to Phase I, with smaller K and n values. As shown in Figure 4, the increase in p shifts the $\dot{K} = 0$ schedule to the left of and the $\dot{n} = 0$ schedule up. Thus, the steady-state level of the capital stock increases to K^{**} and the natural resource stock falls to n^{**} (see equation (22)).

Since both productive assets fall in Phase I, so does total output. As n declines, r increases and the gap $r - (\rho + \delta)$ declines, eventually reaching zero. At that point, K stops declining and as n continues to fall, r rises above $\rho + \delta$ and the economy starts investing. That is, the economy reaches Phase II where K increases and n continues to decline, with potential bifurcation: the larger the increase in p, the greater the upward shift of the $\dot{n} = 0$ schedule and the leftward shift of the $\dot{K} = 0$ schedule.

[13] Trade tax revenues are redistributed in a lump-sum fashion.

Thus, the greater the liberalization of trade, the greater the price increase, the lower the capital and natural resource stocks at the onset of Phase II and, as discussed in Section III, the greater the likelihood of a total resource depletion trap. This finding is supported by several case studies reported by Larson and Nash (2010) who state: "The studies provide examples of how new export-tied demands can arise along with incentives to rapidly diminish important environmental resources, sometimes in irreversible ways." [14]

Under internal equilibrium, the economy reaches n^{**} and K^{**}, and the long-run interest rate and wage rate return to their pre-trade reform levels.

The findings are collected in the following proposition:

Proposition 4. *Trade policy reform that raises the relative commodity price has one of two sets of long-run effects. If the price increase is below a critical level, not too large, the economy may converge to a long-run equilibrium where (a) the stock of natural resources is smaller but still positive; (b) the stock of capital is larger; (c) the wage rate and the rate of interest return to their pre-reform levels; and (d) the level of output of the capital-intensive sector increases and that of the labor-intensive commodity sector declines. On the other hand, if the price increase is sufficiently large, the economy may diverge into a steady state where the natural resource is irreversibly destroyed.*

V. Preventing environmental collapse

Various interventions designed to prevent a potential environmental collapse associated with commodity production are examined in this section.

1. The issue

At was shown in Part III, the natural resource stock falls in Phase II and only starts to increase once Phase III is reached. However, the economy may follow a less favorable path, with its natural resource stock totally depleted before it ever reaches Phase III.

This outcome is more likely when the negative impact of commodity production on the stock of natural resources is large and the exogenous regeneration rate of the natural resource is low, i.e., for a high value of parameter ϕ (equation (3)) and a low value of parameter γ (equation (4)). This outcome can be represented in the middle panel

[14] They add, however, that the result is also likely to depend on location-specific conditions.

of Figure 1 by a point on the vertical axis, for instance by $K(0)$. At that point, $\dot{n}$ continues to be negative and the stock of natural resources cannot regenerate.

Three types of policies to prevent this outcome are examined: trade policy, factor movement policy, and policies tackling the source of the externality directly. The first one is controlled by the country at risk and the second one by developed countries and international organizations. Recent commodity price increases associated with China and other Asian countries' entry into the world market have raised the pressure on natural resources and have thus increased the urgency of implementing such policies.

2. Trade and factor movement policies

This section examines the impact of goods and factor movement policies.

Trade policy

First, as described in Part IV, Section 2, the home country can impose an import tariff or, equivalently, an export tax. These trade taxes reduce commodity production and raise the stock of natural resources or slow down its decline. In terms of the middle panel of Figure 1, these programs result in a decline in the $\dot{n} = 0$ schedule. Thus, an economy that finds itself in Phase II would either be closer to reaching Phase III or would find itself in Phase III right away. This would depend on the size of the tariff or export tax that the country would impose.

Developing countries have typically favored the urban sector and have discriminated against the rural sector. This has been achieved through commodity export taxes as well as through tariffs or other barriers on manufacturing imports, thus turning the internal terms of trade against the output 'exported' by the rural to the urban sector.[15] In addition to being viewed as harmful from the distributional viewpoint, these trade policies have been thought to result in an inefficient allocation of resources. However,

[15] See Schiff and Valdés (1992) and Anderson (2006) for the impact of trade policy on relative prices in agriculture from 1960 forward.

under a lack of property rights, such policies might actually improve efficiency. Whether or not they do depends on the level at which the trade taxes are set.[16]

Factor movement policy

Policies regarding the movement of factors can also help prevent environmental collapse. Two policies are examined in this section, namely immigration policy and transfer of capital (foreign aid). These policies are under the control of the developed countries and the development community rather than under the control of the country at risk.

i. *Foreign aid*

By providing capital in the form of foreign aid to the country at risk, developed countries and international donor organizations can help raise manufacturing sector output, reduce commodity output and reduce natural resource depletion. Thus, foreign aid can move an economy in Phase II closer to Phase III – with a slowdown in natural resource depletion – or to Phase III right away under a sufficiently large inflow of capital and reverse the depletion. This analysis contributes to the ongoing debate as to whether foreign aid benefits or hurts developing countries by showing that it has a positive impact that had so far been ignored, an impact that is particularly important for poor countries that are highly dependent on natural resources.

ii. *Developed country immigration policy*

The second factor-movement policy examined consists of immigration policy liberalization by the developed destination countries. This also raises output in the manufacturing sector and reduces it in the commodity sector, thereby slowing down the depletion of natural resources or even reversing it under a sufficiently large outflow of labor, and reduces the likelihood of total natural resource depletion.

Moreover, the fact that South-North migrants send remittances to their country of origin means that migration results in a reduction in the labor force as well as in an

[16] For instance, any tax below the optimal one raises welfare above its level in the absence of the tax, while a tax above the optimum has an ambiguous welfare impact. A tax above the optimum exists where welfare is equal to that obtained in absence of the tax, and any tax below (above) it raises (lowers) welfare relative to its level in the absence of the tax.

increase in the stock of capital in the country of origin. In other words, the liberalization of immigration policy by the North has two beneficial effects on the country at risk since both the reduction in the labor force and the increase in the remittances-related stock of capital lead to a reduction in output in the commodity sector. Hence, one advantage for the North of liberalizing its immigration policy is that it generates a transfer of capital that is paid by the immigrants rather than by the North's taxpayers. The capital stock and the capital-labor ratio in the new steady state are smaller than in the initial steady state and thus so is per-capita income.

3. <u>Attacking the negative externality at the source</u>

A number of additional policies are likely to help reduce the depletion of the natural resource. Three policy measures are examined under this type of intervention, the first one depending at least in part on the international community and the others under the control of the country facing the problem. The first measure consists in using technology designed to reduce the environmental impact of commodity production, i.e., to reduce the value of parameter ϕ in equation (3). Donor countries as well as regional and multilateral institutions have been actively involved in knowledge development and knowledge diffusion programs designed to help developing countries reduce the destruction of renewable natural resources associated with the production of agricultural and other types of commodities, and have also been involved with the second policy measure, namely establishment of (better) regulations to deal with the negative externalities of commodity production.[17]

The reduction in the environmental demands of commodity production results in an increase in $\dot{n}$ (equation (3')), i.e., in a smaller decline or increase in the natural resource stock, thus raising the likelihood of reaching Phase III or of moving to Phase III

[17] For instance, Chile, Peru and Ecuador possess large fisheries and aquaculture but lack adequate regulatory systems. Overfishing in Peru caused a decline in the anchovy stock (exacerbated by the El Niño cycle) which took years to recover. And though the optimal policy would have been a production tax (or improved regulation), the problem was exacerbated by the subsidies given to the fleets. In Chile, the salmon production, which grew very rapidly in recent years, fell by at least 50 percent in 2009 due to the closely-located fish farms and high salmon density which led to the propagation of diseases, a situation which stands in stark contrast with Norway's strictly regulated industry. An example of involvement by international organizations is the World Bank support for the introduction of a vessel quota system in Peru's fishery, resulting in improved control of anchovy stocks and in increasing economic returns.

right away. As with trade policy, this lowers the $\dot{n}=0$ schedule (see middle panel of Figure 1) since the steady-state natural resource stock is now sustainable at a higher level of commodity production, i.e., with a lower stock of capital. Whether an economy that is in Phase II would be closer to reaching Phase III or move to Phase III right away would depend on the extent of the decline in the $\dot{n}=0$ schedule. This would obviously depend on the extent of reduction of parameter ϕ.

An economy that finds itself above the $g(n)$ schedule and with a stock of natural resources below n^* (see lower panel of Figure 1) is shown to have a transition path that ends up either with a steady-state natural resource stock n^* or with the disappearance of the natural resource stock. The reduction in parameter ϕ implies a reduction of ϕy_c in the economy's position in the (ϕy_c , n) space, with a greater likelihood that the transition path will lead to n^*. These results are collected in Proposition 5 below.

Third, the externality can also be resolved with an optimal production tax, which is preferable to optimal trade taxes since it does not distort the consumption choice. However, implementation of such a production tax is unfeasible in many developing countries, particularly where the sector consists of a large number of small producers.

The results are summarized in the following proposition.

Proposition 5. *Interventions by the countries at risk or by the international community that could help countries avoid a potential environmental collapse are: i) a tariff on imports or, equivalently, a tax on exports; ii)liberalization of the North's immigration policy with respect to the countries at risk; iii) increase in capital flows provided by donor countries and/or regional and multilateral organizations; iv) institutional reform regarding the regulation of commodity production; and iv) transfer and help with the use of technology designed to reduce the intensity of use and destruction of environmental inputs in production. A potential advantage of the liberalization of immigration policy by the North is that, in addition to reducing the labor force in the countries at risk, it would also result in a transfer of capital to them in the form of migrants' remittances.*

VI. Conclusion

This paper provided an analysis of the transition path and steady state outcome in response to various policies and exogenous shocks for a small open economy that obtains a large share of its income from the exploitation of a common-property renewable natural resource. An important contribution is the examination of the various issues in a general equilibrium small-open-economy model, as well as the complete characterization of the steady state and the out-of-steady-state dynamics. The importance of such a framework is revealed by the fact that it enabled the identification of path bifurcation and state dependence as likely prominent features. It was shown that dynamic forces might lead the economy to dramatically different steady states, one of which being characterized by a complete and irreversible depletion of the natural resource.

We examined variables that raise the likelihood that this outcome prevails, as well as policies designed to reduce the chances that it will, with the following results. An economy with a small endowment of capital is more likely to be subject to a "natural resource curse" and to complete natural resource depletion. The latter is also more likely under a higher relative commodity price and under an inflow of labor. A labor inflow results either in a *higher* steady-state capital-labor ratio and manufacturing output, and unchanged natural resource stock and commodity output, or in a total depletion of natural resources.

An import tariff or export tax results in a larger natural resource stock and steady-state commodity output, a smaller capital stock and manufacturing output, and reduces the likelihood of complete natural resource depletion. This may also be prevented through capital inflows (foreign aid), liberalization of immigration policies in developed countries, a production tax, development and diffusion of techniques that lower the natural-resource-intensity of production, and improved regulation.

The trade policy results yield a fundamental policy implication of the paper. Overemphasis on trade liberalization in poor countries with imperfect property rights with respect to natural resources is likely to be much riskier than for developed countries because of the latter's benefit from capital abundance, superior natural-resource-saving technology and better property rights. While increasing trade openness in developed countries may only cause a marginal reduction in the long-run state of natural resources, doing so in a poor natural-resource-dependent country may trigger a qualitative shift in the economy, with a devastating and irreversible impact on its natural resources, an outcome made more likely by the recent increases in commodity prices. Thus, the donor community should beware of automatically providing highly resource-dependent developing countries the type of advice that is valid for developed countries; rather, policymakers should be made aware of the risks associated with trade liberalization and incorporate them in their assessment of any trade reform under consideration.

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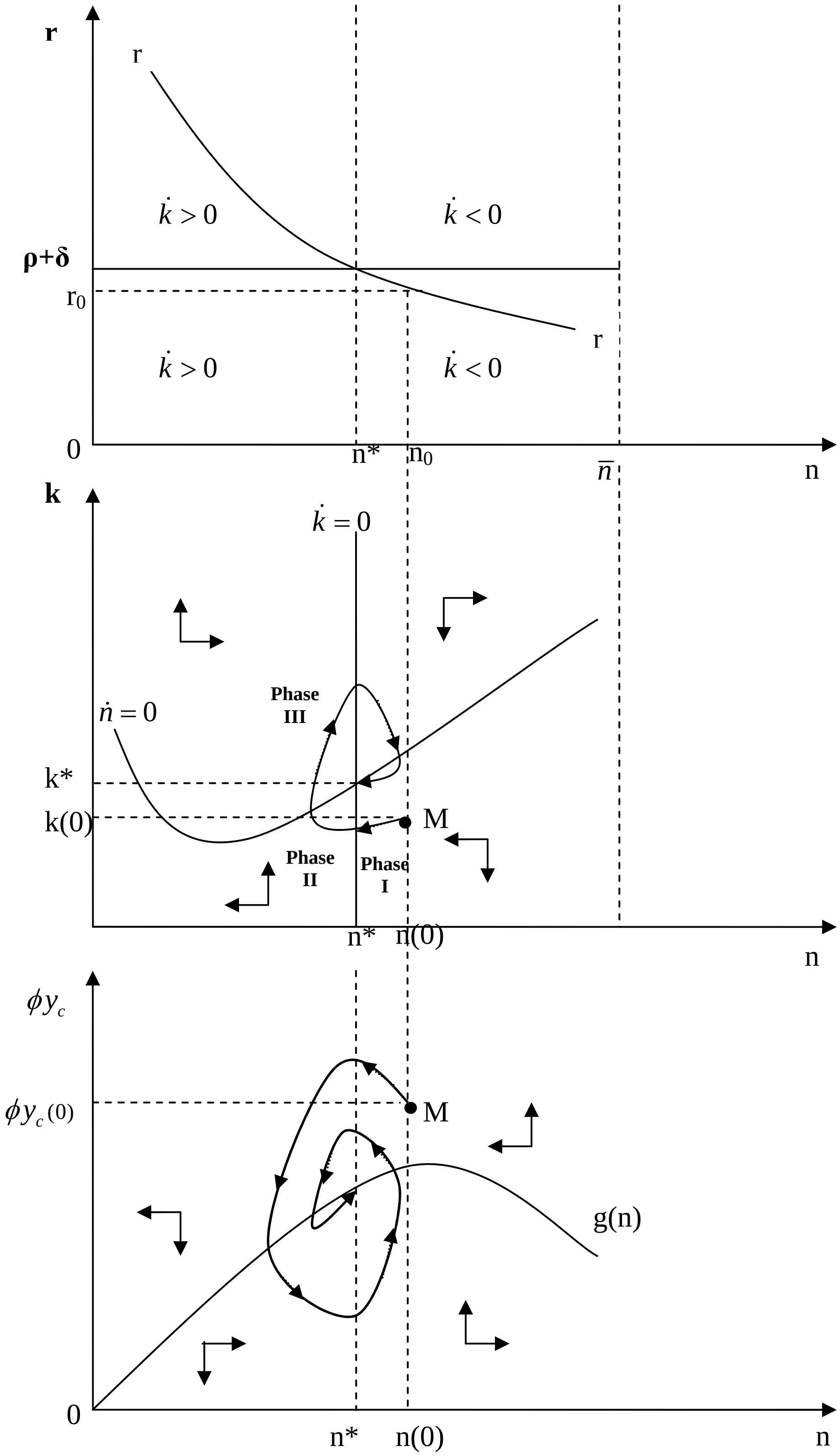

Figure 1: Adjustment towards equilibrium by a resource-rich, capital-poor economy.

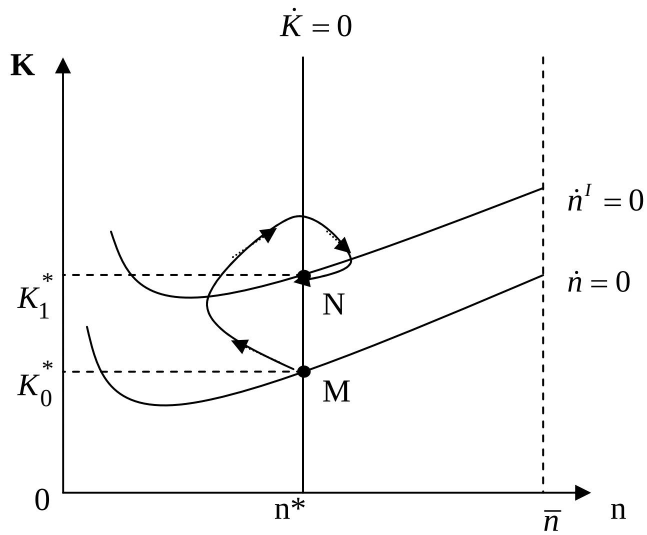

Figure 2: The impact of immigration: internal solution

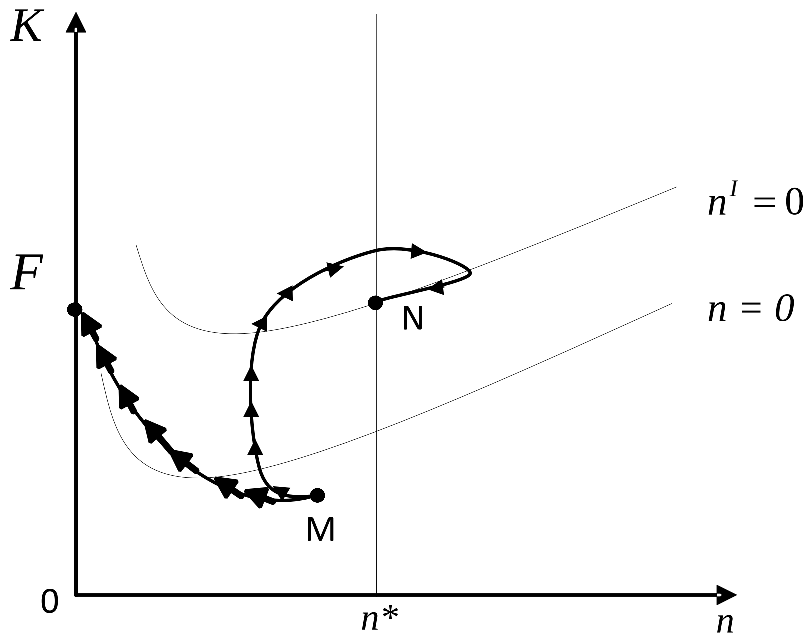

Figure 3: The possible impact of immigration in Phase II

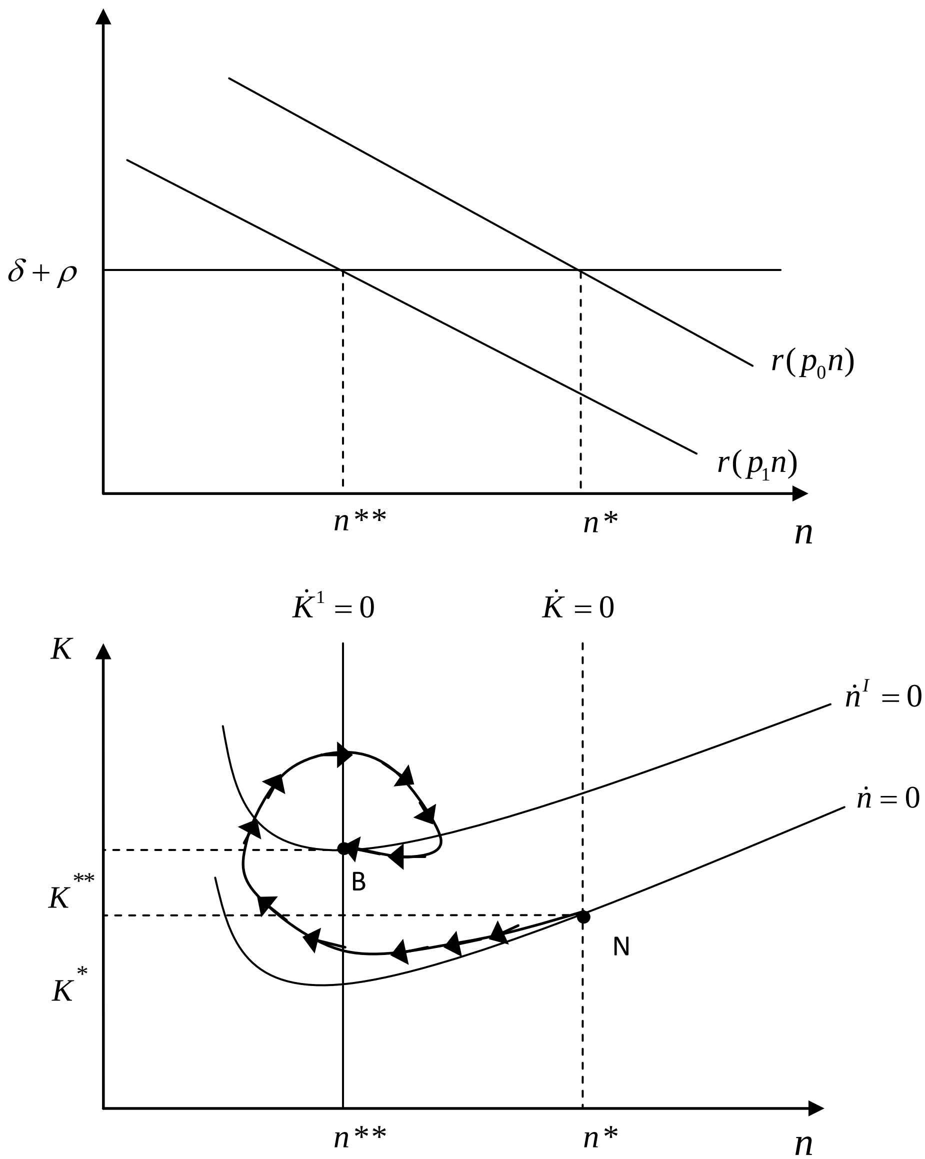

Figure 4: Adjustment following a commodity price increase