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Abstract
Neo-Austrian modelling is still a relatively unfamiliar technique to many ecological economists, although there is now a significant body of published work on the method and its applications.

In this paper we aim to introduce the method, offering a rather brief sketch of its history, indicating how neo-Austrian models are constructed and can be applied to environmental issues, and giving a hint on some of its wider applications. We also show relationships to neoclassical growth theory.

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1. INTRODUCTION

The aims of this paper are:

1. To demonstrate the techniques of neo-Austrian modelling, to show how one can introduce various new techniques of production in a straightforward and intuitive way. (It is the 'construction kit' of modelling techniques in time (Hicks, 1970:257)). This allows one to model innovation and technical progress. As well as having a simple and additive structure, one can drive the dynamics in various ways from full intertemporal optimisation, through rolling myopic plans, to simple savings ratios.
2. To show the richness of its application to environmental matters, including its usefulness in modelling human-nature interactions. For example, the Laws of Thermodynamics show us that joint production of waste materials is inevitable; this joint production is simply embodied in the neo-Austrian framework.
3. To demonstrate the usefulness of the model in two epistemologically distinct situations. Concerning historical understandings (i.e., *ex post* analysis), we know already what new techniques have emerged, using new factors of production and producing new goods. So we can seek to explain the corresponding evolution using the concept of time preference, neo-Austrian ideas such as superiority of roundaboutness, time horizon of decision making, and the thermodynamically necessary relations of production and consumption to nature. Concerning forecasting future developments (i.e., *ex ante* analysis), the very structure of the neo-Austrian model, and its openness to extensions through the invention and innovation of new techniques, always reminds us that forecasting economic evolution is more of an art than a science. The scenario analysis that neo-Austrian analysis allows is, however, very well suited to exploring policy options based on alternative notions of future states of the world.

The remainder of the paper has the following structure. Section 2 discusses approaches to modelling, and offers a brief description of the historical roots of this approach. Section 3 introduces the simplest neo-Austrian model, with three sectors. This simple model is extended in Section 4, to include the environmental issues of natural resource use, pollution emissions, and recycling. Section 5 outlines some other areas of application of the neo-Austrian model, while Sector 6 offers some conclusions.

2. APPROACHES TO MODELLING

One can identify two polar approaches to economic modelling.

1. To begin with the preconception of human behaviour and human motivations, and to construct models consistent with this preconception.
2. To construct models which are empirically oriented, so the prime aim is to represent the activities observed.

We would see neoclassical economics as being of the former type, with its stress on marginal changes on both the consumption and production sides. Concerning production, the neo-Austrian approach is more in the second category, stressing the distinctiveness of methods of production. Thus the neo-Austrian approach, because of its empirical orientation, easily al lows considerations of such issues as the introduction of new techniques, decision making time-horizons, structural change and, of course, the temporal thermodynamic necessities of resource use and waste production (as discussed in Section 4).

2.1 The History of Neo-Austrian Modelling

Neo-Austrian capital theory is a revival of Austrian capital theory, which started in the late-nineteenth century. The characteristic adjective ‘Austrian’ stems from the nationality of the founder of the Austrian School, Carl Menger (1840-1921). At the end of the nineteenth century this School was, with the Neoclassical School, whose most original member was Leon Walras (1834-1910), the most important approach in economics.

The Austrian approach emphasises the ‘vertical’ time structure of an economy; i.e., the fact that production takes time: raw materials have first to be extracted and then intermediate goods have to be manufactured, before the consumption good can be produced. In contrast to the Austrian view, the neoclassical (Walrasian) approach stresses the ‘horizontal’ time structure of an economy. That is, the interdependencies between its markets during one period of time are at the forefront of the analysis (cf. Faber, 1986, p. 12). The second great Austrian economist, Eugen von Böhm-Bawerk (1851-1914), who at the end of the nineteenth century was perhaps the most influential and well-known economist in the world, was the founder of Austrian capital theory. As Schumpeter (1954, p. 847) wrote: ‘A few of the best minds in our field ... have in fact considered him’ as ‘one of the great architects of economic science’.

The insight of the Austrian School, that production takes time, led Böhm-Bawerk to his concept of the ‘roundaboutness’ of the production process and this in turn led to the concept of ‘superiority’. Taken together these two concepts led to his famous notion of the ‘superiority of roundboutness’ (discussed further in Section 3). For various reasons (Faber et al., 1999, p. 24-6) the Austrian theory of capital fell in oblivion in the 1930s. However, the unsatisfactory way in which neoclassical capital theory treated time led to a revival of Austrian capital theory in the 1970s (Bernholz, 1971; Hicks, 1973), which was the beginnings of neo-Austrian capital theory (see Faber et al., 1999, pp. 30-4, for further details).

2.2 Motivation for the Approach

The essence of neo-Austrian capital theory is that it takes an historical approach to economies. It seeks to model how economies evolve, through the invention of new techniques of production, and the accumulation of corresponding stocks of new capital goods specific to those techniques. For example, if one imagines early humans as being comparable to other species, the only means they have to satisfy their wants is through the use of their bodies (e.g., as a bear may hunt live animals, scavenge on dead ones, and forage for plants). Clearly, such behaviour limits the possibilities for the growth of the bear (or early human) population, and indeed we normally observe a stationary set of relationships between species, at least over time horizons of hundreds or thousands of years.

However, an essential characteristic of humans is that they use tools (or capital goods). Indeed, while humans are classified as *homo sapiens* (wise men), they might better be described as *homo faber* (tool using men). What is the outcome of this propensity of humans to use tools, and how might we model it? One outcome is that the ability of humans to access the resources out of nature is improved; indeed, this must be exactly the motivation for using tools/capital goods. However, such tool-using on nature will tend to be self-limiting, as the use of tools will make the aspects of nature they exploit scarcer and therefore more difficult to access. For example, there is very good evidence that when humans first entered Australia (about 40 thousand years ago) and then North America (about 20 thousand years ago), both continents contained megafauna (e.g., in Australia giant kangaroos, and in North America, giant bison, giant armadillos, etc). Very shortly after humans entered these ecosystems, these megafauna disappeared, almost certainly because their hunting tools allowed the humans to predate on them so successfully (Crosby, 1986). So the easy hunting of the early years after human entry to these continents gave way to hunting which was more difficult (on the remaining smaller and less rewarding fauna). That is, the use of capital goods produced constraints on its long-run success.

The consequence was an incentive to search for new techniques of hunting, using new hunting tools (i.e., new sorts of capital). So, historically, we believe that the order of the evolution of hunting tools was: the spear, the spear with throwing stick, the net, the bow and arrow, the gun.

Now the use of tools requires that first they be produced. Of course, this production involves time and effort that could be spent in other activities, such as hunting (without these tools). Under what circumstances would it be considered worthwhile to produce tools? The first obvious necessary condition is that humans have sufficient foresight to envisage the future benefits of present foregone consumption possibilities. So humans need to be able to consider and envisage future events as being in some way comparable with present experiences. For example, fishing with a net is much more effective than fishing with a spear, and fishing with a boat and a net is better still. The benefits of present foregone consumption are clear in this case. We see also from these examples that different time horizons are involved: producing a spear takes less time than producing a boat.

The next necessary condition is that the human needs to be reasonably assured that the benefits from the foregone consumption actually accrue to that individual (or social group). Thus the notion of property rights also flows from the use of capital goods. Of course, to maintain these property rights, some sort of rule of law is also necessary. Therefore, the introduction of capital goods begins to structure the basic requirements for human society; i.e., foresight, property rights, and the rule of law.

So one essential aim of neo-Austrian capital theory is to seek to model the historical development of societies, through the invention and bringing into use of new techniques and new types of capital, over the course of time. Other aims are to analyse the present structure of the economy and to develop scenarios for future developments.

We now move to a more technical introduction to neo-Austrian capital theory, using the simplest possible model. At this stage it is worth noting that the representation of the neo-Austrian approach we use draws on Koopmans (1951) 'activity analysis' method.

3. THE THREE-SECTOR MODEL

We begin with a simple model of production for consumption. This model is initially rather unrealistic, as we do not include either the use of natural resources, or the production of polluting wastes. However, the model will be extended to include these aspects of human-nature interactions in the next section. This discussion serves to introduce the main structure and concepts of the approach.

Let us therefore consider a society where the only non-produced scarce factor of production is labour, which is used directly to produce the consumption good. (For fuller discussion of this model, see Faber and Proops, 1998, Chapters 10, 11; Faber et al., 1999, Chapters 3, 4). We can represent this quite simply if we make the reasonable assumption that the output of the consumption good is proportional to the input of labor. So we can write this (Process 1) as:

$L_1 \rightarrow X_1$; i.e., labour L_1 is transformed into the consumption good X_1.

The proportionality assumption gives:

$$\frac{L_1}{l_1} = X_1;$$

l_1 characterises the production process 1 (Process 1): it is the amount of labour needed to generate one unit of the consumption good.

In the course of time, people will find that it is more productive to manufacture the consumption good by using capital goods. So let us assume that the consumption good can be produced not only with labour alone, but also by labour *combined with* (⊕) a capital good. We represent this (Process 2) as:

$L_2 \oplus K_2 \rightarrow X_2$; i.e., labour is combined with capital to produce the consumption good.

We again assume proportionality of inputs, and that the production factors are complementary, with l_2 units of labour, combined with the *use* of k_2 units of capital, needed to manufacture 1 unit of the consumption good, i.e.:

$$\frac{L_2}{l_2} = \frac{K_2}{k_2} = X_2.$$

However, before it can be employed in this production process, the capital good must first be produced. We assume labour alone can be used to manufacture new, extra capital good, (in Process 3), i.e.:

$$L_3 \rightarrow \Delta K.$$

We again assume proportionality of input to output, giving:

$$\frac{L_3}{l_3} = \Delta K.$$

The quantity of new capital good (produced in period *t)* is added to any already available capital good *K (t)* in period *t*, to be available in period *t*+1; i.e.:

$$K(t+1) = K(t) + \Delta K(t).$$

One would usually represent this capital as having the property that, over time, it would *deteriorate* (in line with the Laws of Thermodynamics). This deterioration would be at a characteristic rate *c*. It is straightforward to extend this model to include such capital deterioration (Faber and Proops, 1998, pp. 205-7; Faber et al., 1999, pp. 58-60), giving:

$$K(t+1) = (1-c)K(t) + \Delta K(t).$$

For the sake of simplicity we assume that the total amount of labour, *L,* available in each period is exogeneously given, hence the labour restriction in each period is given by:

$$L_1 + L_2 + L_3 \leq L.$$

In summary, this model:

- Involves two scarce factors of production, (non-produced) labour and a (produced) capital good.
- Produces two outputs, the consumption good and new capital good (i.e., investment).
- Uses three production processes. Processes 1 and 2 manufacture the same physical consumptions good. Process 1 uses only labour to produce the consumption good. Process 2 uses labour and the capital good, to produce the consumption good. Process 3 uses only labour to produce the capital good.
- The capital good must be produced before it is used, accumulates over time with new investment, and may deteriorate with use.
- In each period there exists a labour constraint.

3.1 Techniques of Production

If we initially focus attention on two production periods, we can represent the time structure of production in this model as in Figure 1.

We can speak of production of the consumption good as being possible by two *Techniques*. Here, a technique of production is defined to be the minimal combination of production processes to produce the consumption good from the non-produced input; so:

Technique T_1 = {Process 1},
Technique T_2 = {Process 2, Process 3}.

(For a fuller discussion of the notion of a technique, see Faber and Proops, 1998, p. 180; Faber et al., 1999, p. 111.)

Figure 1 Time structure of production

Time Period	Technique 1 Process 1	Technique 2 Process 2	 Process 3
1	Labour ↓ Consumption good	- -	Labour ↓ Capital good
2	Labour ↓ Consumption good	Labour ⊕ Capital good ↓ Consumption good	

- Technique 1 consists of only Process 1, and takes only one period to manufacture the consumption good, with labour alone.
- Technique 2 consists of first, Process 3, to manufacture the capital good in one period, and then, in the next period, Process 2 to use the capital good with labour, to produce the consumption good.

Because of its more complex temporal structure, we can speak of Technique 2 as being more *roundabout* than Technique 1 (Faber et al., 1999, pp. 46-50).

We now must address the issue of when the Technique 2 would be regarded as superior to the Technique 1. If we assume that the capital good is long-lasting, and can be used for several periods once it has been produced, the decision of whether the capital good will be manufactured at all will obviously depend on how far-sighted is the decision maker; i.e. it will depend on the time horizon. (For a fuller discussion of the role of the time horizon in the investment decision, see Faber and Proops, 1991a; Faber et al., Chapter 5.)

If there is only a two-period horizon, and if we measure the benefit of each technique as simply the sum of consumption over the two periods, we can show that Technique 2 has 'two-period superiority of roundaboutness' over Technique 1 if:

$$S(2) \equiv \frac{l_1 - l_2}{l_3 k_2} > 1 .$$

If we extend the time horizon to n periods we find the condition for superiority becomes:

$$S(n) \equiv \frac{l_1 - l_2}{l_3 k_2} - \frac{c}{1-(1-c)^{n-1}} + 1 > 1 .$$

For an infinite time horizon it is:

$$S(\infty) \equiv \frac{l_1 - l_2}{l_3 k_2} + (1-c) = S(2) + (1-c) > 1 .$$

(Full derivations of these relations are in Faber et al., 1999, Chapters 3 and 5.)

We can show that $S(n)$ is a strictly increasing function of n (Faber et al. 1999, pp. 114-6); i.e., the longer is the time horizon, the more likely are we to find that Technique 2 is superior to Technique 1, and therefore likely to be brought into use. We note in passing that a necessary decision to bring a technique into use depends on the degree of superiority; i.e., that the degree of superiority is greater than one. Whether this is the case or not depends on two kinds of factors:

- On technical (coefficients of production and the rate of deterioration).
- On a subjective factor, the length of the time horizon, for as we have seen: the longer the time horizon, the higher the degree of superiority.

3.2 The Investment Decision

From the above outline, it is clear that the dynamics of neo-Austrian models are determined by the decision to accumulate new capital; i.e., to invest. To give a detailed description of how this decision is taken, there are two obvious approaches.

- Optimisation of an intertemporal welfare function.
- The use of a savings ratio (as in simple macroeconomic models; see Faber and Proops, 1993; Faber et al., 1999, Chapter 8).

The intertemporal optimisation approach can itself be of two types (Faber and Proops, 1998, pp. 222-40):

- Full intertemporal optimisation, with an indefinite time horizon.
- Rolling-myopic optimisation, where only a limited number of time periods are considered, and only the first few time periods of this plan are considered binding, before a new myopic optimisation occurs.

Regarding these two optimisation approaches, which is selected will obviously depend on the attitude towards the future, and in particular the degree to which it can be predicted (see Faber and Proops, 1998, Chapters 7, 8). If it is felt that the relevant properties of world are stable and known, then a full intertemporal approach will be most efficient. However, in the face of uncertainty about future conditions in the world (e.g., relating to technical change or environmental damage), then a rolling myopic approach is more likely to be appropriate.

3.3 The Traverse

An important notion in neo-Austrian modelling is that of the 'traverse' (Hicks, 1965). This term is taken from rock climbing, and in that context means the movement across a rock face from one point of firm attachment to another. In its neo-Austrian sense, it means the movement of an economy from one steady state to another, through the process of capital accumulation.

The essence of the notion is that the important and interesting parts of economic activity occur while the economy is *not* at a steady state (or equilibrium) but rather is somehow 'unbalanced' (like a rock climber on an exposed rock face).

Perhaps a society is initially in a steady state, having a certain technology of production available to it. If a new technique of production is invented, and is found to be worth bringing into use (because it has enough 'superiority of roundaboutness' over the appropriate time horizon), then it will be innovated, with consequent effects on the economic structure, the wage and interest rates, the distribution of income, environmental resource use and damage, and the level of output per capita. Eventually, in the absence of any further changes to technology (or the environment), the economy will achieve a new equilibrium steady-state (perhaps steady state growth, if the population is increasing).

While Neo-Austrian capital theory can specify the nature of the beginning and final steady states, its greatest strength is that it allows one to explore, in a disaggregated and detailed way, the time structure of economic activities between these steady states, during the traverse (Faber, 1979, pp. 164-6).

3.4 The Input-Output Representation of the Neo-Austrian Model

As has been outlined in Chapter 3 of this volume, input-output (I-O) analysis is an extremely widely used tool in ecological economics. As neo-Austrian models are necessarily multi-sectoral, these too can be represented in I-O format. This allows not only the simple representation of the production relations (for each time period) in a familiar format, but also the calculation of the prices that such a production technology support. (For a fuller discussion, see Faber et al., 1999, pp. 61-6)

If we use the simple three process model (for the sake of simplicity, without deterioration of capital) outlined above, we see that there are two sorts of output, the consumption good and the new capital good (i.e., new investment). Similarly, there are two factors of production, labour and (produced) capital. We can represent these inputs and outputs to the three processes as in Figure 1, where each I-O sector corresponds to the similarly numbered production process.

We see this is a very simple I-O table, with *no* intermediate demand (though below there will be environmental neo-Austrian models where there are intermediate demand elements).

Table 1 Input-output representation of the simple neo-Austrian model

Sectors	1	2	3	Output
1	-	-	-	X_1
2	-	-	-	X_2
3	-	-	-	ΔK
Labour	L_1	L_2	L_3	
Capital	-	K_2	-	

However, the strength of this table is that we can now introduce prices for labour (L), capital use (K), the consumption output (X), and new capital (ΔK). It is important to note the distinction between the two prices of capital: the price for its production (the price of ΔK), and the rental rate for its use (the price of K). Using self-evident price nomenclature, we can rewrite the I-O table to represent the values of the various inputs and outputs, as in Table 2.

Table 2 Value input-output representation of the simple neo-Austrian model

Sectors	1	2	3	Output
1	-	-	-	$p_X X_1$
2	-	-	-	$p_X X_2$
3	-	-	-	$p_{\Delta K}\Delta K$
Labour	$p_L L_1$	$p_L L_2$	$p_L L_3$	
Capital	-	$p_K K_2$	-	

In the usual I-O way, for each sector the values of inputs and outputs can be equated, to give three price equations:

$$p_L L_1 = p_X X_1; \qquad p_L L_2 + p_K K_2 = p_X X_2; \qquad p_L L_3 = p_{\Delta K} \Delta K .$$

Combining these equations with the above relationships between the inputs, outputs and technical coefficients for each sector, allows one to solve for the prices, if one takes one of the prices as a *numéraire* (usually this the price of labour, i.e., p_L=1). This gives:

$$p_X = l_1; \qquad p_{\Delta K} = l_3; \qquad p_K = \frac{l_1 - l_2}{k_2}.$$

Of course, an alternative method of identifying the prices for the system is to set up a full dynamic optimisation system, solving with the method of Lagrange, where the Lagrange multipliers are the shadow prices of the constraints (see Faber and Proops, 1998, 214-9; Faber et al., 1999, pp 67-71). This method has the advantage of finding the (different) prices for each commodity in each period. However, our experience is that for the purposes of most modelling, the I-O method of finding prices is to be much preferred, for its extreme simplicity.

4. INTRODUCING RESOURCES AND THE ENVIRONMENT

The method so far presented, has an obvious flaw for ecological economists: it takes no explicit account of nature! Fortunately the above representation of the production process is simple to extend, to include such important items as: the use of natural resources as an input to production; the corresponding emission of polluting wastes from production; and we can even include a waste treatment sector if we wish. Indeed, a great strength of the neo-Austrian approach is flexibility and ease of extension (cf. Faber et al., 1999, Chapters 8, 9).

Another strength of the neo-Austrian approach is that its emphasis on the time structure of production, as well as its historical orientation, leads naturally to a consideration of irreversibility conditions. As has been shown elsewhere, this can be appropriately considered by including thermodynamic relationships (Faber et al., 1995). Indeed, the laws of physics can be simply used to give structure to neo-Austrian models of human-nature interactions. The Laws of Conservation of Mass and Energy can be used to constrain the physical input and output coefficients for the processes, to ensure that the assumed production processes are firmly based on physical reality. At a more fundamental level, the Second Law of Thermodynamics tells us that any real production process must involve the production of entropy, which leaves the production process in some form, perhaps as polluting waste materials. The production of the desired goods necessarily causes the production of wastes; i.e., 'all production is joint production' (Faber et al., 1998; Baumgärtner et al., 2001). This necessary joint production is something that the neo-Austrian approach to modelling handles very comfortably within its straightforward and disaggregated production structure.

4.1 Resource Extraction

In the first environmental example, we turn to the extraction of a non-renewable natural resource. In particular, this allows the natural resource rent to be included in the intertemporal price system of the neo-Austrian model. (This section draws on Faber and Proops, 1993; Faber et al., 1999, Chapter 8).

A simple model might include the natural resource as an input to the construction of new capital (i.e., an input to Process/Sector 3). Of course, the natural resource must first be extracted, which we assume takes place in a new Process/Sector 4. The natural resource, as it occurs in the ground, constitutes a basic factor of production (along with labour and capital). We can specify the production technology for Process/Sector 4 in the terminology presented earlier. In Process 4, labour is combined with the non-extracted natural resource, to give the extracted natural resource:

$$M \oplus L_4 \rightarrow M \text{ ; i.e.: } \frac{L_4}{l_4} = M \text{ .}$$

We also need to modify the technology for Process 3, to take account for the input of the natural resource. We get:

$$M \oplus L_3 \rightarrow \Delta K \text{ ; i.e.: } \frac{M}{r_3} = \frac{L_3}{l_3} = \Delta K \text{ .}$$

Here, r_3 is the natural resource required to produce one unit of the new capital good.

We can extend Table 1 to include the extraction and use of the natural resource (M), as shown in Table 3.

Table 3 Input-output representation of the neo-Austrian model with resource extraction

Sectors	1	2	3	4	Output
1	-	-	-	-	X_1
2	-	-	-	-	X_2
3	-	-	-	-	ΔK
4	-	-	M	-	-
Labour	L_1	L_2	L_3	L_4	
Capital	-	K_2	-	-	
Resource	-	-	-	M	

We see that the resource term, M, appears twice. First, as a factor of production, with labour and capital, and second as an (intermediate) input of production, from Sector 4 to Sector 3.

We can now further extend the model by introducing prices, though here we need two more prices than appeared in Table 2. First, there is the resource rent, applicable to the natural resource as a factor of production (i.e., its pre-extraction 'price in the ground'). We call this p_R. The new second price corresponds to the (market) price at which the extracted resource is sold by Sector 4 to Sector 3. We call this p_M. Using these prices, we can construct Table 4.

Table 4 Value Input-output representation of the neo-Austrian model with resource extraction

Sectors	1	2	3	4	Output
1	-	-	-	-	$p_X X_1$
2	-	-	-	-	$p_X X_2$
3	-	-	-	-	$p_{\Delta K}\Delta K$
4	-	-	$p_M M$	-	-
Labour	$p_L L_1$	$p_L L_2$	$p_L L_3$	$p_L L_4$	
Capital	-	$p_K K_2$	-	-	
Resource	-	-	-	$p_R M$	

We can now find four price equations from Table 4, following the procedure described above, by equating the values of inputs and outputs for the four sectors; i.e.:

$$p_L L_1 = p_X X_1; \qquad p_L L_2 + p_K K_2 = p_X X_2;$$
$$p_M M + p_L L_3 = p_{\Delta K} \Delta K; \qquad p_R M + p_L L_4 = p_M M.$$

Substituting these relationships (and those for Processes 1 and 2) into the price equations (again taking labour as the *numéraire*, i.e., p_L=1) gives:

$$p_X = l_1; \qquad p_{\Delta K} = l_3 + p_M r_3; \qquad p_K = \frac{l_1 - l_2}{k_2}; \qquad p_M = l_4 + p_R.$$

We note that the first and third equations are identical to those in Section 3.4. The second equation tells us that the price of new capital (in labour value units) now depends on the amount of labour used, and on the amount and price of the natural resource required. The final equation above has the very straightforward interpretation:

Natural Resource Price = Extraction Cost + Resource Rent.

The above model, with its I-O representation, is necessarily static. However, we can add dynamics simply by introducing a rule for the choice of new capital accumulation in each period (i.e.; $\Delta K(t)$).

As mentioned above, one method of specifying ΔK is to use a savings rule, from gross domestic product (GDP - Y). For this model, that is simply the sum of the value of final outputs or the sum of the value of basic factor inputs; i.e.:

$$Y = p_L(L_1+L_2+L_3+L_4) + p_K K + p_r M = p_X(X_1+X_2) + p_{\Delta K}\Delta K.$$

One can then define new investment in each period to be given by:

$$\Delta K(t) = sY(t); \text{ i.e. } K(t+1) = K(t) + \Delta K(t) = K(t) + sY(t).$$

This would give a dynamic model, where the capital accumulation over time would generate a time-path of output (of the various types), as well as altering the balance of the distribution of labour between the sectors (the total quantity of labour can be assumed to be growing over time, at a positive, zero or even negative rate). Also, and most importantly for our purposes, it would define a time-path of resource extraction. (For a fuller discussion, see Faber et al., 1999, Chapter 8).

This very simple model can be made more realistic by allowing the resource rent itself to vary over time. Two obvious approaches here would be either to follow standard resource economics theory, or to use empirical evidence on resource prices. In the first case, we could specify that the resource rent follow the Hotelling Rule; i.e., p_R increases at the interest rate (which here could be taken to be the rental rate of capital, p_K) (see Dasgupta and Heal, 1979:156). In this case would write:

$$\frac{p_R(t) - p_R(t-1)}{p_R(t-1)} = p_K; \qquad \text{i.e: } p_R(t) = p_R(t-1)(1 + p_K).$$

In the second case, we could specify the rental rate of the resource to be falling over time (as has been the common experience for almost all natural resources over the past century; cf. Barnett and Morse, 1963; Proops, 2003).

We note in passing that the determination of the resource rent has important implications to the distribution of income between developed and developing countries (cf. Jöst, 1994; Proops, 2003).

4.2 Pollution

The second application of the neo-Austrian approach to the environment relates to pollution production and abatement (cf. Speck, 1997; Faber et al., 1999, Chapter 10). For example we could specify a model where each production process may produce wastes, which are polluting; e.g., for Process 2, where Z_2 represents polluting waste output:

$$L_2 \oplus K_2 \rightarrow X_2 \oplus Z_2; \qquad \text{i.e.: } \frac{L_2}{l_2} = \frac{K_2}{k_2} = \frac{Z_2}{z_2} = X_2 .$$

We can specify two ways in which this waste may be dealt with. First, we could use pollution abatement techniques, which used economic resources (e.g., labour). Second, we could introduce natural processes of pollution degradation, which would require no use of economic resources.

Using our original production technology, as represented in Table 1, we could add two more sectors: Sector 4 is pollution abatement, and Sector 5 is natural pollution degradation. In Sector 4 labour L_4 is used to neutralise pollution. This gives us the production/pollution system shown in Table 5.

Table 5 Input-output representation of the neo-Austrian model with pollution

Sectors	1	2	3	4	5	Output	Pollution
1	-	-	-	-	-	X_1	-
2	-	-	-	-	-	X_2	Z_2
3	-	-	-	-	-	ΔK	Z_3
4	-	-	-	-	-	-	$-A$
5	-	-	-	-	-	-	$-D$
Labour	L_1	L_2	L_3	L_4	-		
Capital	-	K_2	-	-	-		
Polln Degr	-	-	-	-	$-D$		

Here, the pollution produced in Sectors 2 and 3 is denoted by Z_i. The pollution abatement (Sector 4) is indicated by A, and the natural pollution degradation (Sector 5) is indicated by D. (These are shown with negative signs to indicate *reduction* of pollution.) If the stock of pollution at time t is given by $Q(t)$, then we can write:

$$Q(t+1) = Q(t) + Z_1(t) + Z_2(t) - D(t) - A(t) .$$

We could also make the amount of natural pollution degradation that occurs in each period dependent on, e.g., the stock of pollution: $D(t) = f(Q)$.

We could then introduce prices into the model, as above, to calculate the costs of pollution abatement, and the value to society of natural pollution degradation. Finally, we could give the model a dynamics, through establishing the rate of capital accumulation, by one of the techniques discussed above. Also, there would need to be established a rule to determine the amount of pollution abatement in each period. This could be either dependent on the level of net emission, or the pollution stock, or some other rule. This would then give the dynamics of the model, showing capital accumulation, labour use, and most importantly for us, pollution emissions, natural degradation and abatement, plus the full set of corresponding prices for the system.

4.3 Recycling

An alternative way of reducing the emission of polluting waste is to recycle this material (cf. Faber et al., 1999, Chapter 11). This may be done by a specific Process/Sector; e.g., processed waste from Processes 2 and 3 may be used as a substitute for extracted raw material. Using the natural resource model outlined above, we might add a further Process/Sector 6, which uses labour and waste material from Sector 3, and produces recycled material (*M*), for use in place of raw material. We can represent this recycling as producing -*R* units of pollution, as in Table 6. (Again, the negative sign indicates a reduction in pollution.)

Table 6 Input-output representation of the neo-Austrian model with recycling

Sectors	1	2	3	4	5	6	Output	Pollution
1	-	-	-	-	-	-	X_1	-
2	-	-	-	-	-	-	X_2	Z_2
3	-	-	-	-	-	-	ΔK	Z_3
4	-	-	-	-	-	-	-	$-A$
5	-	-	-	-	-	-	-	$-D$
6	-	-	M	-	-	-	-	$-R$
Labour	L_1	L_2	L_3	L_4	-	L_6		
Capital	-	K_2	-	-	-	-		
Polln Red'n	-	-	-	-	$-D$	$-R$		

Again, we could assume that Process 6 uses labour in fixed proportion to the amount of material recycled. In this model, pollution reduction now comes in two forms: natural pollution degradation (-*D*) and recycling (-*R*). The relationship for the pollution emission is now:

$$Q(t+1) = Q(t) + Z_1(t) + Z_2(t) - D(t) - A(t) - R(t)\,.$$

We could go one step further towards reality, and combine the resource, pollution and recycling models. Using insights from the Second Law of Thermodynamics and the Mass Balance Principle, discussed above, would also give constraints on the various environmental and production coefficients in the model (see Faber et al., Chapter 11). We could also easily add prices to this extended model. Finally, as discussed above, the model could be given an internal dynamics by including a choice of investment path, together with a pollution abatement/recycling policy, and a changing natural resource rent also. As noted in the introduction, the neo-Austrian approach is very like a construction kit, and it is extremely simple to add new Processes/Sectors, to capture further aspects of reality that need modelling.

5. OTHER APPLICATIONS

Other areas to which the neo-Austrian approach has been applied include the following.[2]

Growth Theory
It has been shown that if one takes the approach of neoclassical growth theory, and focuses on the steady state rather than the traverse, then the properties of the neo-Austrian model are almost identical to those of the neo-Austrian (i.e., Swan/Solow) model, even to the extent of having almost identical properties with regard to optimal consumption paths. This suggests that the neo-Austrian approach contains the neoclassical model as a special case, at least in respect of most of its properties. (Stephan, 1995, Chapters 6-8; Speck and Proops, 1996; Faber et al., 1999, Chapter 6).

Long-run interactions between economies and nature
The very nature of neo-Austrian modelling naturally lends itself to long-run considerations. In particular, it is excellent for exploring how the introduction of new techniques of production (because of superiority of roundaboutness) impacts on nature, and how this in turn rebounds on economic activity (Faber et al., 1990; Faber and Proops, 1993; Faber and Proops, 1998, Chapter 12).

National Accounting and the Environment
As has been demonstrated above, the neo-Austrian approach lends itself to representation in an input-output framework, which is also the basis of national accounts. Using the neo-Austrian dynamics of capital accumulation, resource depletion and pollution emissions, which have been sketched above, the issue of how national accounts should be modified to account for environmental issues can be easily assessed. In particular, the Samuelson/ Weitzmann argument for considering the consumption stream, rather than GDP, occurs as a natural conclusion (Faber and Proops, 1991b; Faber et al., Chapter 7).

International Trade and the Environment
Using its 'construction kit' properties, it is relatively simple to extend the neo-Austrian model to encompass international trade, by constructing extra production processes, and representing these as a multi-country I-O model. In particular, models considering trade and environment relations between 'rich' and 'poor' countries have produced some stimulating results, on the distributional effects of climate change taxes (Jöst, 1994; Faber et al., 1999, Chapter 9) and the trade impact of falling resource rents (Proops, 2003).

Empirical Studies
It is relatively straightforward to use the neo-Austrian model for empirical work, as long as reasonable predictions for the various technological coefficients can be estimated (or 'guesstimated'). Examples of such work include studies of water quality (Faber et al., 1983), resource depletion (Faber and Wagenhals, 1988), and the history of production processes in the iron and steel industry (Faber et al., 1999, Chapter 12).

[2] We confine ourselves in the following to areas that are directly relevant to Ecological Economics. For relationships to dynamic games with macroeconomic investment see Böge et al. (1982) and Faber (1986, Chapters 13-16).

6. CONCLUSIONS

In this necessarily brief sketch of the method, we have tried to show the strengths of neo-Austrian modelling, which we would summarise as follows:

- The approach focuses on changes over real (historical) time. In particular, the concept of the 'superiority of roundaboutness' shows why capital accumulation and economic change occur, through the introduction of new techniques of production.
- The method is very straightforward to implement, using easily constructed, estimated and understood production processes.
- The models can be easily represented in terms of I-O models, allowing the simple calculation of the corresponding process system.
- There is a range of methods of giving the model dynamics, from intertemporal optimisation through to the use of savings ratios.
- Environmental issues can be introduced simply, either through joint production (for pollution), or the introduction of new production processes (for resource extraction, pollution abatement, recycling, etc.).
- Finally, the simple structure of the models means that simulations are easy to perform; spreadsheets are sufficient for most purposes.

The considerable strengths of the neo-Austrian approach do have a cost, though. In particular, we should advise the reader of the following difficulties involved in the method.

- In analytical terms, in contrast to neoclassical production-environment models, the neo-Austrian models generate a lot of mathematical formalism on the page. For example, the simple neoclassical production function - $f(K,L)$) is replaced by a number of processes. In particular, if the neo-Austrian approach is used for analytical rather than simulation work, variables and equations soon accumulate.
- For simulation purposes, the approach is rather 'data hungry'. There are many coefficients that need numerical form, and establishing these can be demanding.

However, we feel the benefits of the method far outweigh its costs, and see it as a useful and intuitively appealing approach to modelling human-nature interactions.

REFERENCES

Barnett H., and Morse, C. (1963), *Scarcity and Growth: The Economics of Resource Scarcity*, Baltimore MD: Johns Hopkins University Press.

Baumgärtner, S., H. Dyckhoff, M. Faber, J. Proops and J. Schiller, (2001), 'The concept of joint production and ecological economics', *Ecological Economics*, **36**, 365-72.

Bernholz, P. (1971), 'Superiority of roundabout processes and positive rate of interest: a simple model of capital and growth', *Kyklos*, **24**, 687-721.

Böge, W., M. Faber and W. Güth (1982), 'A dynamic game with macroeconomic investment decisions under alternative market structures', in M. Deistler, E. Fürst and G. Schwödiauer (eds.), *Games, Economic Dynamics, and Time Series Analysis*, Vienna: Physica-Verlag.

Crosby, A. (1986), *Ecological Imperialism*, Cambridge: Cambridge University Press.

Faber, M. (1979), *Introduction to Modern Austrian Capital Theory*, Heidelberg: Springer-Verlag.

Faber, M. (ed.) (1986), *Studies in Austrian Capital Theory*, Heidelberg: Springer-Verlag.

Faber, M., H. Niemes and G. Strephan (1983), *Umweltschutz und Input-Output-Analyse. Mit zwei Fallstudien aus der Wassergütewirtschaft*, Tübingen: Mohr (Paul Siebeck).

Faber, M., H. Niemes and G. Stephan (1995), *Entropy, Environment and Resources: An Essay in Physico-Economics* (2nd edn.), Heidelberg: Spriger-Verlag.

Faber, M. and J. Proops (1991a), 'The innovation of techniques and the time-horizon: a neo-Austrian approach', *Structural Change and Economic Dynamics*, **2**, 143-58.

Faber, M. and J. Proops (1991b), 'National accounting, time and the environment', in R. Costanza (ed.), *Ecological Economics: The Science and Management of Sustainability*, New York: Columbia University Press, pp. 215-33.

Faber, M. and J. Proops (1993), 'Natural resource rents, economic dynamics and structural change: a capital theoretic approach', *Ecological Economics*, **8**,17-44.

Faber, M. and J. Proops (with R. Manstetten) (1998), *Evolution, Time, Production and the Environment* (3rd edn.). Heidelberg: Springer-Verlag.

Faber, M., J. Proops and S. Baumgärtner (1998), 'All production is joint production: a thermodynamic analysis', in S. Faucheux, J. Gowdy, and I. Nicolaï (eds), *Sustainability and Firms: Technological Change and the Changing Regulatory Environment*, Cheltenham: Edward Elgar, pp. 131-158.

Faber, M., J. Proops, M. Ruth and P. Michaelis (1990), 'Economy-environment interactions in the long-run: a neo-Austrian approach', *Ecological Economics*, **2**, 27-55.

Faber, M., J. Proops and S. Speck (with F. Jöst) (1999), *Capital and Time in Ecological Economics: Neo-Austrian Modelling*. Cheltenham: Edward Elgar.

Faber, M. and G. Wagenhals(1988), 'Towards a long-run balance between economic and environmental protection', in W. Salomons and U. Förstner (eds.), *Environmental Impact and Management of Mine Tailings and Dredged Materials*, Heidelberg: Springer-Verlag.

Hicks, J. (1965), *Capital and Growth*, Oxford: Oxford University Press.

Hicks, J. (1979), 'A Neo-Austrian growth theory', *Economic Journal*, **80**:257-81.

Hicks, J. (1973), *Capital and Time: A Neo-Austrian Theory*, Oxford: Oxford University Press.

Jöst, F. (1994), *Klimaänderungen, Rohstoffknappheit und wirtschaftliche Entwicklung. Ein neo-Östereichisches Zwei-Regionen Modell*, Heidlberg: Physica-Verlag.

Koopmans, T. (1951), 'Analysis of production as an efficient combination of activities', in T. Koopmans, (ed.), *Activity Analysis of Production and Allocation*, New York: Wiley, pp. 33-97.

Proops, J. (2003), 'The growth and distributional consequences of international trade in natural resources and capital goods: a neo-Austrian analysis', Ecological Economics Working

Paper (www.ecologicaleconomics.org).

Proops, J. and S. Speck (1996), A comparison of neoclassical and neo-Austrian growth models, *Structural Change and Economic Dynamics*, **7**, 172-92.

Schumpeter, J. (1954), *History of Economic Analysis*, London: George, Allen and Unwin.

Speck, S. (1997), 'A neo-Austrian five process model with resource extraction and pollution abatement', *Ecological Economics*, **21**, 91-103.

Stephan, G. (1995) Introduction into Capital Theory, Heidelberg: Springer-Verlag.