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Accumulation, Structural Change, and External Balances in a World with Internationally Traded Environmental Assets

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By

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Abstract

Environmental literature has largely neglected macroeconomic considerations, especially open economy ones. This paper develops a small country framework that seeks to address these issues. Medium- and long-run aspects are explored using standard trade and portfolio balance models, modified to incorporate trade in claims on non-renewable resources (environmental assets). In the medium-run, changes in environmental regulations, saving behavior, and other variables affect the current account, investment, and composition of output. In the long-run, both the sectoral intensity of environment use and the structure of the economy are affected, as are the capital stock and the global distribution of claims on resources.

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1 Introduction and Background

With rising awareness of environmental issues both amongst the general public and academics, relevant economic issues have come to the forefront in recent years. In attempting to prevent, or at least mitigate, the effects of global warming, a general consensus in favor of internationally agreed upon cap-and-trade schemes appears to be forming. The European Union Emission Trading Scheme (EU ETS), involving all 27 EU member countries, is perhaps the most prominent instance.

The economics profession has started playing a visible role in the analysis of related welfare and efficiency issues. Much less attention, however, has been devoted to macroeconomic or economy-wide aspects. Even lesser effort has been put into analyzing relevant open economy issues. In a future world where some combination of cap-and-trade schemes are likely to operate at a global level, this is a rather glaring omission.

Consider, for example a world where claims on non-renewable natural resources and emission permits for their use are internationally traded. For a price-taking small country, changes in the number of permits issued would likely have a significant impact on the structure of production and relative prices. Moreover, the performance on the current account of the balance of payments will alter the volume of net claims that the country's residents have on the rest of the world, and hence modify access to internationally traded claims on non-renewable resources. Furthermore, these considerations will likely interact over time with changes in other accumulable factors of production to affect the long-run structure of the economy. For, example, depending on which sector uses environmental resources more intensively, tightening of environmental regulations may affect the mix of consumption and investment.

Some recent literature has begun to address aggregate economy-wide issues. For example, a series of papers starting with Heyes (2000) have incorporated an environmental constraint into the standard closed economy IS-LM model to study the impact of short-run stabilization policies. This constraint takes the form of a curve labeled EE, along which the rate of re-generation of the environment exactly offsets its use, leaving the stock of environment available unchanged. This stock is predetermined at any given point in time and the environment and capital are substitutes in production. Raising the interest rate on borrowing for physical capital, therefore, encourages substitution towards less capital-intensive but more environment intensive production methods. Within this framework, Heyes explores the effects of fiscal and monetary policies. Decker and Wohar (2012) modify Heyes's model by assuming complementarity rather than substitutability between physical capital and the environment. This reverses the relative roles of fiscal and monetary policy. Sim (2006) is another effort that works within a broadly similar framework.

Although the literature cited above has addressed highly pertinent issues, there appears to be something fundamentally unsatisfactory about the treatment of factor substitution in production. Considering that the IS-LM model is a short-run fixed price framework , it is hard to see how firms could change production techniques rapidly enough in response to factor price changes. Moreover, the framework used is a single good one, which leaves one unable to incorporate sectoral differences in environmental resource use or the influence of environmental regulation on inter-sector resource movement.

This paper seeks to provide a sounder long-run footing for the interaction between environment use, relative prices, and factor substitution. I assume flexible prices and full employment of resources. Moreover, the analysis is carried out in a more generalized open economy context. The real side of the economy has a Heckscher-Ohlin or Foley-Sidrauski flavor,[1] and the overall structure of the model is inspired by Dornbusch (1975). Claims on non-renewable (environmental) resources and on physical capital serve as assets, while the actual resources and capital are factors of production. Medium-run equilibrium in the goods and asset markets determines the returns on equity, saving, and investment. The long-run framework consists of a series of instantaneous equilibria along which asset markets clear. With a constant (exponential) rate of capital depreciation and limits on environmental permit issuance, savings and investment determine accumulation, holdings of environmental assets, the current account balance, and hence the long-run evolution of the economy. Convergence to a new steady state involves a net foreign asset position consistent with stable stocks of capital per worker and claims on environmental resources. The accumulation or decumulation of assets through saving, accumulation, and international trade in goods and assets generates interesting feedback effects between flows, stocks, and prices. Specifically, it allows us to analyze changes in the production structure and emission intensity of the economy. For example, a shift in domestic preferences towards claims on real capital may create a transitional current account deficit, reduce the environment intensity of production in the traded goods sector, and reduce domestic claims on environmental resources.

In a sense, this paper should be seen as an exercise in futuristic thinking. The world it considers is one where emission permits are widely used and globally traded.[2] Throughout, the focus is on simplicity of treatment rather than comprehensiveness, and I consistently eschew paraphernalia in favor of conciseness. The idea is to suggest possible ways to incorporate environmental concerns in a stylized analysis of aggregate economies rather than modeling a specific economy or carrying out policy experiments in exhaustive detail.

The next section intuitively describes important features of the conceptual framework underlying the model. Section 3 introduces and analyzes the production side of the multi-sector economy. Section 4 introduces the financial side of the economy with the stocks of claims on capital (equity) and non-renewable resources (environmental assets) playing a central role along with money. The real and financial sides are combined in order to enable us later to explore the evolution of stocks over time. The penultimate section then utilizes the combined framework to carry out thought experiments. Section 6 concludes.

2 Conceptual Framework

The model presented in subsequent sections distinguishes between the role of non-renewable resources as generators of claims on environmental resources (e.g., ownership of oil fields) and as factors of production (in

[1] See Foley and Sidrauski (1971).

[2] See Jaffe et al. (2009) for a detailed discussion of issues related to international emission permit trading in the future.

the form of environmental permits for the generation of emissions from the use of oil). To understand the conceptual underpinnings, visualize a world where a given amount of non-renewable resources is distributed across countries. Each country thus starts out with a certain endowment of claims on these resources. International mobility of claims means that these can be traded across countries through capital/financial account transactions. It also means that, for a small country, the price of these assets is given by the rest of the world, which, in turn, allows us to ignore Hotelling rule-related considerations. In other words, countries can increase or reduce their net claims on the rest of the world through current account imbalances at given asset prices.[3]

Next, suppose that each government in our world allows a given amount of these claims to be sold to producers as emission permits per period. Each permit allows the holder to use up a certain amount of non-renewable resources, which, in turn, leads to a given amount of emissions. Thus, claims on resources serve a dual role. First, these act as *assets* that are traded within and across countries at internationally given prices. Second, a limited subset of these act as *permits*, which can be understood as inputs to, or rather factors of, production.[4] Put differently, asset holders are allowed to sell off a stipulated amount of their assets to producers for use in production. International arbitrage ensures that, ignoring transportation and other transaction costs, permit prices too are given for small country producers. Notice, however, that while asset prices are determined by the demand for and supply of non-renewable resources, international permit prices should in the first instance depend on the limits that are placed on emissions per period by international agreements. Thus, while stricter international limits will directly affect permit prices, this may not be the case for asset prices as long as there is no change in the stock demand for and supply of non-renewable resources. Asset prices, in other words, may differ from permit prices even under international arbitrage and perfectly competitive conditions. The normalized difference between the price of environmental assets and that of environmental permits yields the (internationally given) rate of return that holders of these assets expect to earn. Throughout I assume this differential to be non-negative.

It is important to keep in mind this dual nature of claims on environmental resources. As factors of production, environmental permits are (imperfect) substitutes for other factors of production (such as capital). If the relative price of these permits rises, producers switch towards techniques that use non-renewable resources less intensively (i.e., environmental mitigation). As assets, claims on resources represent a source of wealth and a substitute for other assets such as money and bonds. The composition of asset portfolios will, therefore, be influenced by the relative returns. An increase in the rate of rate of return on environmental assets, perhaps due to an increase in the international price of environmental permits, will

[3] A real world example would be the recent spate of agreements that China and India, among others, have signed with resource rich countries in Africa, giving them claims on oil fields and other commodity generating resources. These claims constitute the use that Chinese current account surpluses have partly been put to, and may reflect incipient global tendencies.

[4] As we will see below, insofar as the government re-issues the same amount of permits at the beginning of every period, these are not actually "used up" in production, so that it makes sense to treat these as factors of production rather than intermediate inputs.

tend to cause a reshuffling of portfolios in favor of these assets. While the stock of environmental assets can endogenously adjust through current account imbalances, the volume of permits issued per period is an exogenously given policy variable. Moreover, while the former are non-renewable, the latter are renewed each period.

Market clearing conditions too differ between the two roles. As a factor of production, the number of claims supplied as permits must equal the number of permits demanded and utilized by producers. This is a *flow* equilibrium condition. As assets, the stock of claims available must be readily held by investors. This latter condition constitutes a *stock* equilibrium.

We can now build on this intuitive discussion to flesh out a model in stages, starting with flow considerations before turning to the evolution of stocks.

3 Output and Prices

This section develops the equilibrium conditions for a time period over which available factor endowments are fully employed but pre-determined. In terms of logical time, it should be seen as the window that determines "instantaneous" equilibria, although full employment implies that the time period under analysis be seen as the medium run rather than the short run. The evolution of factor stocks is the subject of the next section.

Consider a simple multi-sector economy with two factors of production: physical capital (K) and permits allowing use of the "environment" (E_p). As discussed in Section 2, the latter factor could be thought of broadly as a fixed number of the total existing claims on non-renewable resources (E) that can be sold to firms each period for generating emissions in the process of production. National authorities fix this number, making it a policy variable possibly subject to international agreements. Equity or claims on physical or "real" capital is non-tradable across countries. The two factors of production along with another non-tradable intermediate input (N) are used to produce two final goods: an internationally traded consumption good (C) and a (non-traded) investment good (K).[5] The small country is a price taker in the global market for the consumption good. The production functions are neoclassical and both goods require environmental resources and intermediate inputs. We assume, to keep the analysis manageable, that real capital is used only in the production of the consumption good.

Another look at the treatment of emission permits may be in order here. These permits are treated as durable factors rather than intermediate inputs that are entirely used up in production. To see why, consider a periodic allocation of E_p permits by a government. Flexible prices ensure that all permits are employed during the period. However, environmental resources are not used up in the sense that intermediate inputs are, since the same number of permits is available all over again for the next period. The only way to increase (reduce) the national use of environmental resources over the next period is for the authorities to

[5] The assumption about the non-traded nature of the investment good is made to render the magnitude of investment determinate.

establish a different limit on E_p.

For the purposes of this stylized framework, it's best to think of the intermediate input as a public good, such as transportation infrastructure, provided to producers by policy makers. The intermediate goods are complements in production so that the unit coefficients of intermediate input use are constant. The public sector provides this good elastically in response to changing demand conditions. At a given international price, the price or fee charged for this good is set with the international competitiveness of the traded sector in mind. An increase in the rental on capital brings forth a proportional decline in the price charged for the intermediate input. These admittedly sharp simplifications serve to communicate the main ideas without venturing too far afield in sorting out the intricacies of a general equilibrium framework with more than two goods. Moreover, by keeping the focus on capital-environment substitutability, these help maintain comparability between the present framework and the literature cited in Section 1.

Expressing all factor and good prices in terms of the consumption good allows us to state the zero profit conditions as follows:

$$a_{KC}r_K + a_{NC}q_N + a_{EC}q_P^* = 1 \tag{1}$$

$$a_{NK}q_N + a_{EK}q_P^* = q_K \tag{2}$$

where r_K and q_P^* denote the real rental on physical capital and the relative price of (internationally traded) emission permits, q_N and q_K are the relative prices of the intermediate input and the investment good, and a_{ij} represents the amount of intermediate input or factor i required to produce one unit of good j. Next, using X_j $(j = C, K, N)$ to represent sector outputs, the full employment conditions can be written,

$$a_{KC}X_C = K \tag{3}$$

$$a_{EC}X_C + a_{EK}X_K = E_P \tag{4}$$

$$a_{NC}X_C + a_{NK}X_K = X_N \tag{5}$$

Differentiating equations (1) and (2), using hats or circumflexes to denote rates of proportional change, applying the envelope theorem, and using θ_{ij} to denote the cost share of factor i in the production of good j,[6] yields two equations in three relative good and factor prices:

$$\theta_{KC}\hat{r}_K + \theta_{NC}\hat{q}_N + \theta_{EC}\hat{q}_P^* = 0$$

[6] For example, $\theta_{EK} = q_P^* a_{EK}/q_K$.

$$\theta_{NK}\hat{q}_N + \theta_{EK}\hat{q}_P^* = \hat{q}_K$$

which allows us to solve for the other relative prices in terms of the real rental:

$$\hat{q}_N = -\frac{1}{\theta_{NC}}\left(\theta_{KC}\hat{r}_K + \theta_{EC}\hat{q}_P^*\right) \tag{6}$$

$$\hat{q}_K = -\frac{1}{\theta_{NC}}\left[\theta_{KC}\theta_{NK}\hat{r}_K + (\theta_{EC}\theta_{NK} - \theta_{EK}\theta_{NC})\hat{q}_P^*\right] \tag{7}$$

The general equilibrium story can be readily explained at this point in intuitive terms. An increase in the rental on capital puts downward pressure on intermediate input prices due to internationally competitive conditions in the consumption goods sector (as well as in the other sectors due to inter-sector mobility). Rising r_K also causes substitution in factor use away from capital and towards environmental resources. But since the output of consumption goods is constrained by the amount of capital available (see equation (3)), factor substitution away from capital loosens the constraint on this sector, which expands at the expense of the investment goods sector (see equations (9) and (10) below). Notice, however, that, with a given price of emission permits, this inter-sectoral re-allocation is possible only if the relative price of investment goods declines, making it more attractive to produce consumption goods.

To see more explicitly how changes in relative prices help determine the intensity of factor use in each sector, recall that the use of the intermediate input is rigid (i.e., $\hat{a}_{NK} = 0 = \hat{a}_{NC}$). Thus, the only factor substitution in the consumption goods sector is that between environmental resources and physical capital. Now define the elasticity of factor substitution in the standard manner so that $\sigma_C = \frac{\hat{a}_{KC} - \hat{a}_{EC}}{\hat{q}_P^* - \hat{r}_K}$. Cost minimization implies a relationship between changes in factor intensity that can be expressed as follows:[7]

$$\hat{a}_{KC} = -\frac{\theta_{EC}}{\theta_{KC}}\hat{a}_{EC}$$

This combined with the definition of σ_C allows us to explicitly express the effects of factor price changes on factor use:

$$\hat{a}_{EC} = \sigma_C \frac{\theta_{KC}}{1-\theta_{NC}}(\hat{r}_K - \hat{q}_P^*), \;\; \hat{a}_{KC} = -\sigma_C \frac{\theta_{EC}}{1-\theta_{NC}}(\hat{r}_K - \hat{q}_P^*) \tag{8}$$

In words, the emission intensity of production in the consumption goods sector is a (weighted) negative function of the cost of emissions (i.e., the price of permits) and a positive function of the rental for capital use.

[7] The tangency of the isocost line to the unit value isoquant imples that:

$$r_K da_{KC} + q_P^* da_{EC} = 0$$

The expression for $\hat{a}_{KC}$ follows.

Next, differentiating equations (3)-(5), using λ_{ij} to denote the proportion of factor i employed in the production of good j,[8] making use of the expressions derived in (8), and solving simultaneously allows us to derive the effects of changes in factor endowments and relative factor prices on sectoral outputs:

$$\hat{X}_C = \widehat{K} + \sigma_C \frac{\theta_{EC}}{1-\theta_{NC}}(\hat{r}_K - \hat{q}_P^*) \tag{9}$$

$$\hat{X}_K = -\frac{1}{\lambda_{EK}}\left[\lambda_{EC}\widehat{K} - \widehat{E}_P + \lambda_{EC}\sigma_C(\hat{r}_K - \hat{q}_P^*)\right] \tag{10}$$

$$\begin{aligned} \hat{X}_N &= \frac{1}{\lambda_{EK}}\left[\left(\lambda_{NC}\lambda_{EK} - \lambda_{EC}\lambda_{NK}\right)\widehat{K} + \lambda_{NK}\widehat{E}_P\right] \\ &\quad -\frac{\sigma_C}{\lambda_{EK}}\left(\frac{\theta_{KC}}{1-\theta_{NC}}\lambda_{NC}\lambda_{EK} - \lambda_{EC}\lambda_{NK}\right)(\hat{r}_K - \hat{q}_P^*) \end{aligned} \tag{11}$$

Equations (9) - (11) capture the Rybczynski effects of changes in factor stocks on outputs at given prices. Availability of a larger pool of environmental permits, at given prices, leaves the output of the internationally traded consumption good unaffected (the output of this good being restricted by the amount of capital available). The extra environmental permits are used up by the other sector that requires these permits, that is, the investment goods sector. As this sector expands, so does the intermediate goods sector as policy makers react to greater demand for inputs.

An increase in the availability of capital, again at given prices, shifts production towards the good that uses these as a factor of production, i.e., the consumption good. As this sector now uses up more environmental permits, the capital goods producing sector shrinks. The impact on the intermediate goods sector depends on the structure of the economy in terms of factor intensity use. If the expanding consumption goods sector is intermediate input-intensive relative to the shrinking capital goods sector, the intermediate goods sector must expand in response to rising demand. Otherwise it contracts.

With factor substitutability, relative factor prices too play a role in determining sectoral output at a given level of resources. An increase in the relative rental ratio $(r_K/\hat{q}_P^*)$ causes factor substitution away from physical capital and increases the output of the consumption good (since these are constrained by the amount of capital available). This increase comes at the cost of the investment good sector that loses emission permits to the consumption goods sector.

Table 1 summarizes these results. I will use them later as we explore the effects of shocks and policy choices with the help of thought experiments.

[8] So that, for example, $\lambda_{KC} = a_{KC}X_C/K$.

Table 1: Medium-Run Comparative Statics

	$\hat{X}_C$	$\hat{X}_K$	$\hat{X}_N$
$\widehat{E}_P > 0$	0	> 0	> 0
$\widehat{K} > 0$	> 0	< 0	$\gtreqless 0$
$\hat{r}_K - \hat{q}_P^* > 0$	> 0	< 0	$\gtreqless 0$

4 Portfolio Considerations, Asset Market Interactions, and Long-Run Dynamics

Analyzing in an interesting manner the evolution of variables and their impact on production over longer periods of time requires that the stocks of capital and environmental assets domestically owned be allowed to adjust. Our long-run set-up reflects a world where individual countries operate under emission caps. However, a country can trade claims on environmental resources with other countries. Thus, the global distribution of claims to the use of environmental resources is a key variable of interest in the long-run analysis. While pre-determined at a point in time, these claims can be accumulated over time through current account surpluses, or through new resource discoveries (net of the stipulated permit use per period). The interaction of stocks and flows influences relative prices, which then affect the sectoral pattern of production and intensity of environment use.

There are three assets which together constitute wealth (W): money (M), equity or claims on capital (K), and internationally traded claims on non-renewable resources, i.e., claims on environmental resources (E). With a fixed exchange rate, the stock of money held by the public is endogenous and the Central Bank/Sovereign Wealth Fund defends the value of the currency by adjusting its holdings of money and environmental assets.[9] Put differently, the Bank accommodates any changes in demand for money or permits by offsetting changes in its balance sheet.[10] The total amount of privately held financial (non-equity) assets ($F = M + E$) is, therefore, predetermined, and the composition in terms of individual components largely irrelevant to our analysis.

The individual asset market clearing conditions are dictated by standard portfolio considerations. Given perfect competition, the return to holding equity, r_K, equals the marginal product of capital, which, in turn, equals the equilibrium rental on capital services. The expected return to holding environmental assets (r_E^*) equals the proportional difference between the price of environmental assets (q_A^*) and the price at which these are expected to be sold to producers as permits (both prices being internationally given and expressed relative to the internationally determined price of consumption goods). Thus,

[9] Again, a real world example would be East Asian central banks/sovereign wealth funds using foreign exchange reserves to purchase claims on oil fields and other primary commodity sources.

[10] Readers will recognize this as simply a manifestation of the "impossible trilemma" or the "unholy trinity."

$$r_E^* = \frac{q_P^* - q_A^*}{q_P^*} = 1 - \frac{q_A^*}{q_P^*} \tag{12}$$

Representing real asset quantities (as expressed in terms of the consumption good) by smaller case letters,[11]

$$m = m^d(r_K, r_E^*, w) \tag{13}$$

$$e = e^d(r_K, r_E^*, w) \tag{14}$$

$$q_K K = k^d(r_K, r_E^*, w) \tag{15}$$

where the partial derivatives are defined in the standard manner so that $m^d_{r_K}$, $m^d_{r_E^*}$, $e^d_{r_K}$, $k^d_{r_E^*}$ < 0 while $k^d_{r_K}$, $e^d_{r_E^*} > 0$ and $0 < m^d_w$, b^d_w, $k^d_w < 1$. Total wealth is the sum of all three assets:

$$w \equiv m + e + q_K K = f + q_K K \tag{16}$$

With a fixed exchange rate, the equity market equilibrium condition suffices to close the model. We know from equation (7) that

$$q_K = q_K(r_K);\ q_K' < 0 \tag{17}$$

The equity market clearing condition can now be used along with equation (17) to determine the returns on equity, and hence pin down the state of the medium-run (flow) equilibrium described in the previous section:

$$q_K(r_K)K = k^d(r_K, r_E^*, w) \tag{18a}$$

It will be convenient as a transition device toward the long run to solve for r_K, after employing the definition of w,

$$r_K = r_K(K, f, r_E^*, k^d) \tag{18b}$$

where $r_{K_K}, r_{K r_{E^*}} > 0$ while $r_{K_f}, r_{K k^d} < 0$.

Panel (a) of Figure 1 captures this information. A bit of discussion may help understand the intuition behind the signs of the partials. A rise in the capital stock or an increase in the returns on permits creates excess supply of equity (assuming in the standard manner that diversification motives lead to a less than

[11] From now on, we will normalize q_A^* to unity without loss of generality.

one-for-one rise in demand for equity as wealth rises). The returns to equity must rise to remove the excess supply both through the substitution channel ($k^d_{r_K} > 0$) and by reducing the value of the capital stock ($q'_K < 0$). A rise in financial wealth or a rise in demand for equity, on the other hand, create excess demand for equity, putting downward pressure on r_K.

Accumulation of real capital depends, as we know from the previous section,[12] positively on its relative price and the amount of emission permits available, and negatively on the current level of capital stock and the rental on capital. Taking into account the rate of capital depreciation, δ,

$$\dot{K} = h[q_K(r_K), K, e_P, q^*_E] - \delta K \tag{19a}$$

which, after substitution from equation (18b) and re-arranging yields

$$\dot{K} = \dot{K}(K, f, e_P, k^d, r^*_E) \tag{19b}$$

with $\dot{K}_{e_P},\ \dot{K}_f,\ \dot{K}_{k^d} > 0$ and $\dot{K}_K,\ \dot{K}_{r^*_E}, < 0$. An increase in the returns to holding environmental assets puts upward pressure on r_K, which in turn, by lowering the relative price of investment goods, reduces accumulation. An increase in the holdings of equity has a similar effect through raising r_K but also has an added direct negative Rybczynski impact on accumulation in addition to increased capital depreciation. Higher holdings of financial assets, or increased demand for equity have the opposite effect since these create demand for equity and thus reduce r_K. Finally, greater allowance of environmental permits shifts output towards investment goods through the Rybczynski channel.

As discussed earlier, environmental assets are accumulated or decumulated through current account imbalances, which in turn reflect saving – (gross) investment imbalances. Put differently, a country can increase its access to environmental resources by exporting its excess savings to the rest of the world. Using equation (19b), gross investment can be written,

$$I = \dot{K} + \delta K = I(K, f, e_P, k^d, r^*_E) \tag{20}$$

where the partials follow from equation (19b). Saving depends positively on the returns to holding equity or financial assets and, via the standard Metzler channel,[13] negatively on wealth.

$$S = \sigma(r_K, r^*_E, w)$$

Or, substituting from equations (16) and (18b) to derive a more explicit form:

$$S = S(K, f, k^d, r^*_E, \sigma) \tag{21}$$

[12] See equation (10) and Table 1.
[13] See Metzler (1951).

with S_f, $S_{k^d} < 0$ and S_σ, $S_{r_E^*} > 0$. The partial with respect to K is ambiguous in sign. By increasing wealth, a higher level of equity holding undermines saving. By reducing the *value* of a given stock of wealth and by increasing the return on equity, however, an increase in K raises saving. Thus, $S_K \lesseqgtr 0$.

Panel (b) of Figure 1 reflects the saving-investment balance as captured by equations (20) and (21). The figure illustrates a situation where investment equals saving at the prevailing rate of return on equity.

The equation of motion for the net accumulation of environmental assets can now be defined. Total access to environmental resources is affected by their use in production, by new discoveries, and by net international purchases. For a given value of e_P, a current account surplus allows domestic residents to increase their net holdings of environmental assets. The net change in environmental assets per period is, therefore, simply the current account balance plus new discoveries (η) adjusted for the assets used up as permits each period.

$$\begin{aligned} \dot{e} &= \dot{f} + (\eta - e_P) = (S - I) + (\eta - e_P) \\ &= S(K, f, k^d, r_E^*, \sigma) - I(K, f, e_P, k^d, r_E^*) + (\eta - e_P) \\ &= \dot{e}(K, f, e_P, k^d, r_E^*, \sigma, \eta) \end{aligned} \tag{22}$$

From now on, it will be convenient to use the term net current account surplus or deficit for the expression $(S - I) + (\eta - e_P) \lesseqgtr 0$. Based on the discussion following equations (20) and (21), the signs of six partials are unambiguous; $\dot{e}_f$, $\dot{e}_{k^d}, \dot{e}_{e_P} < 0$, $\dot{e}_{r_E^*} > 0$, $\dot{e}_\sigma = \dot{e}_\eta = 1$. An increase in K reduces investment via the Rybczynski and capital depreciation effects, as well as by reducing r_K, and thus furthers accumulation of financial assets but, as noted earlier, has ambiguous effects on saving. The number of channels in favor of a positive impact on the current account balance makes this result much more plausible, and we will mostly focus on this case in subsequent analysis.[14] It is important to note, however, that our comparative dynamic results are qualitatively robust to assuming one sign or the other for $\dot{e}_K$, as long as the system is locally stable, a condition which, as shown in the appendix, is unambiguously satisfied.

Given the long-run nature of this exercise, it may be considered a desirable policy objective that the stock of environmental resources stabilize in the steady state. Thus, the steady state ($\dot{e} = 0$) is characterized by current account imbalances vis-á-vis the rest of the world that exactly offset any change in the stock of environmental resources due to use in production (net of new discoveries). Given the stock of labor, the steady state rate of physical capital accumulation per worker too must be such so as to stabilize the stock of capital.

Panels (c) and (d) of Figure 1 illustrate the long-run dynamics of the system based on equations (19b) and (22). The appendix provides the underlying mathematics. Case 1 (Panel c) assumes that the wealth

[14] Note that the only negative effect on saving is that of increased wealth on savings (the Metzler channel).

effect on saving is large enough to overcome the several offsetting effects, so that $\dot{e}_K < 0$. However, for the reasons discussed above, this is the less likely case and I restrict detailed discussion of the thought experiments to Case 2 (Panel d).[15] The adjustment process can either be monotonic or a half-cycle, but not oscillatory. Both isoclines are upward-sloping in this case although the $\dot{K} = 0$ isocline is steeper, that is, the accumulation of physical capital is relatively more sensitive than environmental asset accumulation to changes in the capital stock. The slopes can be explained intuitively. Higher financial wealth reduces r_K, boosts investment and reduces savings, creating a net current account deficit. With $\dot{e}_K > 0$, the level of the capital stock must rise to restore current account balance, partly by boosting returns on equity. Moreover, the increased rate of capital accumulation due to greater financial wealth requires, again, a rise in K to make investment less attractive and restore the steady state level of accumulation.

How does the system ensure dynamic stability? In order to understand the nature of the model, consider an exogenous shock that displaces the economy to point A in Panel (d). At A the level of physical capital stock is too high for both steady state capital and environmental asset accumulation. A high level of physical capital is associated with a high r_K, low investment and high savings in this case, so that there is capital decumulation and a net current account surplus (i.e., an increase in the availability of environmental assets). Since the latter is less sensitive to the falling capital stock, the system arrives at the steady state level of capital accumulation first. Beyond this point, continued current account surpluses boost both environmental asset and physical capital accumulation (equation (19b)) – the latter via the reduced cost of capital – as the system approaches its steady state.

In short, our framework consists of a long-run steady state punctuated by a series of instantaneous/medium-run equilibria. Panels (a) and (b) capture the latter. With stocks predetermined, the steady state level of r_K determines relative prices and the structure of output in the medium run. Over time, accumulation of capital and net current account imbalances lead to evolution of stocks and the associated changes in the steady state levels of the variables. Notice that, with the stocks of assets stabilized at their steady state levels, wealth and asset returns are also constant, as is the structure of the economy in terms of sectoral output.

5 Thought experiments

This section pursues the logical implications of the framework developed. Table 2 summarizes the results.

5.1 A change in saving behavior

Lets begin with a relatively simple case. Consider the consequences of an increase in the saving function, perhaps triggered by increased precautionary savings owing to uncertainty regarding future economic prospects.

[15] As noted earlier, the results are qualitatively the same in both cases so that analyzing case 1 does not add much to the discussion.

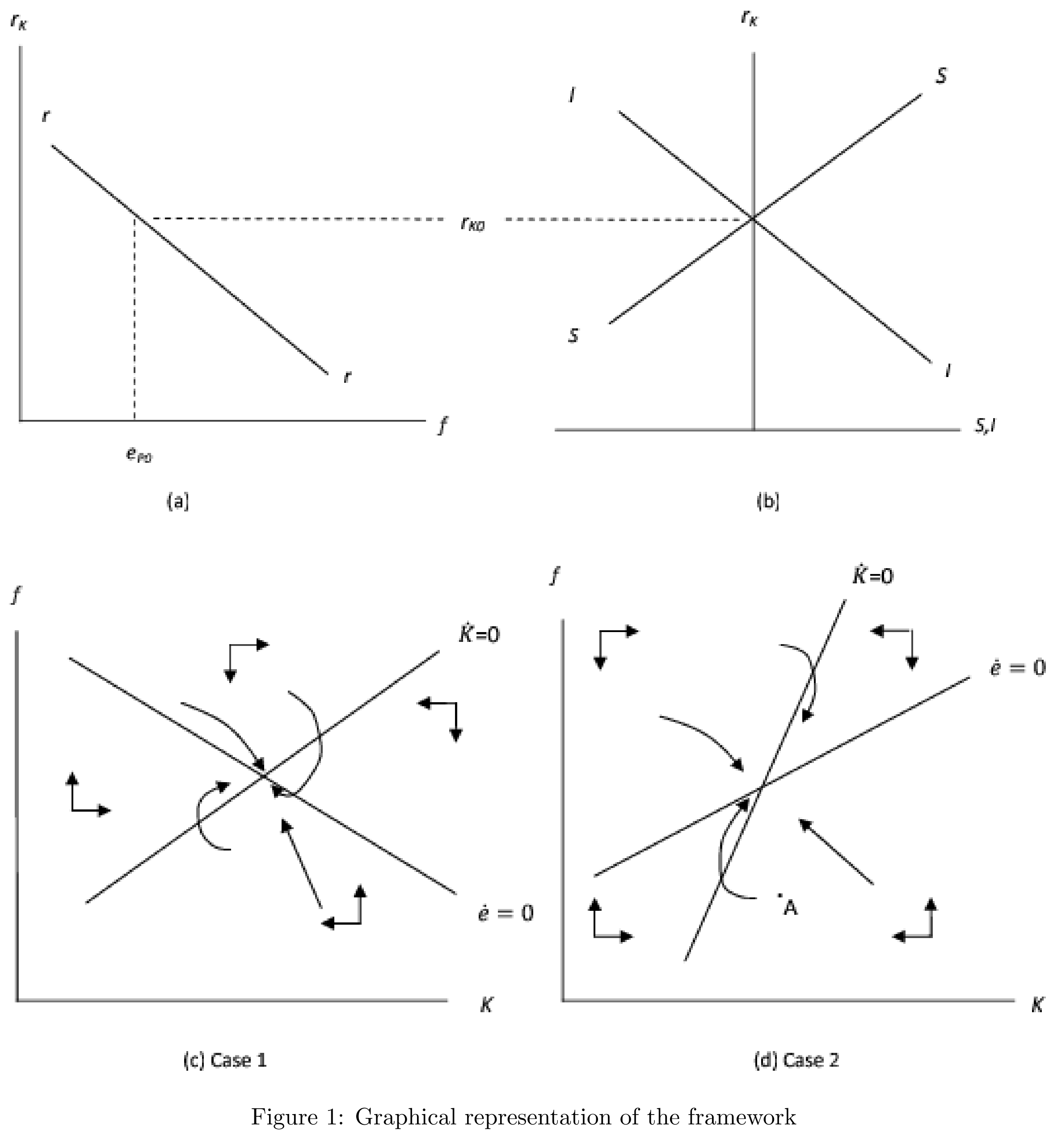

Figure 1: Graphical representation of the framework

There is no direct impact on returns to equity or wealth, and hence none on the flow of investment or the medium-run equilibrium.

Increased savings create a current account surplus in excess of permit use. This surplus then has long-run repercussions. As domestic agents gain access to environmental assets, r_K declines and investment gets a boost. The economy continues to accumulate claims on both physical capital and environmental assets culminating in an outcome with higher steady state stocks of both K and e (and thus of f). Figure 2 illustrates the dynamics. The $\dot{e} = 0$ isocline shifts upward as zero steady state accumulation of environmental assets is now consistent with a greater stock of these at the original level of capital stock.

What are the effects on the structure of the economy and relative prices? Since K and e are both higher in the new steady state, a first glance at equation (18b) would suggest that the new steady state level of returns on equity may be lower or higher. As demonstrated in the appendix, however, r_K is unambiguously lower. This, in turn, means that the intensity of environment use in the consumer goods sector is also lower. With a higher capital stock and unchanged permit use, the composition of output *at given prices* shifts towards consumption goods at the cost of investment goods (see Section 3). Moreover, in the absence of changes in permit regulations or resource discoveries, the decline in investment must be matched by a decline in savings in the new steady state, more than neutralizing the initial change in saving behavior. Note that this decline in savings is consistent with increased wealth. Also, the expansion of the capital-using consumption goods sector is consistent with capital accumulation with full employment of resources.

5.2 Fewer new resource discoveries

Next, what happens if the rate of new non-renewable resource discoveries slows down? Again, there is no direct impact on the state of the medium run. At the initial level of returns to equity, a net current account deficit is created (see Panel (b) of Figure 3). The $\dot{e} = 0$ isocline shifts downwards as a lower level of wealth and a higher level of r_K are now consistent with net current account balance at a given level of the capital stock. As domestic ownership of environmental assets declines, wealth falls while r_K rises. Both the latter changes help shrink the net current account deficit while at the same time starting a process of capital decumulation.

In the long run, capital decumulation and net current account deficits lead to lower stocks of both environmental assets and equity in the new steady state.

With the new steady state values of both K and e being lower, the effects on the structure of the economy and relative prices are the mirror image of those resulting from increased savings. Specifically, the new steady state level of returns on equity is higher, resulting in greater intensity of environment use in the consumption goods sector. At given relative prices, the capital goods sector expands at the expense of the consumption goods sector. This latter result is reminiscent of the "Dutch disease" literature, which

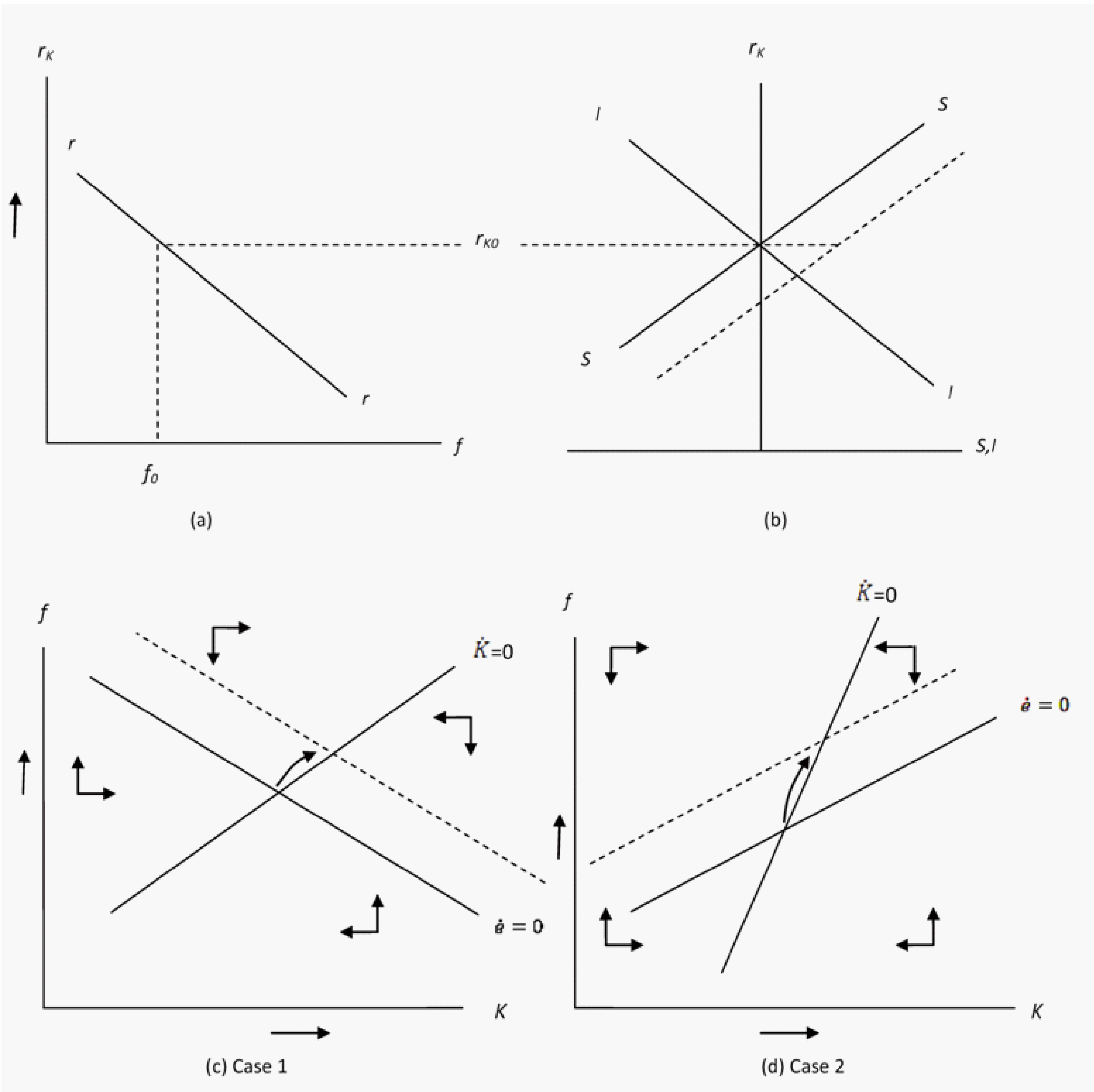

Figure 2: An increase in the saving function

often focuses on the negative effects of resource discoveries on manufacturing and investment, although the transmission mechanisms are different.

Can policy makers offset the impact of dwindling discoveries? One option perhaps could be to subsidize savings in order to prevent the medium-run impact. In terms of panel (b) of Figure 3, this shifts the SS-curve down. A second option that prevents the stock of capital from declining is to shift the $\dot{K} = 0$ isocline up, perhaps through incentives for accelerated capital depreciation. The accompanying increased claims on environmental assets, moreover, have the side effect of lowering the steady state rental on capital, causing substitution away from the use of environmental resources, and boosting the production of investment goods at the expense of the consumption goods sector.

5.3 Shift in preferences towards holding domestic equity

Suppose domestic preferences shift in favor of holding equity. This brings down the return on equity in the short run as investors are willing to hold equity at a lower level of r_K. The rr-curve in panel (a) of Figure 4 shifts down. A net current account deficit develops as investment exceeds saving net of permit use at the now lower level of r_K.

Over time, the combination of the net current account deficit and higher investment lead to fewer environmental assets for domestic residents and accumulation of claims on real capital (see panels (c) and (d) of Figure 4). The most direct (monotonic) path to the new steady state involves continuous current account deficits and capital accumulation. The new steady state stock of capital is higher but domestic access to environmental assets is more constricted.

Graphically, both isoclines shift downwards but by less so in the case of the $\dot{e} = 0$ isocline. The $\dot{e} = 0$ isocline shifts more in the horizontal direction than the other isocline. Notice that, although a change in the stock of capital affects capital accumulation, it affects environmental asset accumulation through both capital accumulation (or investment) *and* saving.

The new steady state level of r_K is higher. Changed steady state values of r_K and K have structural consequences for the economy. Production shifts away from capital goods and towards consumption goods. Moreover, the intensity of environment use in the latter sector rises. Since the new steady state level of investment is lower, so is the new steady state level of savings.

5.4 Tighter environmental regulation

Consider the effect of a more limited allowance of environmental permits. Such a development, in turn, could be due either to a new international agreement or to a unilateral decision to further limit emissions.

The immediate effect is to reduce the output of investment goods via the Rybczynksi channel (see equation (10)) and to create a net current account surplus. In terms of Panel (b) of Figure 5, the SS-curve shifts down.

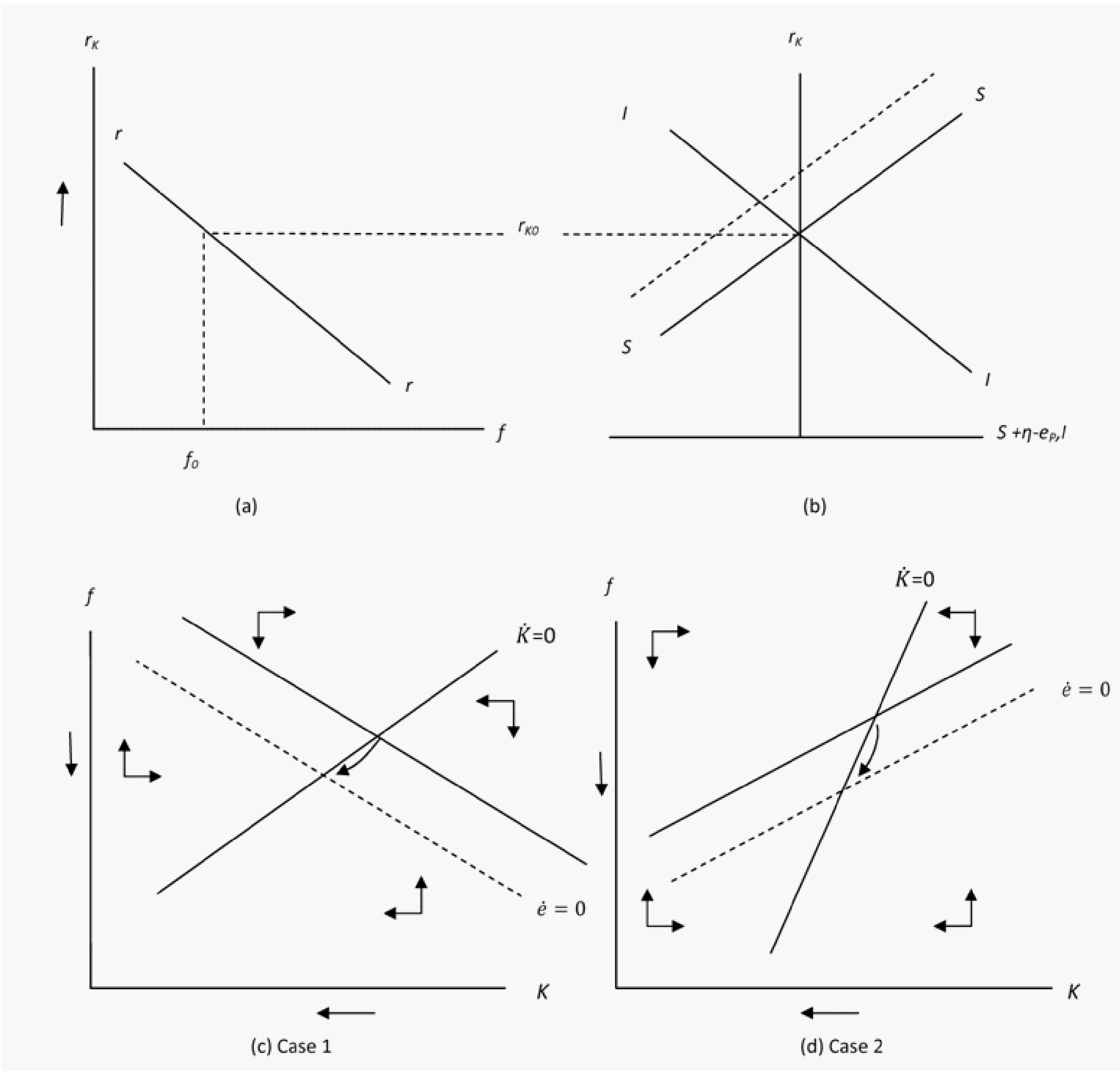

Figure 3: Fewer resource discoveries

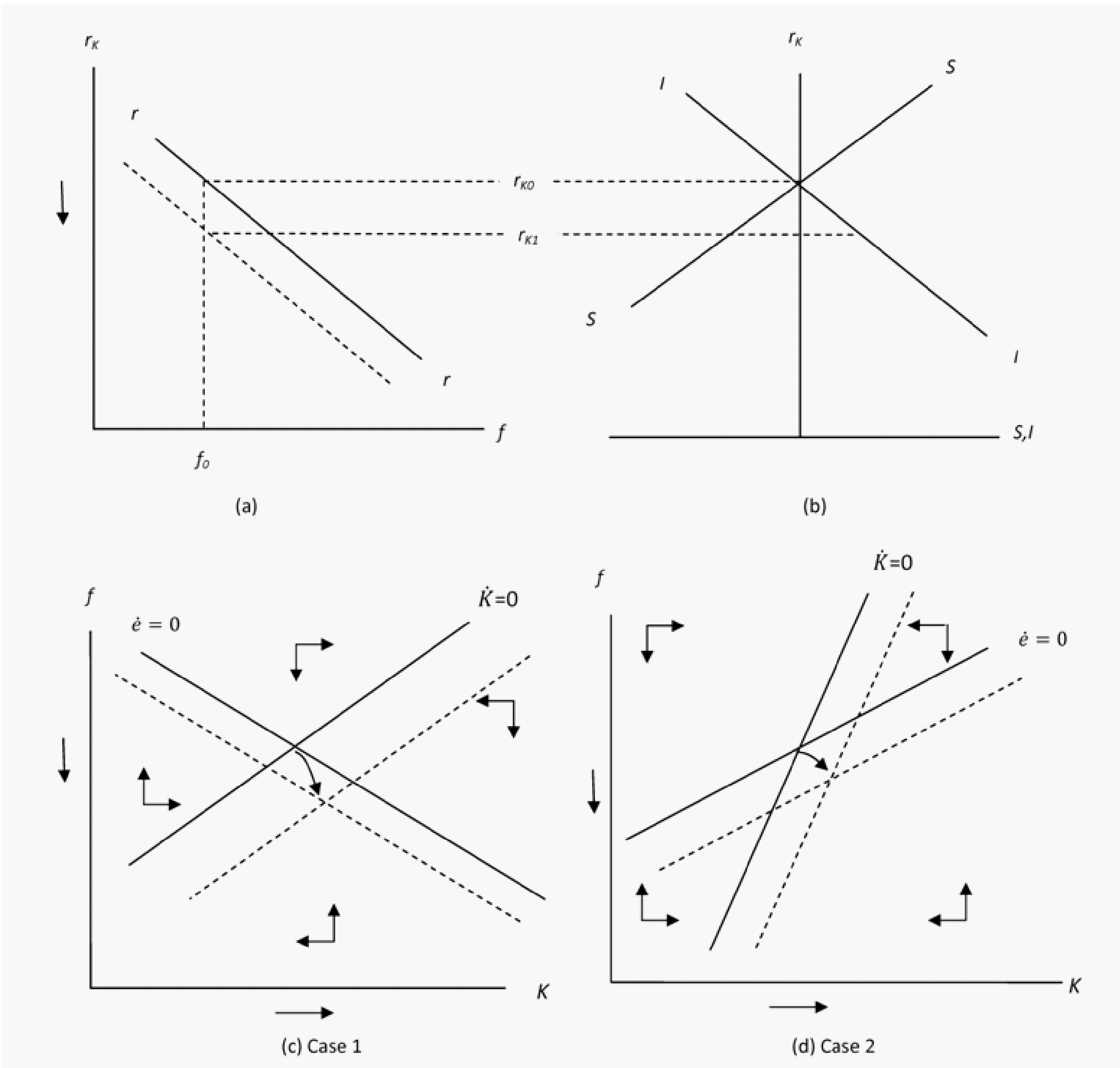

Figure 4: Shift in domestic portfolio demand toward equity

Over time, the combination of the current account surplus and lower investment leads to environmental asset accumulation by domestic agents and decumulation of real capital. Declining K has a dampening effect on capital decumulation as does the rise in f. The most direct approach to the new steady state (see Panel c of Figure 5) involves continuous net current account surpluses and capital decumulation and occurs in the presence of strong Rybczynski effects.[16] Both isoclines shift leftward, although the $\dot{e} = 0$ isocline shifts more. The steady state involves greater access to environmental assets for domestic agents but at the cost of a lower stock of physical capital.

Panel (d) illustrates the case where the Rybczynski effects are weak. In this case, the initial decline in investment due to reduced permit use is sufficiently small so that the economy continues to have a net current account surplus when capital decumulation ceases. The resulting continued expansion of environmental asset ownership that leads to a further decline in r_K then results in capital *accumulation* and the eventual steady state involves greater stocks of both environmental assets and capital than the initial steady state. Thus, the most direct path between the steady states is non-monotonic when Rybczynski effects are weak and involves capital decumulation followed by accumulation along with continuous net current account surpluses.

What are the long-run effects on the goods and factor markets? In the case where the Rybczynski channel is strong, equation (18b) implies that a higher steady state level of emission permits and lower level of physical capital stock together exist with a decline in r_K and a higher price of capital goods. An increase in the output of investment goods occurs at the expense of consumption goods. The impact on steady state savings is ambiguous, and depends on the extent to which the new higher steady state level of investment compensates for lower emission permit allowance.

Lower rental on capital means that there is substitution in production away from environmental inputs. How is substitution toward physical capital possible in the presence of full utilization of resources if the stock of capital in the new steady state is lower? The answer of course is that this is made possible by the contraction of the capital-using consumption goods sector. The emission intensity of production is now lower in the consumption goods sector, as is the overall level of emissions created by domestic producers.

Finally, could policy preempt the transitional volatility that accumulation suffers in the presence of weak Rybczysnki effects? An obvious recourse would be to penalize savings in order to dampen the shift of the $\dot{e} = 0$ isocline, or perhaps to even completely offset the initial shift of the SS-curve. Another possibility would be to take away incentives for new resource discoveries, essentially matching fewer new permits with fewer new environmental assets. Either course has political-economic implications which we do not pursue here.

[16] Note that, unlike earlier figures, Figure 5 does not show the case where the $\dot{e} = 0$ isocline is downward-sloping. The results are qualitatively identical between the two cases.

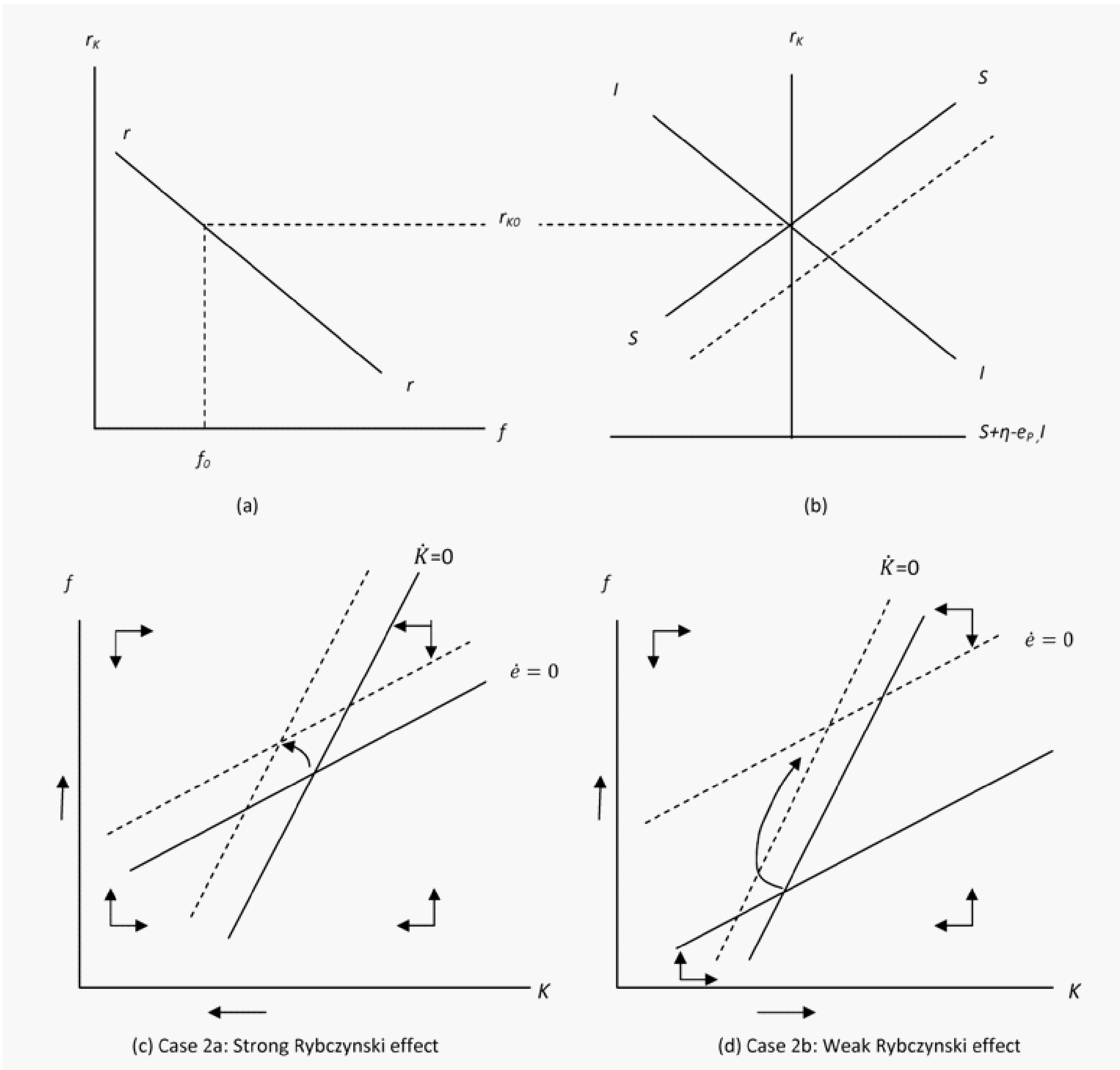

Figure 5: More restricted allowance of environmental permits

Table 2: Long-run thought experiments (effects on steady state values of endogenous variables)

	r$_K$	S	I	K	e	q_K	X_C	X_K	a_{EC}
Rise in σ	-	-*	-*	+	+	+	+*	-*	-
Decline in η	+	+*	+*	-	-	-	-*	+*	+
Rise in k^d	+	-	-	+	-	-	+	-	+
Decline in e_P**	-	?	+	-	+	+	-	+	-

* At given factor prices

** With strong Rybczynski effects

6 Concluding remarks

This paper is an attempt to incorporate macroeconomic analysis into environmental economics in order to study a world where claims on natural resources are traded among countries in the presence of a cap-and-trade regime. Recognizing the dual nature of claims on environmental resources as assets and factors of production, I develop a long-run, flexible price framework which can be used to explore long-run interactions between goods, factor, and asset markets. The set-up used is that of a price taking small country where, in line with previous literature, capital and environmental use are substitutes in production.

In the long run, a country can modify its claims on environmental resources by trading access to these with the rest of the world. Moreover, factor substitution in response to price signals may change the intensity of resource use in production. These developments, however, have structural consequences. In our model, for example, limiting the number of emission permits issued per period could result in shifting the structure of output from consumer goods to investment goods, in addition to lowering the intensity of environment use in production. Under certain conditions, however, this generates investment volatility unless countered by policy actions. A shift in domestic portfolio preferences towards equity is likely to have the opposite effect on the steady state structure of the economy as well as the steady state composition of asset portfolios. Moreover, the intensity of environment use rises in the consumption goods sector. Finally, by reducing the rental on capital, increased precautionary savings could raise the capital intensity of domestic production and boost the output of the capital-using consumption good while reducing investment.

The work presented here is suggestive. In order to simplify the analysis, we imposed substantial structure on the economy. Given the externalities involved, one would like to limit emissions across the world, not just in one country. This would require the analysis of longer-run issues such as technological change. Countries differ in terms of income, degree of industrialization, and resource intensity of production. Production of a good in a highly industrialized economy may, for example, create less pollution per unit than production of the same good in a developing country. Future work will focus on these issues and extend the ideas presented here to analyze aspects related to North-South interactions.

7 Mathematical Appendix

Equations (15), (16), (17) and (18a) yield the following partials:

$r_{KK} = -\frac{\left(1-k_w^d\right)q_K}{\Omega}$, $r_{Kf} = \frac{k_w^d q_A^*}{\Omega}$, $r_{K_{r_E^*}} = \frac{k_{r_E^*}^d}{\Omega}$, and $r_{Kk^d} = \frac{1}{\Omega}$, where $\Omega = \left(1-k_w^d\right) q_K' K - k_{r_K}^d < 0$.

The determinant of the Jacobian for the long-run dynamic system consisting of equations (19b) and (22) is given by:

$$\begin{aligned}
\Delta_1 &= \begin{vmatrix} \dot{K}_K & \dot{K}_f \\ \dot{e}_K & \dot{e}_f \end{vmatrix} \\
&= \sigma_W h_{r_K}(r_{K_K} - q_K r_{K_f}) + h_K(\sigma_W + \Lambda r_{K_f}) - \delta[\sigma_W + (\Lambda - h_{r_K}) r_{K_f}] > 0
\end{aligned}$$

where $\Lambda = \sigma_{r_K} r_{Kf} + \sigma_W q'_K K > 0$ captures the effects of r_K on savings. Thus, Δ_1 is unambiguously positive, i.e., the system is *locally* stable.

Changed saving behavior

The long-run comparative dynamic effects on steady state values are given by:

$$\frac{dK}{d\sigma} = \frac{\begin{vmatrix} -\dot{K}_\sigma & \dot{K}_f \\ -\dot{e}_\sigma & \dot{e}_f \end{vmatrix}}{\Delta_1} = \frac{h_{r_K} r_{K_f}}{\Delta_1} > 0$$

$$\frac{df}{d\sigma} = \frac{\begin{vmatrix} \dot{K}_K & -\dot{K}_\sigma \\ \dot{e}_K & -\dot{e}_\sigma \end{vmatrix}}{\Delta_1} = -\frac{h_K + h_{r_K} r_{K_K} - \delta}{\Delta_1} > 0$$

$$\frac{dr_K}{d\sigma} = -\frac{(h_K - \delta)}{\Delta_1} r_{K_f} < 0$$

The expressions for the horizontal and vertical shifts of the isoclines in Figure 2 are as follows (the signs of the shifts are for Case 2 of the text):

$$\left.\frac{\partial K}{\partial \sigma}\right|_{\dot{K}=0} = 0$$

$$\left.\frac{\partial K}{\partial \sigma}\right|_{\dot{e}=0} = -\frac{1}{(\Lambda - h_{r_K})\, r_{K_K} + \sigma_W q_K - h_K} < 0$$

$$\left.\frac{\partial f}{\partial \sigma}\right|_{\dot{K}=0} = 0$$

$$\left.\frac{\partial f}{\partial \sigma}\right|_{\dot{e}=0} = -\frac{1}{(\Lambda - h_{r_K}) r_{K_f} + \sigma_W} > 0$$

Fewer discoveries of natural resources

The long-run comparative dynamic effects on steady state values are given by:

$$\frac{dK}{d\eta} = \frac{\begin{vmatrix} -\dot{K}_\eta & \dot{K}_f \\ -\dot{e}_\eta & \dot{e}_f \end{vmatrix}}{\Delta_1} = \frac{h_{r_K} r_{K_f}}{\Delta_1} > 0$$

$$\frac{df}{d\eta} = \frac{\begin{vmatrix} \dot{K}_K & -\dot{K}_\eta \\ \dot{e}_K & -\dot{e}_\eta \end{vmatrix}}{\Delta_1} = -\frac{h_K + h_{r_K} r_{K_K} - \delta}{\Delta_1} > 0$$

$$\frac{dr_K}{d\eta} = -\frac{(h_K - \delta)}{\Delta_1} r_{K_f} < 0$$

The expressions for the horizontal and vertical shifts of the isoclines in Figure 3 are as follows (the signs of the shifts are for Case 2 of the text):

$$\left.\frac{\partial K}{\partial \eta}\right|_{\dot{K}=0} = 0$$

$$\left.\frac{\partial K}{\partial \eta}\right|_{\dot{e}=0} = -\frac{1}{(\Lambda - h_{r_K})r_{K_K} + \sigma_W q_K - h_K} < 0$$

$$\left.\frac{\partial f}{\partial \eta}\right|_{\dot{K}=0} = 0$$

$$\left.\frac{\partial f}{\partial \eta}\right|_{\dot{e}=0} = -\frac{1}{(\Lambda - h_{r_K})\, r_{K_f} + \sigma_W} > 0$$

Shift in preferences towards holding domestic equity

The impact effects on the return to equity, investment, and saving are as follows:

From equation (18b):

$$r_{K_k^d} = \frac{1}{\left(1 - k_W^d\right) q_K' K - k_{r_K}^d} < 0$$

The long-run comparative dynamic effects on steady state values are given by:

$$\frac{dK}{dk^d} = \frac{\begin{vmatrix} -\dot{K}_{k^d} & \dot{K}_f \\ -\dot{f}_{k^d} & \dot{f}_f \end{vmatrix}}{\Delta_1} = -\frac{\sigma_W h_{r_K} r_{K_k^d}}{\Delta_1} > 0$$

$$\frac{df}{dk^d} = \frac{\begin{vmatrix} \dot{K}_K & -\dot{K}_{k^d} \\ \dot{f}_K & -\dot{f}_{k^d} \end{vmatrix}}{\Delta_1} = \frac{\left[(\sigma_W q_K - \delta)h_{r_K} - \Lambda(h_K - \delta)\right] r_{K_k^d}}{\Delta_1} < 0$$

$$\frac{dr_K}{dk^d} = -\frac{\sigma_W (h_K - \delta)}{\Delta_1} r_{K_{k^d}} > 0$$

The expressions for the horizontal and vertical shifts of the isoclines in Figure 4 are as follows (the signs of the shifts are for Case 2 of the text):

$$\left.\frac{\partial K}{\partial k^d}\right|_{\dot{K}=0} = -\frac{r_{K_k^d}}{r_{K_K} + \frac{(h_K - \delta)}{h_{r_K}}} > 0$$

$$\left.\frac{\partial K}{\partial k^d}\right|_{\dot{e}=0} = -\frac{r_{K_k^d}}{r_{K_K} + \frac{\sigma_W q_K - h_K}{\Lambda - h_{r_K}}} > 0$$

$$\left.\frac{\partial f}{\partial k^d}\right|_{\dot{K}=0} = -\frac{r_{K_k^d}}{r_{K_f}} < 0$$

$$\left.\frac{\partial f}{\partial k^d}\right|_{\dot{e}=0} = -\frac{r_{K_k^d}}{r_{K_f} + \frac{\sigma_W}{\Lambda - h_{r_K}}} < 0$$

Tighter environmental regulation

The long-run comparative dynamic effects on steady state values are given by:

$$\frac{dK}{de_P} = \frac{\begin{vmatrix} -\dot{K}_{e_P} & \dot{K}_f \\ -\dot{e}_{e_P} & \dot{e}_f \end{vmatrix}}{\Delta_1} = -\frac{h_{r_K} r_{K_f} + (\Lambda r_{K_f} + \sigma_W) h_{e_P}}{\Delta_1} \gtrless 0$$

$$\frac{df}{de_P} = \frac{\begin{vmatrix} \dot{K}_K & -\dot{K}_{e_P} \\ \dot{e}_K & -\dot{e}_{e_P} \end{vmatrix}}{\Delta_1}$$

$$= \frac{h_{r_K} r_{K_K} + h_K - \delta + (\Lambda r_{K_K} + \sigma_W q_K - \delta) h_{e_P}}{\Delta_1} < 0$$

$$\frac{dr_K}{de_P} = \frac{(h_K - \delta) r_{K_f} + \left[(\sigma_W q_K - \delta) r_{K_f} - \sigma_W r_{K_K}\right] h_{e_P}}{\Delta_1} > 0$$

The expressions for the horizontal and vertical shifts of the isoclines in Figure 5 are as follows (the signs of the shifts are for Case 2 of the text):

$$\left.\frac{\partial K}{\partial e_P}\right|_{\dot{K}=0} = -\frac{h_{e_P}}{h_{r_K} r_{K_K} + h_K - \delta} > 0$$

$$\left.\frac{\partial K}{\partial e_P}\right|_{\dot{e}=0} = \frac{1 + h_{e_P}}{(\Lambda - h_{r_K}) r_{K_K} + \sigma_W q_K - h_K} > 0$$

$$\left.\frac{\partial f}{\partial e_P}\right|_{\dot{K}=0} = -\frac{h_{e_P}}{h_{r_K} r_{K_f}} < 0$$

$$\left.\frac{\partial f}{\partial e_P}\right|_{\dot{e}=0} = \frac{1 + h_{e_P}}{(\Lambda - h_{r_K})\, r_{K_f} + \sigma_W} < 0$$

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