Environment and Development Economics 8: 31–56 © 2003 Cambridge University Press
DOI:10.1017/S1355770X03000032 Printed in the United Kingdom

On Heyes' IS–LM–EE proposal to establish an environmental macroeconomics

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ABSTRACT. A decade has now passed since Daly made a plea for an environmental macroeconomics. Despite an expanding literature on 'green' national accounting and the efforts of ecological economists to measure the sustainable net benefits of a growing macroeconomy, it is only recently that Daly's plea has been adequately answered. This has been achieved with the incorporation by Heyes of an 'environmental equilibrium' or EE curve into the familiar IS–LM model. However, the IS–LM–EE model proposed by Heyes is incomplete. By extending Heyes' model to include the role of technological progress and the sustainable net benefits of economic activity, this paper shows that conclusions regarding the desirability of expansionary fiscal and monetary policies alter quite radically. Moreover, it sends out a clear message that environmental concerns should be incorporated into macroeconomic models. They should not be solely confined to microeconomics.

1. Introduction

It is ten years since Daly (1991) urged the incorporation of environmental concerns into the macroeconomic models used to conduct policy analysis. Until recently, Daly's plea has been ignored. Of course, it would be erroneous of me to overlook the many attempts to integrate environmental factors into macro policy issues. The expanding literature on 'green' national accounting, ecological tax reform, and the debate surrounding the existence of an environmental Kuznets curve is ample evidence of the extent to which environment–economy relations have made their way into policy analysis. Furthermore, considerable work has been undertaken to answer the following questions put forward by Daly at the time he was urging the development of an environmental macroeconomics: (a) How big can a macroeconomy grow before the throughput of matter-energy required to sustain the macroeconomy exceeds the regenerative and waste assimilative capacities of the natural environment? And (b) How big can a macroeconomy grow before the additional benefits of growth are exceeded by the additional costs—i.e., before the net benefits of growth begin to decline? As far as Daly is concerned, the failure of macroeconomists to deal

I would like to thank two anonymous referees for their constructive criticisms. The responsibility of any errors rests solely with myself.

with the second question is at odds with microeconomic theory. Microeconomics is based largely on the concept of optimal scale. Whether it is the output of a firm or the number of hours spent at work, the customary microeconomic rule is to increase the scale of an activity while marginal benefits exceed marginal costs. Once marginal benefits and costs equate, the expansion in the scale should cease because the optimal scale has been reached. Yet, strangely, at a time with the micro foundations of macroeconomics are gaining prominence, macroeconomics totally overlooks the concept of optimal scale.

The questions posed by Daly have not been altogether ignored. In response to the first question, 'ecological footprint' measures have been calculated at the national level to ascertain the physical scale of a nation's economic activity.[1] These have been compared with the available biocapacity of a nation to determine whether macroeconomic systems have exceeded their maximum sustainable scale. A recent study by Wackernagel *et al*. (1999) indicates that the biocapacity of 35 of the 52 countries surveyed has been exceeded. This suggests that the macroeconomies of most nations have surpassed their maximum sustainable scale.

The second of Daly's questions has been addressed by ecological economists who have sought to identify, measure, and compare the benefits and costs of economic activity at the national level (Diefenbacher, 1994; Redefining Progress, 1995; Jackson and Stymne, 1996; Stockhammer, 1997; Lawn and Sanders, 1999; and Lawn, 2001). Despite some obvious shortcomings of the methods used to calculate benefits and costs (Neumayer, 2000), the trend movement in the sustainable net benefits of growth has been similar for virtually all the countries surveyed. That is, for a certain period of time, sustainable net benefits have risen in line with real GDP but have then tended to decline (Max-Neef, 1995). As such, the macroeconomies of all the surveyed nations appear to have surpassed their optimal scale.[2]

Despite the value of ecological footprint studies and measures of sustainable net benefits, neither involve the explicit incorporation of environmental concerns into standard macroeconomic models. Clearly, they do not constitute a satisfactory response to Daly's plea for an environmental macroeconomics. This has all changed thanks to a recent proposal by Heyes (2000) to include an 'environmental equilibrium' or EE curve into the standard IS–LM framework. The new curve, which aims to incorporate an environmental constraint into the IS–LM model, has considerable implications for fiscal and monetary policy. Indeed, as I will soon show, the implications go much further than Heyes has indicated in his paper.

To consider the deeper implications of Heyes' proposal, this paper is

[1] A nation's ecological footprint refers to the area of productive land required to sustain its resource throughput requirements.

[2] Some observers believe this conclusion is an artifact of the methodologies used to measure sustainable net benefits and not a genuine reflection of empirical facts (Neumayer, 2000; England, 2001). While it is true that some of the valuation methods employed are crude, the various methodologies are, nonetheless, based on a sound theoretical foundation.

structured as follows: First, the IS–LM–EE model is briefly outlined, as is the rationale for the EE curve and the factors effecting its slope and position. Being an environmental constraint, the EE curve is only of value if appropriate institutional arrangements are in place to ensure the macroeconomy adjusts back to the curve should there be forces pushing the macroeconomy beyond it. It is therefore explained in the second section of the paper why it is necessary to institute two separate policy instruments—one to restrict the incoming resource flow to an ecologically sustainable rate; another to ensure the sustainable resource flow is efficiently allocated. The third section includes a demonstration of the difference between the effect of expansionary fiscal and monetary policies on real output in circumstances where, firstly, the separate policy instruments have been instituted (the Lawn position), and, secondly, where they have not (the Heyes position). In the final section the IS–LM–EE framework is extended to show how considerations of the maximum sustainable scale and the optimal scale of macroeconomic systems determining the desirability or otherwise of an expansionary monetary policy under the Heyes and Lawn positions.

2. The IS–LM–EE model

The IS–LM–EE framework used in this paper is an extension of an IS–LM model first expounded by Blanchard (1981). It is the same IS–LM model employed by Heyes (2000). Although not the most sophisticated in existence, it has been chosen for the same two reasons given by Heyes. First, it is the mainstay of modern macroeconomics (Blanchard and Fischer, 1989). Second, it deals with the major deficiencies of the fixed-price IS–LM model.

The IS–LM–EE framework includes the following notation:

- Y = real output (real GDP)
- A = aggregate spending on all goods
- R = long-term real interest rate
- r = short-term real interest rate
- i = short-term nominal interest rate
- π^* = expected inflation rate
- G = autonomous government expenditure
- L = demand for nominal money balances
- M = supply of nominal money balances
- P = price level
- t = time
- T = total throughput of matter energy (input of resources and output of wastes)
- E = technical efficiency of production (where $0 < E < 1$)
- β = institutional parameter capturing the extent to which spillover depletion and pollution costs are borne by the resource user and polluter (where $0 \leq \beta \leq 1$)
- γ = technological parameter capturing the state of resource-saving and pollution-reducing technological progress (where $0 \leq \gamma \leq 1$)
- s = regeneration rate of the natural environment (natural capital)
- N = physical stock of natural capital.

The IS curve

It will be assumed that household expenditure on consumer goods as well as investment spending on producer goods are influenced by the long-term real interest rate R. It will also be assumed that real output adjustments to changes in aggregate spending are sluggish. By denoting the aggregate spending on all goods as $A(R, Y, G)$, adjustments in real output can be written as

$$\frac{dY}{dt} = \phi[A(R, Y, G) - Y] \\ = \phi(R, Y, G) \quad (1)$$

where $\phi_R < 0$, $\phi_Y < 0$, and $\phi_G > 0$. Because equilibrium in the goods market requires $A = Y$, equation (1) defines the IS curve in (R, Y) space when $dY/dt = 0$. The slope of the IS curve is $-\phi_Y/\phi_R$ which is negative. An increase in G, which implies an expansionary fiscal policy, activates a rightward shift of the IS curve.

The LM curve

To derive the LM curve, it is assumed that agents have rational expectations and are risk neutral. It is also assumed that asset holders equalize the rates of return on short-term nominal bonds and real consols such that

$$R - \frac{dR/dt}{R} = r \quad (2)$$

Since $r = i - \pi^*$ then

$$R - \frac{dR/dt}{R} = i - \pi^* \quad (3)$$

Money market equilibrium requires the demand for money to equal the supply of real money balances. This is where

$$M/P = L(i,Y) \quad (4)$$

By rearranging equation (3) and substituting for i in equation (4), one obtains the following equilibrium equation for the money market

$$\frac{M}{P} = L\left(R - \frac{dR/dt}{R} + \pi^*, Y\right) \quad (5)$$

Equation (5) defines the LM curve in (R, Y) space when $dR/dt = 0$. The slope of the LM curve is positive. An expansionary monetary policy, which involves an increase in the nominal money supply M, leads to a rightward shift of the LM curve. Macroeconomic equilibrium occurs where the IS and LM curves intersect, that is, at an (R, Y) combination where both the goods and money markets are in equilibrium.

The EE curve

To explain the rationale for the EE curve, imagine a fixed state of technological progress. Imagine, also, that the throughput of matter-energy required to produce the equilibrium output level exceeds the regenerative and waste assimilative capacities of the natural environment. This would render the output level unsustainable in the sense that natural capital stocks would diminish and thus be unable to provide the required rate of throughput in the long-run. Of course, technology is not fixed and improvements in the range of all production techniques enable a given level of output to be sustained by a lessened rate of throughput. To some observers, this constitutes a substitution of human-made capital for resource-providing natural capital. This is a false observation, for three main reasons. First, genuine substitution requires human-made capital to reproduce itself without the need for natural capital. Yet natural capital is the only provider of low entropy matter-energy—the *material* cause of production (Georgescu-Roegen, 1971; Daly, 1996). Hence the absence of natural capital precludes the production of any quantity of output, indeed, the very existence of human-made capital itself. Second, from a physical perspective, the technological progress embodied in human-made capital merely reduces the high entropy waste generated by the production process (Lawn, 1999). Because of the first and second laws of thermodynamics, there is a limit to by how much production waste can be reduced—there can be no 100 percent production efficiency; there can never by 100 per cent recycling of matter; and there is no way to recycle energy at all. Consequently, a minimum amount of resource-providing natural capital is necessary to produce a given quantity of output. Third, the quantity of natural capital required to maintain critical life-support services far exceeds the quantity needed to sustain the economic process alone. Clearly, natural capital and human-made capital are complements, not substitutes. As such, sustainability requires the maintenance of both forms of capital. The need for natural capital intactness implies that a macro-environmental constraint should be incorporated into the standard IS–LM framework. It is the EE curve that, in (R,Y) space, constitutes the necessary macro-environmental constraint.

To construct the EE curve, let E be the technical efficiency of resource use in production, where (Ayres, 1978)

$$E = \frac{\textit{available energy embodied in real output produced } (Y)}{\textit{available energy embodied in resource throughput } (T)} \tag{6}$$

For reasons just given in relation to the complementarity of natural and human-made capital, E is always less than one. At equilibrium, E is determined by the aggregate choice of production techniques. The more resource intensive and/or highly pollutive are the techniques used by producers, the lower is E. It will be assumed that E is a function of R, β and γ, that is, $E = E(R, \beta, \gamma)$. Low values of R and high values of β induce the adoption of cleaner production techniques from the range of available techniques. In addition, an increase in γ avails producers with more advanced resource-saving and pollution-reducing techniques. Increases in γ also make it easier and therefore less costly to produce at a given technical efficiency level. Hence $E_R < 0$, $E\beta > 0$, and $E\gamma > 0$.

Unlike Heyes, I do not believe that the freedom to choose among the range of available techniques amounts to an assumption that natural and

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human-made capital are substitutes. Yes, producers can opt for dirty techniques; however, because the total rate of throughput must not exceed the long-term carrying capacity of the natural environment, dirtier techniques mean a reduction in the maximum permissible output level. If natural and human-made capital were substitutes then, presumably, the permissible output level should remain unchanged because a higher rate of throughput and a subsequent diminution of natural capital could simply be offset by a larger stock of human-made capital. Yet, since Heyes' construction of the EE curve is based on the need to keep natural capital intact his model forbids what the substitutability condition supposedly permits.

By rearranging equation (6) the total throughput of matter-energy used in the economic process can be denoted by $T = Y/E$, where $T_Y > 0$ and $T_E < 0$. As such, the total throughput of matter-energy used can be written as

$$T = \frac{Y}{E(R, \beta, \gamma)} \tag{7}$$

Let N_t denote the physical stock of natural capital at time t. Assume, also, that natural capital regenerates at a rate equal to $s.N_t$.[3] It follows, therefore, that the net rate of natural capital enhancement/depletion is

$$-\left(\frac{dN}{dt}\right) = T - s.N \tag{8}$$

$$\therefore \quad -\left(\frac{dN}{dt}\right) = \frac{Y}{E(R, \beta, \gamma)} - s.N \tag{9}$$

Since environmental equilibrium requires natural capital intactness, equation (9) defines the EE curve in (R, Y) space when $dN/dt = 0$. Differentiation of equation (9) implies that the EE curve has the following slope

$$\left.\frac{dR}{dY}\right|_{dN/dt=0} = \frac{E}{Y.E_R} \tag{10}$$

Because $E_R < 0$, the slope of the EE curve is negative. However the slope will change over the length of its locus. Indeed it will be steep whenever the technical efficiency of production is insensitive to changes in R. As figure 1 demonstrates, this will increasingly be the case as the maximum permissible output level is approached (Y_{max}). The reason for this is

[3] Of course natural capital, like human-made capital, is not a uniform physical stock but a diverse set of physical stocks. Denoting N as the physical stock of natural capital, as I have done, ignores some of the aggregation issues associated with macroeconomic theory. Having said this, a change in the make-up of the total stock of natural capital is likely to affect its productivity. That is, while more of one type of natural capital and less of another may leave the total physical stock of natural capital unchanged, the differing productivity of the various forms of natural capital is likely to alter the productivity of the entire stock. This would alter the value of s. Thus, by having N denote the physical quantity of natural capital and s its productivity or quality, the aggregation problem is somewhat allayed.

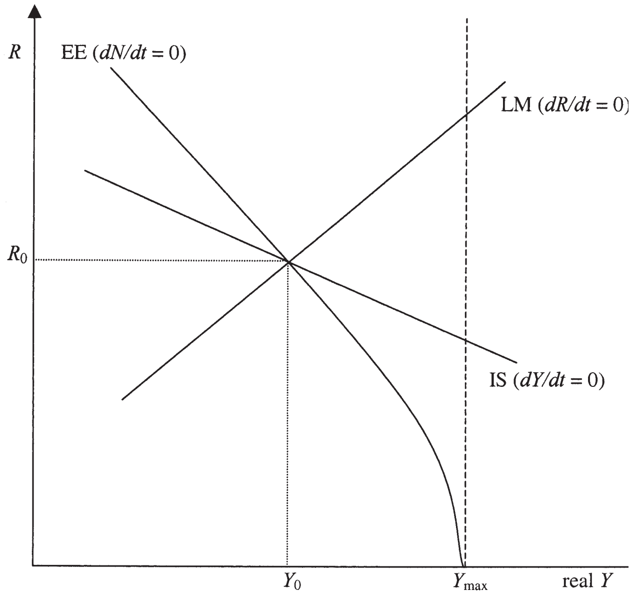

Figure 1. *Environmental-macroeconomic equilibrium*
Source: Philip Lawn, 'Environmental macroeconomics: extending the IS–LM model to include an environmental equilibrium curve', *Australian Economic Papers*, edited by Richard Damania, Oxford: Blackwell.

straightforward. As real output approaches Y_{max}, the marginal cost of pollution abatement becomes progressively higher. So, therefore, does the marginal cost of employing cleaner production techniques to increase the technical efficiency of production. Consequently, an increasingly larger decline in the real rate of interest is necessary to render a switch to a cleaner production technique profitable. Once Y_{max} is reached, and the cleanest available technique is employed, further resource savings and reductions in pollution are no longer possible through a switch in production technique alone. It is at this point that the EE curve is effectively vertical (i.e., $E_R \rightarrow 0$ and the slope $\rightarrow \infty$).

Figure 1 also shows how the EE curve is incorporated into the standard IS–LM diagram. With all three curves intersecting at the same point, figure 1 depicts an environmental–macroeconomic equilibrium whereby the interest rate/output combination of (R_0, Y_0) leads to environmental equilibrium as well as equilibrium in both the goods and money markets. Like Heyes, figure 1 is presented such that the intersection point is where the EE curve is steeper than the IS curve. This need not be the case, but will be assumed in order to simplify later comparisons with Heyes' paper.

To explain the position of an EE curve and the factors that cause it to shift, consider figure 2. The first curve is EE_0 where $\beta < 1$ and $\gamma < 1$. In this instance, not all spillover costs are borne by resource users and polluters. Furthermore, should the cleanest available production technique be

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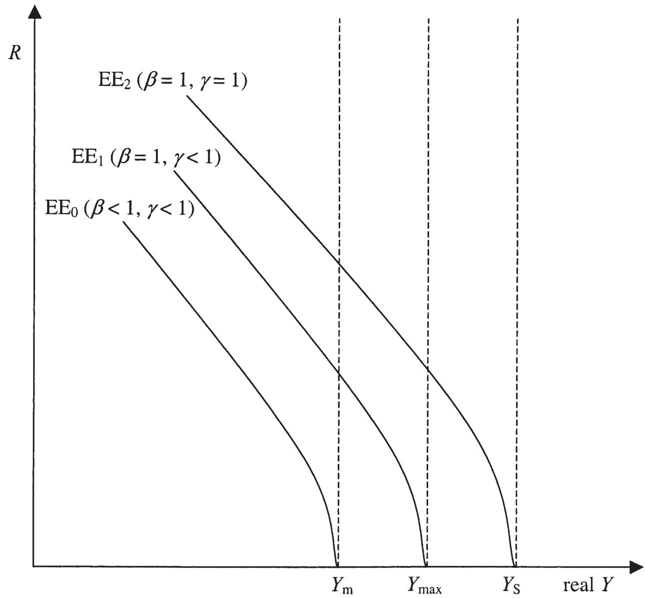

Figure 2. *Position and shift of the EE curve*
Source: see figure 1.

employed, the technical efficiency of production is less than the thermodynamic limit of $E \rightarrow 1$. EE_0 is near vertical at Y_m to denote the maximum permissible output level.

Now consider EE_2, where $\beta = 1$ and γ is the same as for EE_1. The only difference between EE_0 and EE_1 is that spillover depletion and pollution costs are now entirely borne by resource users and polluters. The increase in β causes the EE curve to shift rightward. It also leads to an increase in the maximum permissible output level from Y_m to Y_{max}. The reason for this is obvious. As β increases to a value of one and the environmental spillover costs of economic activity are fully internalized, the cost of dirty forms of production increases relative to cleaner alternatives. This results in resources being allocated towards cleaner production techniques and, thus to an in crease in the sustainable output level.

Once $\beta = 1$, a rightward sift of the EE curve can only be secured via increases in γ. Consider, in figure 2, the shift of the EE curve from EE_1 to EE_2, where $\beta = 1$ and $\gamma = 1$. In this particular instance, the maximum permissible output level increases from Y_{max} to Y_S. Y_S differs to Y_{max} in that it is no longer institutionally or technologically possible to increase output without exceeding the natural environment's long-term carrying capacity. Hence, the EE curve can no longer shift rightward of EE_2. Furthermore, Y_S stands as the maximum sustainable output level.

How does my EE curve differ to that of Heyes? They are in many ways the same except the EE curve I am proposing includes the technological parameter γ. The reason for incorporating this shift parameter will become obvious later in the paper. Like Heyes I will ignore the fact that both s and N can serve as additional shift parameters. Increases in both variables lead to a rightward shift in the EE curve. I have decided to overlook this because, firstly, there is insufficient space to incorporate it into the analysis. Second, while increases in s and N can augment the maximum sustainable rate of throughput, any such increases can only be achieved very slowly (Norgaard, 1984).[4] Interestingly, as Heyes pointed out, the EE curve can shift leftward if the total throughput used to produce a given level of output exceeds the carrying capacity of the natural environment. This is because an excessive output level degrades the natural environment and diminishes its future capacity to provide low entropy resources and absorb high entropy wastes. Again, for simplification and lack of space, environmental feedback effects of this sort will be ignored.

3. Ensuring the macroeconomy adjusts towards the EE curve

As I pointed out in the introduction, incorporating an environmental constraint into the IS–LM model is of little value if the macroeconomy is unable to adjust back to an interest rate/output combination existing on the EE curve. Natural forces already exist to ensure the macroeconomy adjusts towards the IS and LM curves. In my opinion, there are no natural forces to ensure a macroeconomic adjustment towards the EE curve. To explain why, assume that the macroeconomy is operating at an interest rate/output combination to the right of the EE curve (i.e. where $T > s.N$). For the macroeconomy to move back on to the EE curve, resource markets must reduce the total throughput of matter-energy to a rate equal to the regenerative and waste assimilative capacities of natural capital. Unfortunately, markets are unlikely to accomplish this, even if all spillover costs have been fully internalized (Howarth and Norgaard 1990; Norgaard, 1990; Bishop, 1993; Daly, 1996; Lawn 2000). The reasons are as follows. First, relative price signals only provide information regarding the scarcity of one thing relative to another, for instance the scarcity of one type of resource (oil) relative to another (coal). While this information is useful in terms of how to best allocate oil, coal, and other resources, sustainability is a question of the absolute scarcity of the non-substitutable low entropy that sustains the economic process, not the relative scarcity of its constituent types. Second, relative prices are generated by market demand and supply forces that are essentially flow-based forces. In other words, the demand for resources refers to the inflowing quantity of low entropy resources demanded by resource buyers, whereas the supply of resources refers to the inflowing quantity of the various types and grades of low entropy resources being supplied by resource sellers. While the stock of a particular resource has some bearing over the inflowing quantity being supplied, the supply of a particular incoming flow at any point in time is much less restricted than the supply of the same incoming flow

[4] Increases in N are confined to the expansion of renewable natural capital. Discoveries of non-renewable resources do not increase the maximum sustainable rate of throughput unless some of the proceeds earned from their exploitation are used to augment renewable resource stocks (Lawn, 1998).

over time. For example, if timber suppliers opted to double the quantity of timbers supplied in a timber market, they could do so for some limited period of time even if the supply rate exceeded the capacity of forests/timber plantations to supply the same quantity of timber over time. As for the suppliers of a non-renewable resource, say oil, any quantity supplied at a particular point in time cannot be continued indefinitely. What is the significance of this? In the short term, when a larger yet unsustainable quantity of a particular resource is being supplied, it is possible for its relative price to fall. Is this fall in price a reflection of its declining absolute scarcity? No. It is a reflection of a higher inflowing quantity (declining relative scarcity) at a time when the remaining stock is shrinking (increasing absolute scarcity).

It is true that the stock effect on resource prices must eventually outweigh the flow effect since, on the supply side, resource prices are also influenced by the cost of extraction/harvesting. This cost must eventually rise sharply as it becomes increasingly difficult to sustain the same inflowing quantity from an ever-diminishing stock. Clearly, resource prices must eventually reflect an increase in the absolute scarcity of low entropy. But there are two main reasons why the conveyance of this information in markets is likely to be delayed. First, resources themselves are required to extract/harvest resources. If the prices of the resources used to extract/harvest new resources are understated, so is the cost of extraction. This, in turn, understates the cost of future extraction, and so on. Second, futures markets are designed to capture the stock effect on future supplies of particular resources. For example, if the stock of a particular resource is severely limited so will be future supplies. One would expect the price of a rapidly dwindling resource in a futures contract to be very high to reflect the shortage of future supplies. While the price might well be higher, it is unlikely to be sufficiently high because people have the tendency to discount future values, including the cost to future generations of having small resource stocks. This might in no way threaten the intergenerational efficiency of resource use; however intergenerational efficiency does not guarantee intergenerational equity (sustainability) in the same way intragenerational efficiency need not coincide with intragenerational equity. In all, the price signals generated by resource markets, including futures markets, are ineffective at ensuring natural capital maintenance and a sustainable resource flow.

Since ecological sustainability is a throughput problem, not an allocation problem, getting the macroeconomy to automatically operate on an EE curve requires two policy instruments—one to restrict the incoming resource flow to an ecologically sustainable rate; another to ensure the incoming resource flow is efficiently allocated. The need for two distinct policy instruments arises because the resolution of separate policy goals requires the application of separate policy instruments (Tinbergen 1952; Daly, 1996). One highly feasible means of instituting this policy approach is to introduce assurance bonds and a system of tradeable resource use permits—what will henceforth be referred to as the Lawn position (Lawn, 2000). By auctioning off a limited number of resource use permits, a government can restrict the incoming resource flow to the maximum sustainable rate. Meanwhile, the premium paid for permits can serve as a throughput tax to facilitate its efficient allocation. Assurance bonds are required because, as a consequence of the Entropy Law, a quantitative restriction on the incoming resource flow has no influence on the qualitative nature of outgoing waste. Pollution taxes are a possible option; however, because the cost of pollution often takes considerable time to emerge, polluters only pay for the cost of their pollutive activities at some stage in the future. Since people discount future values, the prospect of having to pay much later is less of a disincentive to pollute than having to pay upfront. Assurance bonds overcome this problem by bringing into the present decision-making domain the potential ecological damage caused by highly toxic and intractable wastes (Costanza and Perrings, 1990).[5] This promotes an acceleration of investment into pollution-reducing human-made capital, thereby minimizing the pollution impact on the natural environment.

Another way of getting the macroeconomy to operate on the EE curve is to sift the IS and/or LM curves so that the intersection of both curves lies on an EE curve. This can be done with the use of fiscal and monetary policy settings. Since this was the approach adopted by Heyes (2000), it will henceforth be refereed to as the Heyes position. There is, however, a major problem with this approach. The policy setter must know exactly what variations in policy settings are required to shift the IS and/or LM curves sufficiently to move the macroeconomy back to the EE curve. In addition, the policy setter must be knowledgable of the impact on the IS and LM curves of any changes in exogenous variables. This is a near impossible task. The same problem does not arise with a resource use permit system because, first and foremost, the permissible incoming resource flow is restricted to the maximum sustainable rate. This ensures the macroeconomy adjusts back to the EE curve. Furthermore, with the premium paid for permits being able to facilitate the efficient allocation of the incoming resource flow, a resource use permit system can also induce beneficial shifts of the EE curve. This does not occur when fiscal and monetary and monetary policy settings are used to move the macroeconomy back on to the EE curve. More on this soon.

4. Fiscal and monetary policy within the IS–LM–EE framework

Fiscal and monetary policy settings can be used to achieve any one of a number of macroeconomic objectives. For now, consideration is given to

[5] With assurance bonds, a polluting firm pays upfront a bond equal to the cost of the worst-case pollution scenario. Should the owners of the firm be able to demonstrate that the pollution generated has had no deleterious impact on the natural environment, they receive the bond back in full plus any interest accrued over the period in which the bond has been held by a government authority. If the pollution has had an undesirable impact on the natural environment, the bond is confiscated either in full (where pollution damage equals the worst case scenario) or in part (where pollution damage is something less than the worst case scenario). If the worst case scenario is unacceptably risky (i.e., it involves highly toxic substances), the generation of the substances in question may require prohibition or generation under very strictly controlled conditions.

the likely impact of expansionary fiscal and monetary policies on the equilibrium output level. To demonstrate the full effect of both policies within the IS–LM–EE framework, the following is assumed:

- The policy setter is omniscient with respect to what is required to ensure the intersection of the IS and LM curves lies on an EE curve.
- All spillover costs are borne by the resource user and polluter (i.e., $\beta = 1$).
- Prior to any expansionary fiscal or monetary policy the technological parameter capturing the state of resource-saving and pollution–reducing technological progress is less than one (i.e. $\gamma < 1$). This allows for technological progress following an expansionary fiscal or monetary policy and, thus, a rightward shift of the EE curve;
- If the rate of throughput exceeds the regenerative and waste assimilative capacities of the natural environment, resource prices will only rise to fully reflect ecological *limits*, not just spillover costs, if the incoming resource flow has been explicitly restricted to the maximum sustainable rate (i.e. if a resource use permit system has been introduced).[6]

An expansionary fiscal policy

Figures 3 and 4 illustrate the impact of an expansionary fiscal policy on the equilibrium output for a different set of underlying conditions. Figure 3 is the impact under the Heyes position, where macro policy settings are used to ensure the intersection of the IS and LM curves lies on the EE curve. Figure 4, on the other hand, is the impact under the Lawn position, where assurance bonds and a resource use permit scheme have been instituted.

In figure 3, the macroeconomy is initially at the equilibrium point *a* where the equilibrium interest rate/output combination is (R_0, Y_0). Due to an increase in *G*, the IS curve shifts rightward to IS_1. A new macroeconomic equilibrium is established at point *b*, where, if no environmental constraint is imposed, the equilibrium output level increases to Y_0^1. However, the new macroeconomic equilibrium is inconsistent with environmental equilibrium (i.e., $T > s.N$). To keep natural capital intact, the fiscal expansion must be accompanied by a monetary contraction—a leftward shift of the LM curve to LM_1. This moves the macroeconomy to a new environmental–macroeconomic equilibrium at point *c*. The interest rate/output combination at the new equilibrium position is (R_1, Y_1). Overall, the real interest rate has increased while real output has fallen.

Figure 4 is the same as figure 3 from point *a* to point *b*. However on this occasion the excess demand for low entropy matter-energy leads to a rise in resource prices as resource buyers bid up the price of the limited number of resource use permits. This increases the resource input cost of the production process. Exactly how much of this transfers into higher goods prices depends on the extent of any resource-saving technological

[6] This assumes that resource prices in resource markets will not, by themselves, rise to reflect an increase in the absolute scarcity of low entropy matter-energy. I could instead assume that resource prices will rise to some degree. However, my aim is to show the implications if they do not fully reflect ecological limits. For ease of exposition, it is better to assume that resource prices will not rise at all.

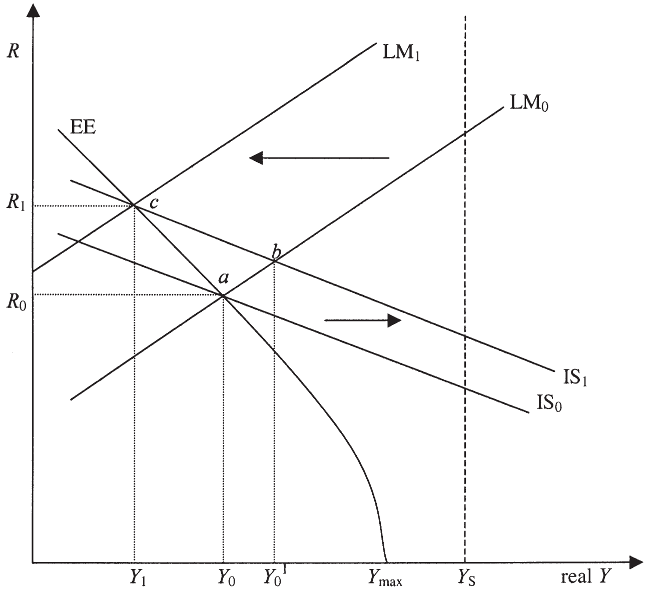

Figure 3. *Expansionary fiscal policy (no tradeable resource use permits)*
Source: see figure 1.

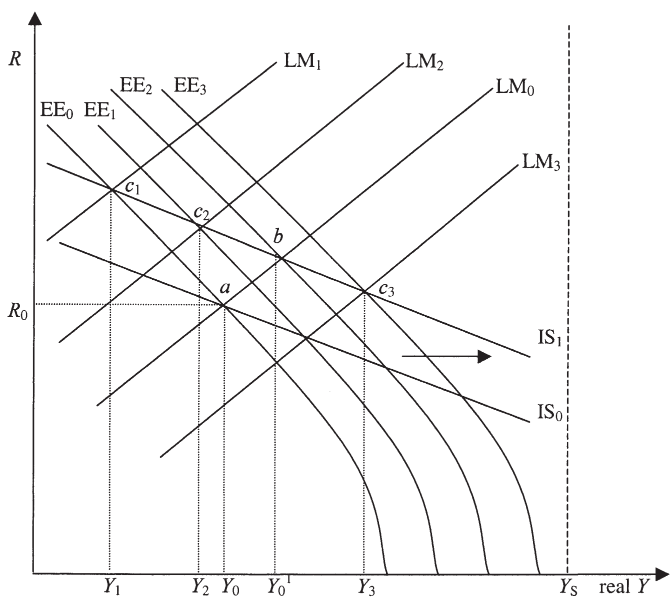

Figure 4. *Expansionary fiscal policy (with tradeable resource permits)*
Source: see figure 1.

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progress induced by the higher resource costs. If there is no subsequent technological progress (i.e. γ remains unchanged), two things will happen. First, the EE curve will maintain its present position at EE_0. Second, higher resource input costs will flow on into higher goods prices such that the LM curve will shift leftward to LM_1. The LM curve shifts because higher goods prices reduce the supply of real money balances (i.e., M/P falls). With a new environmental–macroeconomic equilibrium at point c_1, real output falls to Y_1 as it did in figure 3.

What, however, if the higher resource costs led to the development of resource-saving technological progress? The EE curve will shift rightward. The shifts from EE_0 to EE_1, EE_2, and EE_3 represent different degrees of technological progress, whereby the shift to EE_3 represents the highest progress. The movement of the LM curve also depends on the extent of any technological progress. Consider the shift of the EE curve to EE_1 and the accompanying shift of the LM curve to LM_2. In this particular instance, there has been a small increase in resource-saving progress. While, to some extent this nullifies the impact of higher resource input costs, it is insufficient to prevent goods prices from rising. Nevertheless, the rise in goods prices is less than the case of no technological progress. Consequently, the LM curve does not shift as far leftward; however, it shifts sufficiently enough to restore environmental–macroeconomic equilibrium, this time at point c_2. Overall, real output falls slightly to Y_2.

The shift of the EE curve to EE_2 is the result of a much larger increase in technological progress. On this occasion, there is no rise in goods prices and, therefore, no shift of the LM curve. The new environmental–macroeconomic equilibrium moves to point *b* and, overall, real output increases to Y_0^1—the same output level when no environmental constraint is imposed. Where the EE curve shifts to EE_3, the extent of the resource-saving technological progress is sufficient to cause goods prices to fall. This leads to a rightward shift of the LM curve to LM_3, a new environmental–macroeconomic equilibrium at point c_3, and an increase in real output to Y_3.

Note the benefit of having in place a resource use permit scheme to restrict the incoming resource flow to the maximum sustainable rate. The LM curve automatically shifts to ensure the IS and LM curves intersect at a point lying on the newly positioned EE curve. In addition the induced technological progress leads to a beneficial shift of the EE curve and the potential to sustain a higher output level.

An expansionary monetary policy

Figures 5 and 6 illustrate the comparative impact of an expansionary monetary policy. Figure 5 is the impact under the Heyes position, while figure 6 is the impact under the Lawn position. In figure 5, the macroeconomy is initially at the equilibrium point *a* where the equilibrium interest rate/output combination is (R_0, Y_0). Because of an increase in *M*, the LM curve shifts rightward to LM_1. A new macroeconomic equilibrium is established at point *b* where, if no environmental constraint is imposed, the equilibrium output level increases to Y_0^1. Again, the new macroeconomic equilibrium is inconsistent with environmental equilibrium. To keep

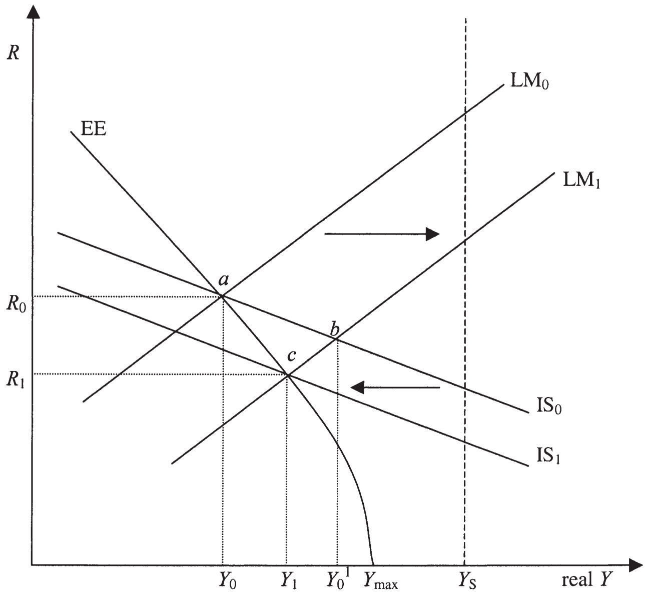

Figure 5. *Expansionary monetary policy (no tradeable resource use permits)*
Source: see figure 1.

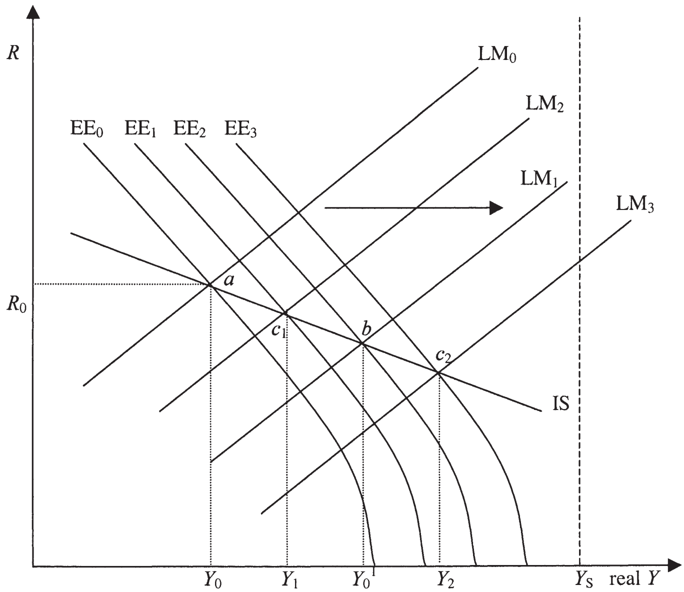

Figure 6. *Expansionary monetary policy (with tradeable resource use permits)*
Source: see figure 1.

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natural capital intact, the monetary expansion must be accompanied by a fiscal contraction—a leftward shift of the IS curve to IS_1. This moves the macroeconomy to point *c*. The interest rate/output combination at the new environmental–macroeconomic equilibrium is (R_1, Y_1). Overall the real interest rate has declined while real output has increased, although the extent of the increase in output is less than a situation where no environmental constraint has been imposed (i.e., $Y_1 < Y_0^1$).

Figure 6 is again the same as figure 5 from point *a* to point *b*. Once more, the excess demand for low entropy matter-energy leads to a rise in resource prices and an increase in the resource input cost of the production process. If the increase in resource input costs fails to induce any technological progress, the EE curve maintains its present position at EE_0. In addition, the higher resource input costs flow on into higher goods prices such that the LM curve shifts back to its original position. Overall, the new environmental–macroeconomic equilibrium is back at point *a*. In addition, real output remains unchanged at Y_0.

The shifts from EE_0 to EE_1, EE_2, or EE_3 represent different degrees of technological progress. Once again the movement of the LM curve depends on the extent of any technological progress. The greater is the degree of technological progress, the larger is the new equilibrium output level. A combined shift of the EE curve to EE_1 and the LM curve to LM_2 (minimal technological progress) brings about a new environmental–macroeconomic equilibrium at point c_1 and an increase in real output to Y_1; a shift of the EE curve to EE_2 and no accompanying shift of the LM curve (larger increase in technological progress) produces a new equilibrium at point *b* and a rise in real output to Y_0^1; while a combined shift of the EE curve to EE_3 and the LM curve to LM_3 (considerable technological progress) brings about a new equilibrium at point c_2 and an increase in real output to Y_2. In this latter case, real output increases beyond the level achieved when no environmental constraint is imposed (i.e., $Y_2 > Y_0^1$).

5. Maximum sustainable scale and optimal scale

Give the above, is an expansionary fiscal policy to be preferred to an expansionary monetary policy? This will depend on a number of things. First, it will depend on the relative slopes of the IS, LM, and EE curves. Figures 3–6 confine the analysis to circumstances where the EE curve is steeper than the IS curve. Second, it will depend on whether the prevailing conditions are consistent with the Heyes or Lawn position. Based on figures 3 and 5 (the Heyes position), an expansionary monetary policy leads to an increase in sustainable equilibrium output, while an expansionary fiscal policy causes it to fall. This suggests that an expansionary monetary policy is preferred. As for figures 4 and 6 (the Lawn position), determining the impact of expansionary fiscal and monetary policies is not as clear-cut. This is because the overall impact depends on the extent of any resource-saving technological progress.

There is, however, a third factor to consider. Since the well-being of a nation depends on the sustainable net benefits of economic activity (Daly, 1996; Lawn and Sanders, 1999; Lawn, 2001), ascertaining the impact of expansionary fiscal and monetary policies requires a comparison of production benefits and production costs. If the latter are increasing faster than the former a policy that leads to an increase in output will lower sustainable net benefits. Hence, an evaluation of fiscal and monetary policies cannot be made simply by observing the impact on the equilibrium output level.

To incorporate the impact on sustainable net benefits, consider figure 7. It will again be assumed that $\beta = 1$ and $\gamma < 1$. Panel 7a depicts an environmental–macroeconomic equilibrium condition. The equilibrium interest rate/output combination is (R^*, Y^*). Panel 7b is a 45° line to allow the real output level in panel 7a to be extended to panel 7c. The vertical axis in panel 7b indicates that real output is the sustainable production level when the macroeconomy is operating on the EE curve. Moreover, Y_{max} indicates the maximum permissible production level at the prevailing state of technological progress. Y_S, on the other hand, indicates the maximum sustainable production level once technical efficiency reaches the thermodynamic limit of $E \rightarrow 1$ (i.e., once $\gamma = 1$).

Panel 7c depicts a consumption line where the consumption level (C) is equivalent to the physical depreciation rate (d) of the total stock of all goods (S). That is, $C = d.S$. The stock of goods, which indicates the physical scale of the macroeconomy expands if production exceeds consumption. Naturally the scale of the macroeconomy stabilizes once the two equate. For an equilibrium output level of Y^*, the physical scale of the macroeconomy is S^*. At the prevailing state of technological progress, the maximum sustainable scale of the macroeconomy is S_{max}. S_s indicates the maximum sustainable scale once $\gamma = 1$.

Panel 7d includes two curves to represent the benefits and costs of an expanding macroeconomic scale. The uncancelled benefits (UB) curve represents the net psychic income (net utility) yielded by a growing macroeconomy.[7] The characteristic shape of the UB curve is attributable to the law of diminishing marginal benefits which, barring improvements in the service-yielding qualities of all newly produced goods, is equally applicable to the total stock of goods as it is to individual items. The cost of increasing the physical scale of the macroeconomy is represented by the uncancelled cost (UC) curve. It represents the source, sink, and life-support services lost in the process of transforming natural capital into physical goods. The shape and nature of the UC curve is attributable to the law of increasing marginal costs—a reflection of the increase in costs arising from the macroeconomy growing relative to a finite natural environment. The UC curve is vertical at S_{max} to indicate that the uncancelled cost of economic activity is infinite once the incoming resource flow exceeds the carrying capacity of the natural environment. For any given macroeconomic scale, sustainable net benefits are measured by the vertical distance between the UB and UC curves. Sustainable net benefits are maximized at a macroeconomic scale of S^* (i.e. when sustainable net benefits = SNB*). Thus, S^* denotes the optimal macroeconomic scale. Overall, figure 7 has

[7] See Lawn (2000 and 2001) for more on net psychic income, uncancelled benefits, and uncancelled costs.

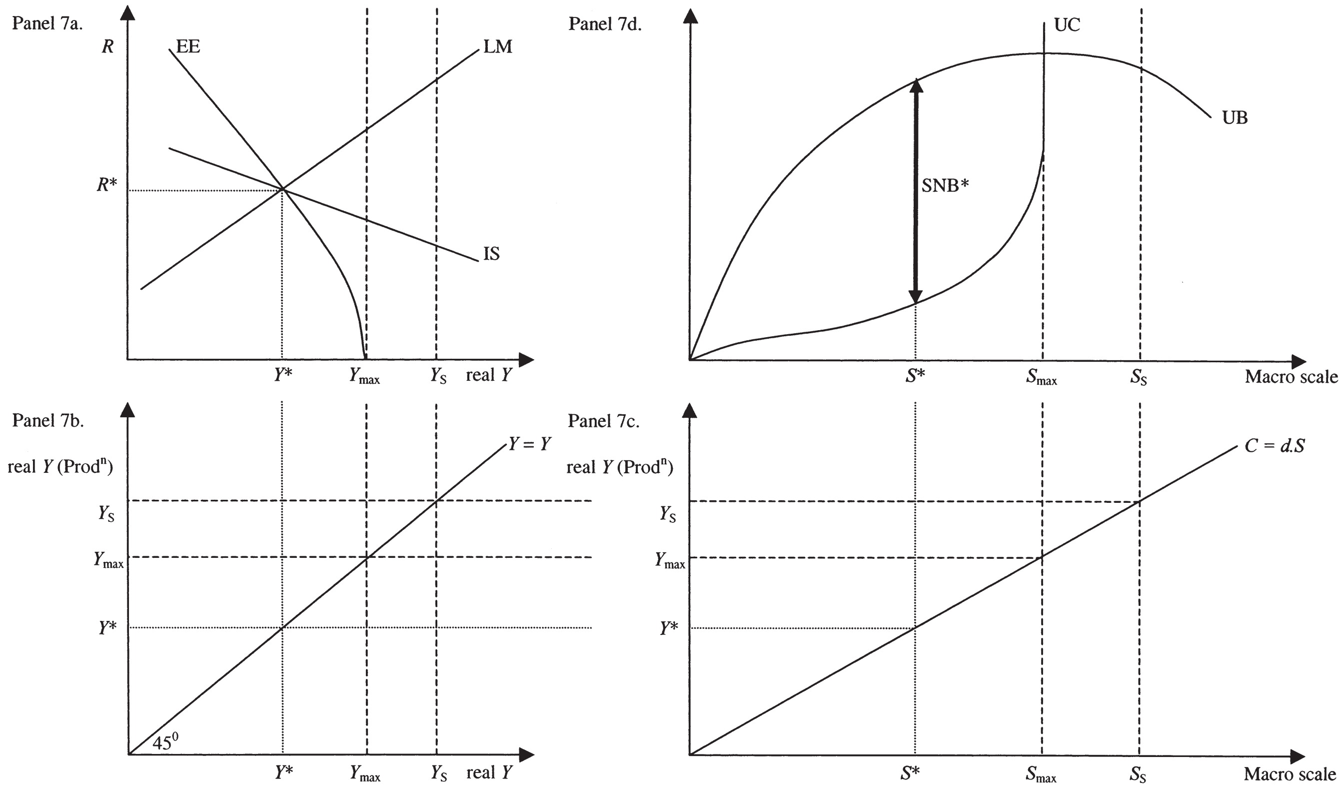

Figure 7. *IS–LM–EE and sustainable net benefits (optimal macroeconomic scale)*

been drawn so the optimal macroeconomic scale is consistent with the prevailing environmental–macroeconomic equilibrium.

Now consider figure 8 where an expansionary fiscal policy is enacted under the Heyes position (no tradeable resource use permits). Prior to the fiscal expansion, the initial environmental–macroeconomic equilibrium at point *a* is such that the sustainable net benefits of economic activity are being maximized. Due to an increase in *G*, the IS curve shifts rightward to IS_1. Since the new equilibrium at point *b* is inconsistent with environmental equilibrium, the fiscal expansion must be accompanied by a monetary contraction—a leftward shift of the LM curve to LM_1. This moves the macroeconomy to a new environmental–macroeconomic equilibrium at point *c*. Because the equilibrium output level falls to Y_1, the physical scale of the macroeconomy reduces to S_1. At S_1, the sustainable net benefits of economic activity decline to SNB_1. Clearly under these conditions, an expansionary fiscal policy is inimical to the well-being of the nation.

Naturally, a conclusion of this nature will differ if, prior to the introduction of an expansionary fiscal policy the macroeconomy has already surpassed its optimal scale (i.e., at a scale larger than S^*). In this situation, a reduction in the scale of the macroeconomy increases the sustainable net benefits of economic activity. Indeed, it is conceivable that an expansionary fiscal policy could move the macroeconomy back to its optimal scale.

Figure 9 illustrates the impact of an expansionary monetary policy under the Heyes position. Prior to the monetary expansion, the initial environmental–macroeconomic equilibrium at point *a* is again consistent with the macroeconomy operating at the optimal scale. Because of an increase in *M*, the LM curve shifts rightward to LM_1. Once again, the new equilibrium at point *b* is inconsistent with environmental equilibrium. To keep natural capital intact the monetary expansion must be accompanied by a fiscal contraction—a leftward shift of the IS curve to IS_1. This moves the macroeconomy to point *c*. Because the equilibrium output level rises to Y_1, the scale of the macroeconomy increases to S_1. At a larger macroeconomic scale, the sustainable net benefits of economic activity decline to SNB^1. Despite an expansionary monetary policy having the opposite impact of an expansionary fiscal policy on real output and the macroeconomic scale, it too reduces the well-being of the nation. Of course, this conclusion can also differ if the macroeconomy is initially smaller than its optimal scale, as it may well be for many impoverished nations.

Figures 10 and 11 will now illustrate the impact on sustainable net benefits of an expansionary monetary policy under the Lawn position (where a resource use permit scheme is in place). Figure 10 is the same as figure 9 from point *a* to point *b*. However, the excess demand for low entropy matter-energy leads to a rise in both resource prices and the resource input cost of the production process. In this particular instance, higher resource input costs fail to induce any technological progress. Consequently, the EE curve maintains its present position at EE. The higher resource input costs flow on into higher goods prices so that the LM curve shifts back to its original position. Because the equilibrium output level remains at Y^*, the macroeconomy continues to operate at the prevailing optimal scale of S^*.

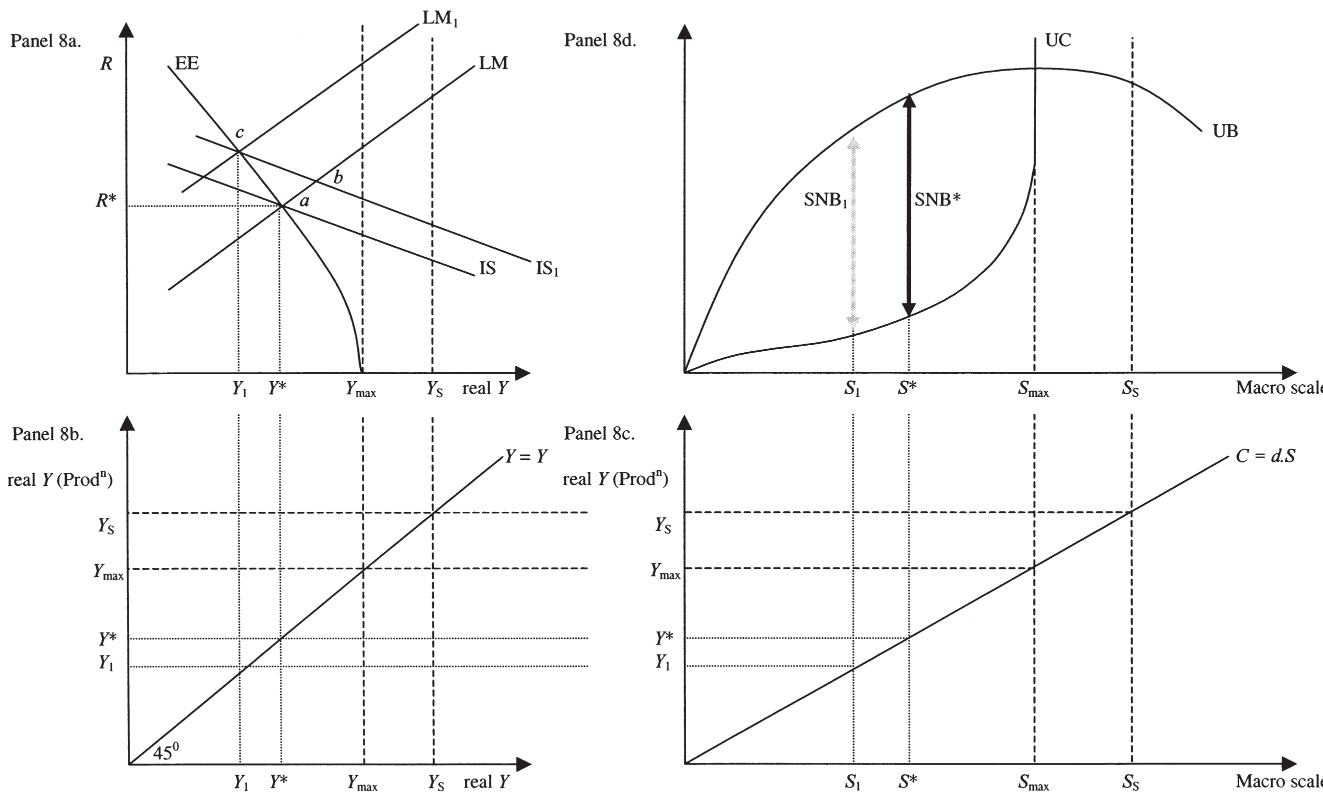

Figure 8. *Expansionary fiscal policy with no tradeable resource use permits*

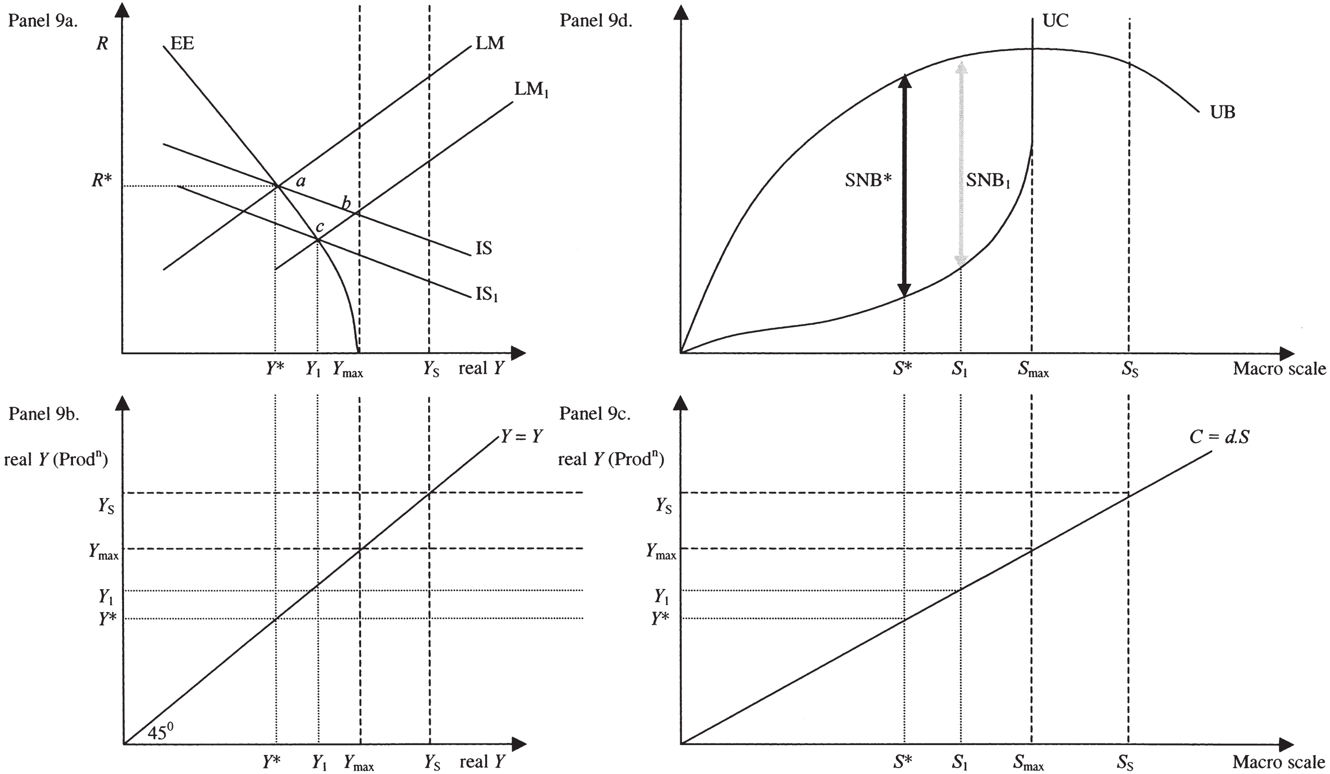

Figure 9. *Expansionary monetary policy with no tradeable resource use permits*

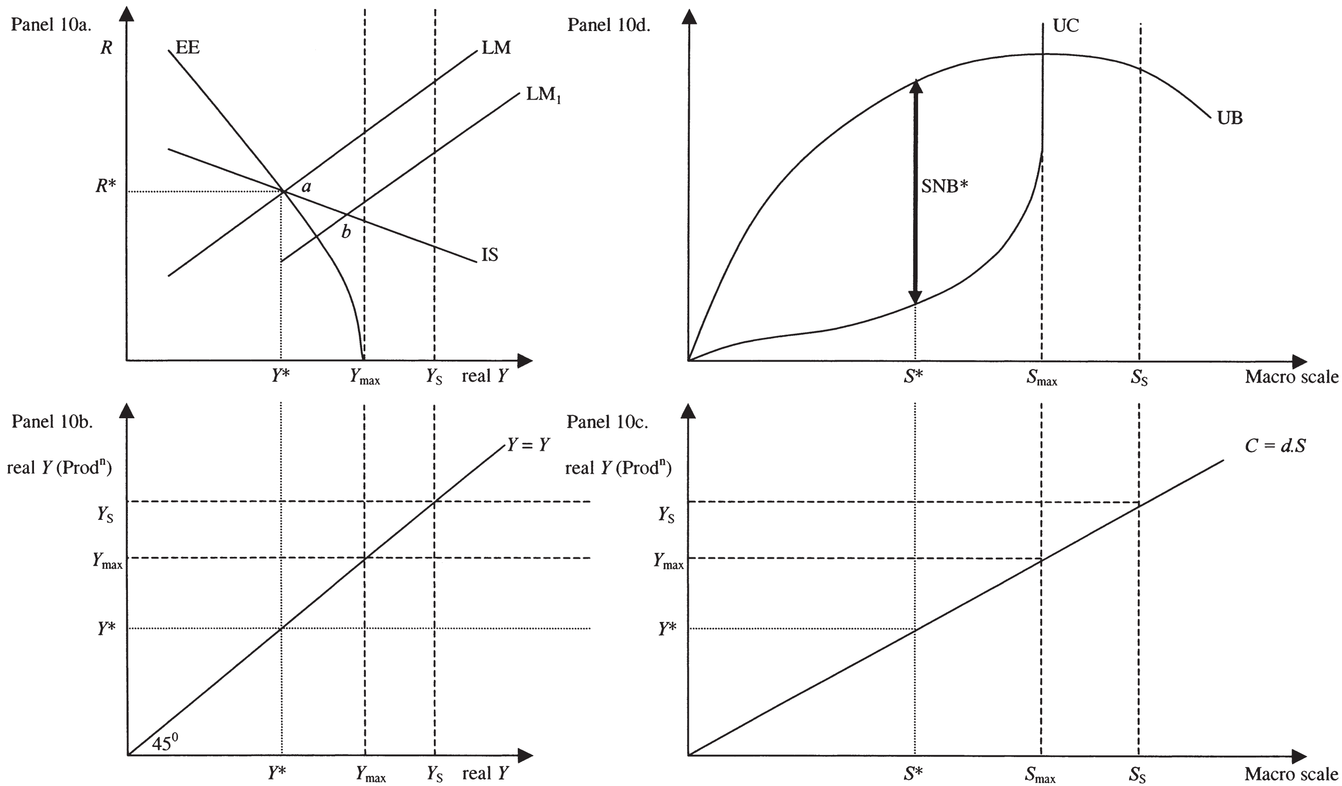

Figure 10. *Expansionary monetary policy with tradeable resource use permits—no technological progress*

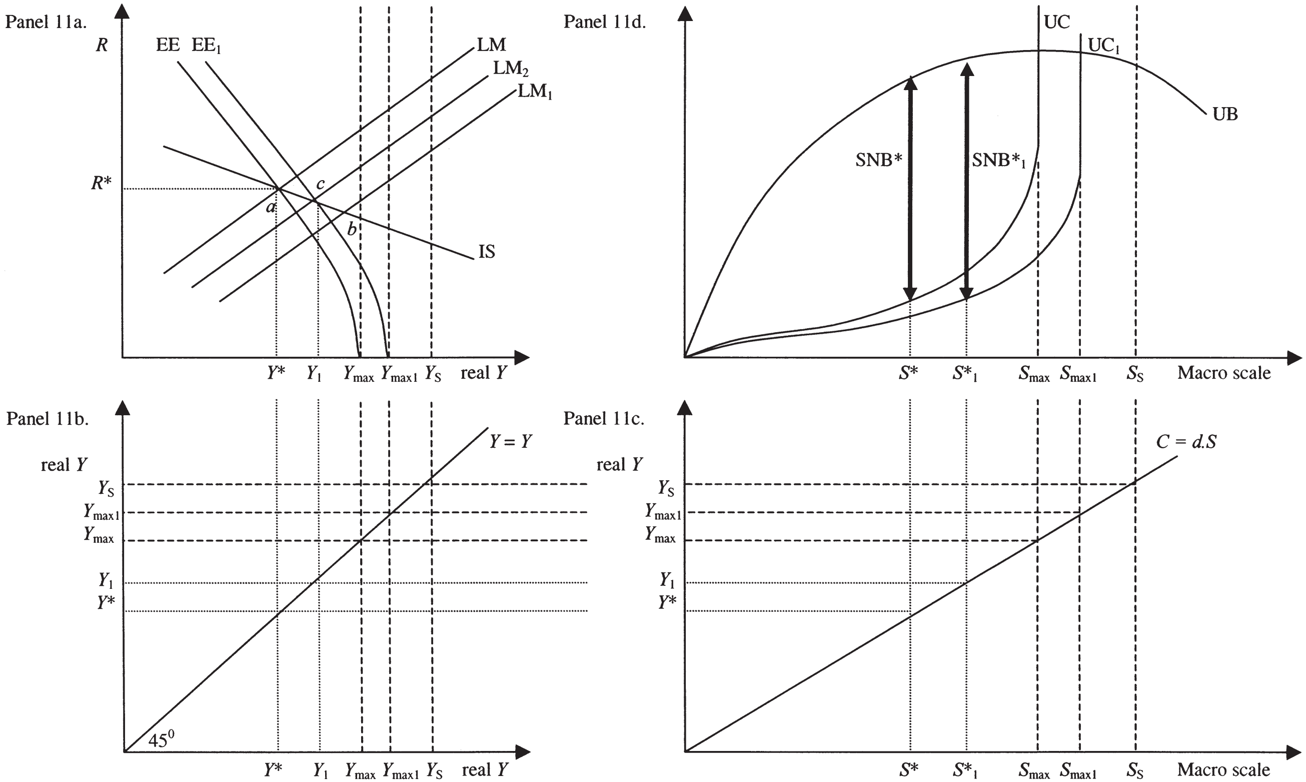

Figure 11. *Expansionary monetary policy with tradeable resource use permits—small technological progress*

Now consider figure 11. Everything is the same as figure 10 except, on this occasion, higher resource input costs bring about an increase in resource-saving technological progress. This not only shifts the EE curve rightward to EE_1, it also causes a downward/rightward shift of the UC curve in panel 11d to UC_1. The rightward movement of the UC curve is due to the fact that an increase in the maximum permissible output level to Y_{max1} corresponds to an increase in the maximum sustainable scale to S_{max1}. The downward movement of the UC curve comes about because an increase in resource-saving technological progress reduces the source, sink, and life-support services lost in the process of maintaining a given macroeconomic scale. This, in turn, reduces the uncancelled cost of economic activity.

Because the increase in technological progress is insufficient to prevent goods prices from rising, the LM curve shifts leftward to LM_1. This brings about a new environmental–macroeconomic equilibrium at point *c*. The increase in equilibrium output to Y^*_1 corresponds to a larger macroeconomic scale of S^*_1. Unlike an expansionary monetary policy under the Heyes position, the increase in output and macroeconomic scale does not lower sustainable net benefits. Indeed, on this occasion, the expansion of the macroeconomy leads to an increase in sustainable net benefits to SNB^{*1}. Hence, there is a beneficial expansion from one optimal macroeconomic scale to another.

6. Concluding comments

Given the importance now placed on the sustainability of economic activity, macroeconomists can no longer ignore the need to incorporate environmental constraints into macroeconomic models. Thanks to Heyes, any excuse macroeconomists have had in the past has now vanished. Nevertheless, Heyes' IS–LM–EE proposal is far from complete. Hence in this paper, I have endeavoured to demonstrate the far-reaching implications an extended IS–LM–EE model can have for fiscal and monetary policy. In all, these implications depend largely on four key aspects: (a) the means by which the macroeconomy is manipulated to ensure it operates on an EE curve; (b) the extent of any resource-saving and/or pollution-reducing technological progress; (c) the impact on the sustainable net benefits of economic activity, not just the impact on real output; and (d) whether a nation is initially operating at an optimal macroeconomic scale.

Assuming the macroeconomy is operating at the optimal scale, this paper has shown that an expansionary fiscal policy, when accompanied by a monetary contraction to keep the macroeconomy on the EE curve, lowers the sustainable net benefits of economic activity. The same also occurs when an expansionary monetary policy is accompanied by a fiscal contraction. In both cases, the macroeconomy moves to a sub-optimal scale. The story is much different if assurance bonds and a resource use permit scheme have been instituted. For example, when an expansionary monetary policy is adopted, sustainable net benefits remain unchanged if there is no technological progress, but increase if there is. While, in the former instance, the macroeconomy continues to operate at the prevailing optimal scale, in the latter case, it expands from one optimal scale to another.

Of course, the extended IS–LM–EE model used in this paper is also far from complete. To begin with, the model assumes a macroeconomy that is closed to international transactions although, as Heyes pointed out, this deficiency can be easily dealt with by including a 'balance of payments' or BP curve. It can also be addressed by permitting the international trade in resources and wastes, both of which allow for a rightward shift of the EE curve. A wealth of other factors can also be included at the researcher's discretion to strengthen the validity of the model's findings. These include such customary additions as adaptive expectations, bond-financed government deficits, or policy announcement effects. Other additions include the feedback effect of a degraded natural environment, incentive-based initiatives to shift the UB curve upwards (e.g., reduced taxes on labour and income), or an increase in the durability of all newly produced goods. Whatever the case, it does not alter the fact that environmental concerns should not remain the exclusive domain of microeconomic analysis. They should also be incorporated into macroeconomic models, thereby opening the door to a whole new branch of macroeconomics.

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