ENERGY POLICY, ENVIRONMENT AND INCOME DISTRIBUTION IN LDCs: AN INPUT-OUTPUT APPROACH

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Synopsis

There are important but often neglected interrelationships between energy, environment and the distribution of income and wealth in Less Developed Countries. This paper discusses these interrelationships and shows how they relate to significant policy issues, particularly energy policy. It demonstrates that it is possible to investigate these relations through a straightforward extension of existing multi-sectoral modelling approaches based on input-output analysis. The model offers a conceptual and empirical framework that enables the implications of alternative policy strategies and technical possibilities to be explored.

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The Interrelationships between Energy, Environment and Income Distribution

Significant policy issues arise from the links between energy, the environment and the distribution of income and wealth in LDCs. This paper illustrates some of these issues and suggests how a multi-sectoral model can be used to investigate the links.

When environmental issues became prominent in the 1970s, LDC representatives argued that they embraced much more than questions of wildlife conservation and loss of green-and-pleasantness. It was stressed that poverty and its attributes - defective water supplies, poor health and housing, damaged soil productivity - are central to the quality of a person's environment. Hence environmental issues were recognised to be closely related to questions not only of use but also of access to resources and, by implication, to the level and distribution of income and wealth (Pearson and Pryor, 1978). The 1970s also saw increased concern over energy problems in LDCs, in relation to both commercial energy (especially, of course, oil) and traditional energy (fuelwood, charcoal, animal dung and crop residues), vital for meeting the basic needs of the poor. Moreover, attention was drawn to the environmental impacts of energy production and use, and to the distribution of these impacts. It was becoming clear that energy, environment and distribution have to be seen as interrelated areas.

In the same decade there was increasing criticism of the ability of existing growth-based development strategies to meet basic needs in the absence of accompanying policies to create employment and promote income redistribution. To re-tell a well-known story briefly, the ensuing reduction to the ranks of strategies based only on rapid 'growth through industrialisation' was followed by the preferment of 'redistribution with growth' and, most recently, accelerated promotion for 'basic needs' strategies (Chenery et al., 1974, Singer, 1979). A number of models were constructed with the aim of investigating the interrelationships among income distribution, sectoral output patterns, employment and other key variables (see, for example, Ballentine and Soligo, 1978, Cline, 1975, Pyatt et al., 1977, Sinha et al., 1979, and Weisskoff, 1976). These approaches later developed into computable general equilibrium models (Adelman and Robinson, 1978, Dervis et al., 1982). Input-output analysis played an important part in these income distribution models. Also at this time, input-output models were being extended to incorporate a more detailed analysis of energy variables (Bullard and Herendeen, 1977, Denton, 1977, Herendeen, 1974, Park, 1982, Reardon, 1973), while others were being designed to take account of environmental variables (Kneese, 1977, Leontief, 1970, Leontief and Ford, 1972, Leontief et al., 1977, Victor, 1972). Surprisingly, however, to my knowledge no attempt has been made to link the income distribution modelling with both the energy and the environment models, despite their common input-output basis and their clear and important interrelationships. This paper suggests a simple consolidated model which can yield insights into policy issues that can only be explored properly by taking into account all three areas.

Energy policy provides a useful illustration of some of the interrelationships. The importance of developing appropriate energy strategies was emphasised by the dramatic problems that followed the 1973 oil price rises. As one study (Asian Development Bank, 1982, p. xxxi) puts it:

> "The energy problem of the DMCs (Developing Member Countries) has three dimensions: first the increased price of oil imposes a heavy and increasing foreign exchange burden; second, to relieve this burden alternative indigenous energy resources must be developed at high capital costs; third, the already greatly-diminished non-commercial energy resources of the rural areas will be further reduced because of the high cost of substitute fuels. This will particularly affect the rural poor."

Integrated energy strategies need to encompass these dimensions of the problem, whilst taking proper account of potentially significant energy-related environmental impacts. In practice, however, energy planning has concentrated on commercial energy and has neglected the role of traditional (or 'non-commercial') fuels, while environmental impacts are assessed separately if at all (Agarwal, 1983, Sankar, 1977, p.224, World Bank, 1979a, p.19).

The concentration on commercial energy can be explained partly by the oil price rises and partly by a preoccupation among planners with the 'organised', industrialised and mainly urban sectors. It was in these sectors that the demand for commercial energy was both high and rapidly-growing (for example, the Asian Development Bank (1982, p.30) reports that in its DMCs commercial energy consumption grew at 10 per cent per year in 1965-73 and 8.5 per cent in 1973-78). The basic needs strategy, on the other hand, with its increased emphasis on rural development, directs attention towards both traditional energy and environmental impacts.

The neglect of traditional energy matters for two reasons. Firstly, it is important in its own right in meeting basic needs. Recent data confirms what everybody should have known, that traditional energy use is substantial, both absolutely and relative to commercial energy, among the urban poor and the predominantly rural populations of LDCs (see, for example, Asian Development Bank, 1982, Barnett et al., 1982, Douglas, 1982, Foley and van Buren, 1982, Hall et al., 1982, Sankar, 1977, World Bank, 1979a and 1979b). It has been claimed that traditional energy sources may supply up to a quarter (World Bank, 1980, p.38) or two-fifths (Hall et al., 1982, p.7) of the energy used in the Third World. Moreover, traditional energy is also widely and increasingly used in industrial processes, from tobacco-curing to steel-making, where it can substitute for commercial fuels needing scarce foreign exchange.

Secondly, the neglect of traditional energy matters because it and commercial energy cannot sensibly be viewed in isolation from each other (Pearson and Stevens, 1984); for example,

> "It needs little imagination to visualise what would happen if demand for traditional energy sources were to be shifted to the commercial sector, yet this is what may happen if no steps are taken to improve their availability" (World Bank, 1979a, p.19).

On the other side of the coin, increased relative prices of commercial energy encourage the substitution of traditional energy where this is feasible. Furthermore, changes in the level and distribution of incomes will affect the absolute levels and relative shares of commercial and traditional energy in the future. Energy planning has to take account of these interactions, especially where governments wish to pursue specific distributional strategies.

Energy-related environmental impacts require analysis because they can be substantial and there is no reason to assume that they will not seriously affect the ability of the poorer sections of the community to meet their basic needs. People feel these effects both as consumers (for example, through health damage, recreational and amenity losses) and, significantly, as producers (for example, through loss of farm and fishery output and productivity, and from reduced ability to work because of impaired health) (Cooper, 1981, Pearson and Pryor, 1978). Although the environmental effects of commercial energy production and use have long been known, it has only recently been acknowledged that traditional energy can also significantly affect environmental quality and hence the quality of people's lives. This is particularly because of the 'fuelwood crisis' in a number of LDCs, which has brought with it associated problems of deforestation, desertification and siltification, as well as loss of soil fertility through the substitution of dung for fuelwood (Eckholm, 1979; Global 2,000, 1982, pp.318-32,374-80; World Bank, 1979b, pp.40-42,77, 1980, pp.38-39).

Changing development priorities and growing concern over energy and the environment reinforce the argument for integrating the currently separate approaches to modelling the relations between the distribution of income and wealth, the energy sectors and the environment. The benefits from this integrated modelling lie in its ability to capture some of the complexity of the interrelationships. This complexity means that it is not possible a priori to specify with confidence the repercussions of a policy. Attempts to do so based, for example, only on simple comparisons of marginal propensities to consume commercial and traditional energy and on 'first-round' effects are almost certain to be misleading.

Income Redistribution: An Illustrative Example

As an aid in identifying the important features of an integrated model, consider what might happen in an economy in the event of a fiscal policy designed to lead to a specific, more equal income distribution. Assume that transfers take place from the richer groups in rural and urban areas to the poorer groups in these areas. The crude flowchart (Figure 1) depicts the income, expenditure, output and environmental flows and may help to visualise what happens.

The initial impact of the redistribution would be on the level and patterns of expenditure of the income groups involved. The expenditure of the poorer groups would increase, particularly on commodities for which they have a relatively high marginal propensity to consume, including foodgrains and other basic foods and traditional and modern fuels for cooking. By contrast, the expenditure of the richer groups decreases, particularly on commodities for which they have a relatively high mpc, including less basic foods, manufactures and services, commercial energy and imported goods. Moreover, the now higher overall weighted average mpc for all groups leads to

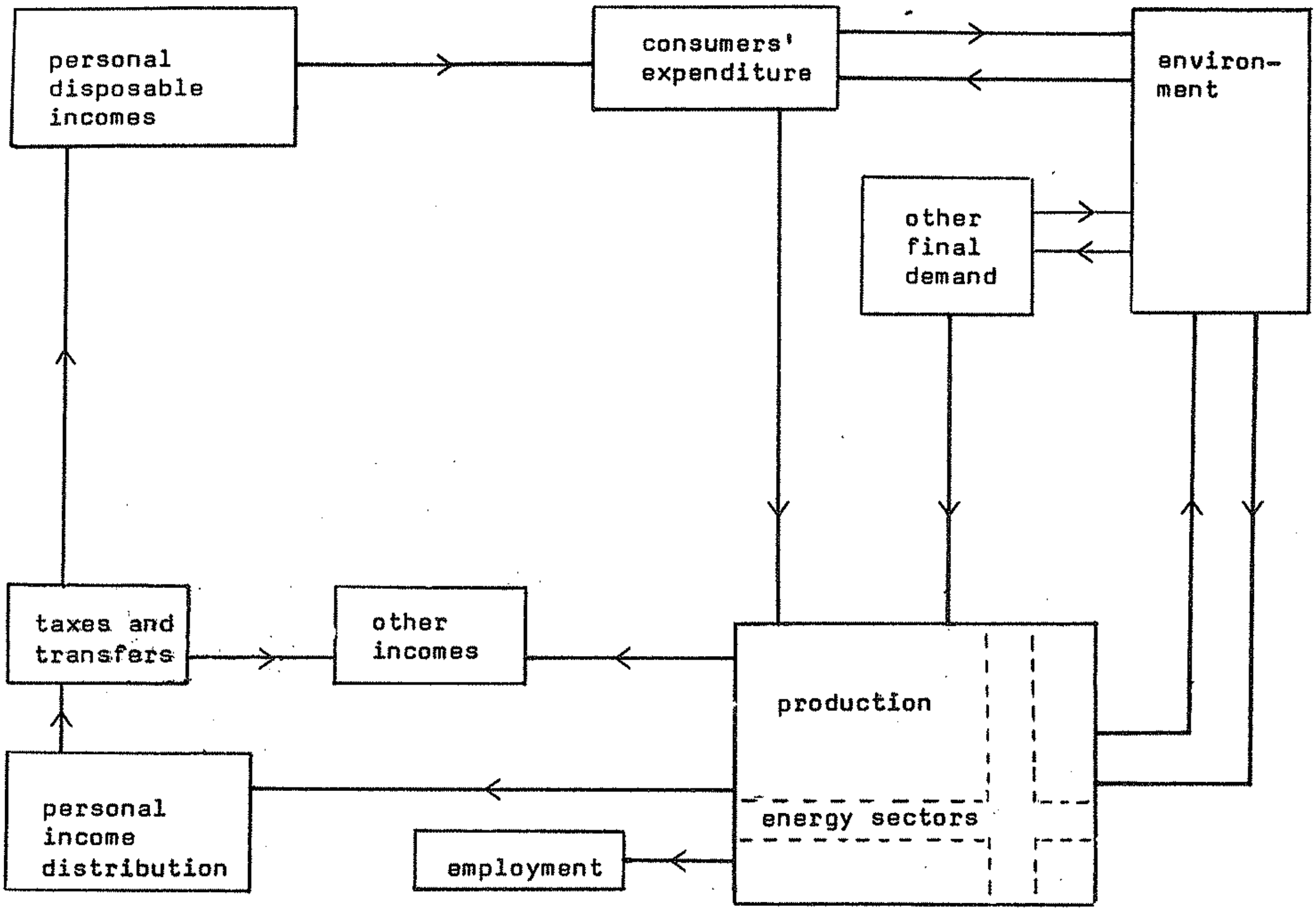

Figure 1: Outline of Principal Flows

an increase in aggregate consumer demand. These initial changes in the level and pattern of sectoral final demand lead, via a series of interindustry repercussions, to a new set of gross outputs in all directly and indirectly affected production sectors. This includes changed outputs in both commercial and traditional energy sectors to satisfy both intermediate and final demands for energy. There is a new level of imports, although not necessarily an overall reduction.

The new levels of gross output in turn imply changes in factor inputs, employment and value added in each sector. The greater part of the changes in value added feeds through to personal incomes, affecting both their level and distribution for all income groups in rural and urban areas, not just those specific groups originally involved in the redistribution. Rural property owners in particular could be expected to benefit from the net increase in agricultural demand and output, countering the loss from the income transfer. The income changes then set off a new round in the multiplier process by changing the expenditure of all groups, leading eventually to further new sectoral levels of gross output, employment, value added and incomes. Successive rounds take place until the multiplier process has worked itself out and the system converges to a new equilibrium. One not immediately obvious result is worth noting: because of the feedback via incomes generated in each production sector, the change in the equilibrium levels of income of the richer groups is likely to be significantly different from the initial income transfers they make to the poorer groups (see Gregory et al., 1979, p.33, or Sinha et al., 1979, pp.93-109).

Throughout the process just decribed environmental impacts would be occurring, both from consumers' activities on producers and other consumers and from producers' activities on consumers and other producers. In particular, the use of commercial and traditional energy for production, transport and domestic cooking and lighting creates a variety of impacts, mainly via different forms of air pollution. Also production of commercial energy itself, especially coal mining, affects both consumers and producers via air, water and land pollution. Production of traditional energy, particularly fuelwood and charcoal, can lead to deforestation and attendant problems of soil erosion, siltification and flooding (Global 2,000, 1982; Sharma, 1983). All of these environmental impacts can be expected to vary spatially and by income group. Income redistribution affects the patterns of commercial and traditional energy production and use, and hence alters the level, composition and distribution of environmental impacts. These changed impacts will in turn influence not only current income and consumption flows but also stocks of physical and human assets.

The Features of an Integrated Model

This example of income redistribution illustrates that there is in effect a simultaneous system in which changes in one set of variables trigger a complex series of repercussions. A number of the outcomes may be obscure or counter-intuitive and are, therefore, only likely to be revealed by an integrated model. Such a model would be driven by four main structural features: (a) the pattern of consumer spending by income groups (via expenditure functions); (b) the interindustry production structure, including appropriately disaggregated energy sectors (via input-output coefficients); (c) the distribution of personal incomes by income group, generated in each production sector (via value added distribution coefficients); and (d) the structure of environmental impacts from production, consumption and use of energy (via environmental coefficients). Underlying these features is the structure of ownership of human and physical assets, particularly education and land. It is the interaction between the features that determines the nature of the system's response to exogenous changes in income distribution, and hence what happens in the energy sectors.

Of course, the four features also determine the direction and magnitude of the system's response to changes in any exogenous variables or parameters, not just income distribution. For example, a model with these features could be used to investigate the effects of changes in non-personal final demand in the energy sectors (or in a sub-set of them) on equilibrium outputs, employment and incomes, and on environmental impacts. Also the energy and environment implications of different development strategies could be examined; for example, the implications of an agriculture-based expansion in exogenous final demand could be compared with an industry-based expansion. Moreover, the impact of changes in energy technology or pollution coefficients might be traced through.

The model described below represents the major elements in the income-expenditure-output-income cycle discussed earlier. It is a semi-closed Leontief input-output system, with personal consumption endogenously determined because the model incorporates the generation of the size distribution of incomes from values added in sectoral production. The distributions of income and expenditure are disaggregated by income group and area. The core of the model is similar to that described in Miyazawa (1976, Ch. 1) and also similar to a model used to investigate income distribution, employment and basic needs in India (Gregory et al., 1979, 1981, Sinha et al., 1979). This version, however, incorporates a new emphasis on the energy sectors and an additional treatment of energy-related environmental impacts. An advantage of the model is that it represents a relatively simple extension of an already operational modelling approach.

The Model

The model is built up from two sets of simultaneous equations, one set for the output and one for the income flows. The output set shows that gross output satisfies intermediate demand plus endogenous personal consumption and exogenous other final demands (investment, government expenditure and exports). The income equations show that income arises from value added in production and from exogenous taxes and transfers. The output and income flow equations are

$$X = AX + CY + F \tag{1}$$

$$Y = VX + T \tag{2}$$

There are n production sectors, including $m < n$ energy sectors. There is a total of s social groups in r areas or regions (e.g. lower and upper income groups in rural and urban areas), all claiming personal incomes, except for one group claiming non-personal 'other' (corporate and government) incomes. There are p types of environmental impact. X (of dimension $n*1$) is a vector of gross output by sector, A ($n*n$) is a matrix of technical input-output coefficients and C ($n*s$) is a matrix of coefficients of sectoral personal consumption per unit of each income group's disposable income. Y ($s*1$) is a vector of disposable incomes, F ($n*1$) is a vector of exogenous, non-personal sectoral final demands, V ($s*n$) is a matrix of coefficients of value added per unit of sectoral output, claimed by each income group, and T ($s*1$) is a vector of exogenous net taxes and transfers.

Once equations (1) and (2) have been solved for the equilibrium output and income vectors, X and Y, the energy, environmental impact and employment flows can be obtained from the following expressions

$$E = E^{x}X + E^{c}CY + E^{f}F \tag{3}$$

$$D = D^{x}X + D^{c}CY + D^{f}F \tag{4}$$

$$w = L'X \tag{5}$$

E (m*1) is a vector of physical energy outputs from the energy sectors, E^{x} (m*n) is a matrix of direct energy use coefficients per unit value of gross output and E^{c} and E^{f} (both m*n) are matrices of energy coefficients per unit value of personal consumption and non-personal final demand, respectively, in the energy sectors. D (p*1) is a vector of environmental impacts (e.g. physical outputs of pollutants or other physical indicators of ecological damage). D^{x} (p*n) is a matrix of coefficients of environmental impacts per unit value of gross output, while D^{c} and D^{f} (both p*n) are matrices of coefficients of environmental impacts per unit value of personal consumption and of non-personal final expenditure, respectively (D^{c} could be disaggregated to distinguish between the impacts of different social groups). Total employment is given by the scalar w, while L' (1*n) is a row vector of employment coefficients per unit of gross output.[1]

The model can be used to find the effect on endogenous X, Y, E, D and w of projected changes in exogenous non-personal final demand (in the energy sectors or any others) and personal taxes and transfers. Taking differentials of (1) and (2) and rearranging gives

$$\left[\begin{array}{c|c} \begin{matrix} I - A \\ (n*n) \end{matrix} & \begin{matrix} -C \\ (n*s) \end{matrix} \\ \hline \begin{matrix} -V \\ (s*n) \end{matrix} & \begin{matrix} I \\ (s*s) \end{matrix} \end{array}\right] \left[\begin{array}{c} dX \\ \hline dY \end{array}\right] = \left[\begin{array}{c} dF \\ \hline dT \end{array}\right] \tag{6}$$

This system can now be solved for dX and dY by finding the inverse of the partitioned matrix of coefficients by the usual method

(Intriligator, 1971, p.488), beginning by assuming that (I-A) or I has an inverse. The latter assumption yields

$$\begin{bmatrix} dX \\ \hline dY \end{bmatrix} = \left[\begin{array}{c|c} (I-A-CV)^{-1} & (I-A-CV)^{-1}C \\ \hline V(I-A-CV)^{-1} & I+V(I-A-CV)^{-1}C \end{array}\right] \begin{bmatrix} dF \\ \hline dT \end{bmatrix} \qquad (7)$$

where $(I-A-CV)^{-1}$ is the enlarged inverse matrix multiplier, showing the total effects of changes in F on gross output X (including the outputs of the energy sectors), through interindustry and induced consumption activities. This multiplier can be split into two parts, a production and a consumption inverse:

$$(I-A-CV)^{-1} = (I-A)^{-1}(I-CV(I-A)^{-1})^{-1} = B(I-CVB)^{-1} \qquad (8)$$

where $B = (I-A)^{-1}$ is the standard Leontief open system production inverse. $(I-CVB)^{-1}$ is the consumption inverse, reflecting endogenous changes in each income group's consumption because of induced income from direct and indirect output changes triggered by an exogenous change in final demand, such as a change in the pattern of demand in the energy sectors.

The other elements of the partitioned inverse in (7) are now easily interpreted. Consider, for example, the effects of an exogenous income change, dT (possibly an income redistribution via fiscal policy). The change in equilibrium group incomes is

$$dY = (I+V(I-A-CV)^{-1}C)dT = (I+VB(I-CVB)^{-1}C)dT \qquad (9)$$

so that the change in net transfers has multiplier effects on top of its own direct impact. Induced consumption leads, through the consumption and production inverses, to spillover effects on personal incomes via values added in production. The whole expression in brackets in (9) is the income spillover matrix K, yielding the incomes of each income group per unit injection of exogenous income to each income group.

Once the changes in the equilibrium vectors of gross output and personal incomes, dX and dY, have been obtained from (7), the changes in physical energy use, environmental impacts and employment can be calculated. Expressions (3), (4) and (5) become:

$$dE = E^{x}dX + E^{c}CdY + E^{f}dF \tag{10}$$

$$dD = D^{x}dX + D^{c}CdY + D^{f}dF \tag{11}$$

$$dw = L'dX \tag{12}$$

The income spillover matrix K (Miyazawa, 1976, calls it the 'interrelational income multiplier') turns out to be an important feature in the impact of any changes in exogenous final demand or group incomes. This becomes evident on inverting the partitioned matrix in (6) the second way, by starting with the assumption that $B = (I-A)^{-1}$ exists. Then (7) can instead be written as

$$\begin{bmatrix} dX \\ \hline dY \end{bmatrix} = \left[\begin{array}{c|c} B(I+CKVB) & BCK \\ \hline KVB & K \end{array}\right] \begin{bmatrix} dF \\ \hline dT \end{bmatrix} \tag{7a}$$

where $K = (I-VBC)^{-1}$ appears in every sub-matrix of the inverse[2]. Miyazawa (op. cit.) has shown that these sub-matrices can be interpreted in ways which illuminate the underlying economic processes. For example, sub-matrix KVB consists of the income spillover matrix post-multiplied by the matrix of induced incomes per unit of gross output per unit of exogenous final demand.

This version of the solution illustrates clearly how the core of the model is driven by three structural coefficient matrices: B, the open system Leontief production inverse; C, the matrix of sectoral consumption per unit of group income; and V, the matrix of personal incomes generated from values added in each sector. K is built up from B, C and V. There are also three other important sets of coefficients that influence the model's results, namely the energy, environmental impact and employment matrices in expressions (3), (4) and (5).

Changes in any of these key structural matrices will influence the system's behaviour in analysable ways. Alterations of this nature could include: changes in technology, particularly in energy production, conservation and use[3]; changes in the pattern of consumer tastes of different income groups, for example for types of commercial and traditional energy; changes in the distribution of sectoral value added to income groups (Sinha et al. (1979) simulated the effects of a land redistribution, for example); changes in environmental impacts from energy production and use; and finally, changes in sectoral employment requirements.

The model can thus be used to simulate the effects of a variety of policies and possibilities, not only through changes in exogenous variables (final demand and income taxes and transfers) but also through changes in the structural matrices. In each case the full effects, direct, indirect and income-induced, can be traced and the changes in comparative static equilibrium values discovered. In this way, policy issues connected with energy use and conservation, environmental impacts, employment, and basic needs can be investigated. In particular, it is possible to explore the nature of any trade-off between different energy and basic needs policies.

Data Requirements

The main point here is that, by and large, the major innovatory data work would be required only for traditional energy and for the environmental impacts. Input-output tables are now available for many countries, as are data on employment and consumers' expenditure. Appropriate disaggregation would be important, particularly for the commercial and traditional energy sectors, but also for sectors where techniques differing in energy and labour intensity are used, such as handloom and mill-made cotton clothing. Data on traditional energy production and use, however, are not yet widely available and are not necessarily reliable. Nonetheless, more data is now coming forth (Barnett et al., 1982, Hall et al., 1982) and for some countries it should be possible to break down traditional energy into sub-sectors[4]. The analysis of the demand for traditional energy also poses some problems[5]. In the past, household sample surveys tended to record negligible imputed expenditure on fuel and light for poorer expenditure classes, for example.

The environmental impact data might suggest more formidable problems, although data availability is improving (e.g., Global 2,000, 1982; Sharma, 1983). In some respects the problems of building the environmental matrix are similar to those of constructing the matrix to distribute each sector's value added to different social groups. This has been done for India (Sinha et al., 1979) and for a limited number of other countries, although the work is complex and laborious and the data base less than ideal.

Even if only broad ranges of environmental impact could be asessed, they might nonetheless enable the model to produce policy-relevant results.

Comments on the Model

In the form presented here the model is linear throughout. However, consumers' expenditure, employment and environmental impacts could all be treated in a non-linear fashion. In particular, if consumers' expenditure is determined by non-linear sectoral and regional expenditure functions, the model cannot be solved in a single matrix inversion and instead must use an iterative procedure which converges to a solution, as was done by Sinha et al. (1979). This has the added benefit of yielding insights into the repercussions within the model as the iterations proceed. Thus it is possible to exploit the conceptual and computational advantages of input-output analysis while relaxing the severity of the linearity assumption.

The model is clearly a simplified representation of the complex relationships outlined earlier. At this stage in its development it shares with many other input-output-environment models the limitation that environmental repercussions are modelled only in terms of immediate physical flows.[6] Thus we have not tried explicitly to model what happens after the flows have occurred, and the consequent damage to people and resources. In principle such an extension can be envisaged and the admittedly difficult task of including some valuation of the social costs of damage (Freeman, 1979) could also be attempted. Although such extensions are currently being considered, they would add considerably to the model's complexity and might prove too demanding of presently available data. Similarly, it would in principle be possible to add pollution abatement activities to the model, following Leontief (1970), but practical implementation of this would be another story (Leontief et al., 1977, p.25). Of course, the model also shares the well-known limitations and strengths inherent in the assumptions underlying all input-output models.

Conclusion

This paper has sought to show that it is possible to model the relations between energy, environment and income distribution through a straightforward extension of existing input-output approaches. The model enables the implications of alternative policy strategies and technical possibilities to be investigated. So, for example, an energy conservation strategy designed to reduce final demand for commercial energy (say oil) will have repercussions not only on other sectors, including traditional energy, but also on the environment, on employment and the level and distribution of incomes. Moreover, because the model incorporates the vital feedback from group incomes generated in production to incomes spent on consumption, it takes account not just of direct and indirect but also of significant income-induced effects on all endogenous variables. These income-induced effects, often counter-intuitive, are not captured when only the open input-output model is used.[7]

Despite its limitations and the associated problems of obtaining good data, a modelling exercise of the type described here is valuable because it provides a conceptual and empirical framework incorporating important links between energy, both commercial and traditional, the environment and income distribution. It both reminds us of the need to account for these links and can be used to generate insights into policy formulation and policy trade-offs. Given the undoubted importance of these areas to the basic needs of LDC populations, an integrated model of this type should be developed.

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Notes

1. Imports can be calculated in the usual way through import coefficients.

2. Miyazawa (1976) provides an alternative, more detailed derivation and explanation of $K = I+VB(I-CVB)^{-1}C = (I-VBC)^{-1}$.

3. Park (1982) presents the detailed algebra of some of the changes suggested here, although he does not deal explicitly with income redistribution and environmental impacts.

4. There would, however, be problems associated with the fact that several forms of traditional energy are essenially joint products or by-products.

5. The problems of collecting, analysing and interpreting data on traditional energy are discussed in Barnett et al. (1982), Hall et al. (1982) and World Bank (1979b).

6. Assessments of existing input-output-environment models can be found in Cooper (1981), Kneese (1977), Pearce (1976) and Victor (1972).

7. Further explanation and empirical demonstration of the significance of income-induced effects resulting from the incorporation of feedback from incomes generated in production to incomes spent on consumption can be found in Sinha et al. (1979). One interesting recent paper estimates the impact of geothermal energy development on income distribution by using only an open-system regional input-output model and thus does not include the potential effects of income feedback in its estimates (Rose et al., 1982).