Abstract

This paper outlines a conceptual framework for dealing with non-efficiency objectives in the pricing of publicly controlled natural resources. A general equilibrium model is developed and issues of model specification and solution are discussed. Finally, a numerical example serves to illustrate some of the important economic interactions which the model captures.

THE PRICING OF PUBLICLY CONTROLLED NATURAL RESOURCES: A GENERAL EQUILIBRIUM APPROACH

by

Thomas W. Hertel*

July 1982 No. 82-21

Contributed paper accepted for presentation at the annual meeting of the American Agricultural Economics Association in Logan, Utah, August 1-4, 1982.

---

*Ph.D. candidate, Department of Agricultural Economics, Cornell University.

INTRODUCTION

Despite a decline in absolute allegiance to efficiency considerations among many resource economists (Castle *et al*. 1981, p. 463), a majority of the applied work on the pricing of publicly controlled natural resources retains economic efficiency as its focus. This work is typically partial equilibrium in character and has generally highlighted the benefits associated with marginal cost pricing, perhaps adjusted in light of second-best or dynamic considerations. However, existing price structures often differ markedly from these recommendations. There are many reasons for such discrepancies. This paper focusses attention on the impact which alternative pricing schemes have on non-efficiency objectives.

A familiar example of inefficient natural resource pricing is provided by the current allocation of water within agriculture and between the farm and non-farm sectors in the Western United States. LeVeen and Stavins (1981, p. 6) note that water prices in California range from $2 per acre foot, in the case of some agricultural users, to over $100 per acre foot for urban, residential consumers. A similar, but less obvious resource pricing problem confronts New York in the allocation of inexpensive, state-owned hydropower. Historically, most of this natural resource has been sold to a subset of residential customers as well as electricity intensive industry. The latter sector has been attracted to the state largely due to this resource availability. Recent increases in petroleum prices have resulted in rapidly rising electric prices for customers relying on oil-generated power. Subsequent inequities in electric rates have prompted the Chairman of the publicly owned utility to propose a major reallocation of hydropower in the state (Dyson, 1981).

The purpose of this paper is to outline a conceptual framework which will facilitate the analysis of non-efficiency objectives as well as guide additional empirical investigation into these natural resource pricing problems. Emphasis is placed on a general equilibrium approach in deference to extensive work in the field of public finance which illustrates that, particularly in the case of partial factor taxes (subsidies), partial equilibrium analysis can lead to seriously faulty results.[1] After a brief discussion of the underlying methodology, issues of model structure, numerical specification and solution are discussed, and a simple numerical illustration is provided. Efforts are currently underway to employ this type of model in the analysis of New York's hydroallocation problem.

THE STATE'S PLANNING PROBLEM

Following recent developments in the public economics literature, the state's planning problem may be conceptualized as a two-step process. The first step involves determining the optimal, social welfare maximizing allocation of factors and commodities. The second step utilizes models of producer and consumer behavior to identify a pricing scheme which will guide the decentralized economy to this optimal outcome. Elsewhere (Hertel, 1981a) the author has developed a simple illustration of this planning problem for a one sector economy which controls the allocation of a natural resource. As long as the social welfare function is devoid of any distributional component (i.e. it depends only on the utility of a representative consumer), the solution of this problem leads to a marginal cost pricing rule.

Using the simple example as a baseline, minimal conditions for desirable departures from marginal cost pricing may be examined (Hertel, 1981a). One

---

[1] Harberger's application of a simple general equilibrium model to the analysis of the corporate income tax is the "classic" in this area (Harberger, 1962). It illustrated that such a tax may well be borne by all capital in the long run, as capital shifts to the non-corporate sector in an attempt to equalize after tax returns.

such set of conditions involves introducing representative consumers from each of two substate regions into the social welfare function. Further, assume that the two regions have substantially different endowments of an aggregate (capital/labor) factor of production, and that the poorer region is specialized in the production of a resource intensive good. Ideally the solution of this extended planning problem would involve efficient pricing of the natural resource, using lump sum transfers to accomplish an "optimal" distribution of income between the two regions. However, in practice the range of instruments available to state policymakers is severely limited. Depending on the parameters of the problem, it is conceivable that the state might choose to price the natural resource below marginal cost in order to encourage output and incomes in the lagging region. Furthermore, if differential pricing of the resource input were administratively feasible (e.g. electricity), policymakers may choose to "subsidize" its use in the resource intensive sector (the lagging region), while charging a higher price elsewhere.[2] In short, <u>departures from marginal cost pricing may be desirable for achieving non-efficiency objectives when policy instruments are limited</u>.

While the formal planning problem is a useful intellectual construct, it is of little empirical value as long as we cannot agree upon a social welfare function. Proceeding in a more practical vein, we may adopt the notion of targets and instruments from the macroeconomic theory of policy. For example, a state might consider directing its resource pricing instrument towards the achievement of a single objective (e.g. attracting capital or increasing employment). In the context of a 2 x 2 general equilibrium model, Mieszkowski (1966)

---

[2] A desire to diminish regional disparities has been reflected in many of the arguments in favor of the sale of inexpensive hydropower to electricity intensive industry in parts of Upstate New York.

examined the cost (excess burden) associated with subsidizing output in one sector of the economy, and concludes that, in a competitive economy, a production subsidy dominates the factor subsidy. In the case of New York, this would imply that its hydro-resource should be sold to both sectors at opportunity cost, with the proceeds being employed to subsidize output in the desired sector. McClure (1970) employs a similar model to derive results which allow us to compare the effectiveness of alternative subsidy schemes in attracting factors of production to a particular region (state).

It is quite likely that the state's planning problem cannot be reduced to a question of optimizing over one or two objectives. In this case it is important to investigate the entire range of output and incidence effects resulting from alternative price structures. Qualitative results for the simple 2 x 2 model are concisely stated in Jones (1965). In the case of partial factor taxation, changes in the factor price ratio are made up of output and substitution effects. If the resource intensive sector receives the input subsidy, these work in the same direction, serving to raise the return on resources relative to other primary factors. However, even in this simplest of general equilibrium models, we find that there is little more that can be said without further knowledge of the model's parameters. Additional factors of production rapidly increase the number of interactions, and hence parameters, which must be accommodated. Of particular importance in determining the incidence of a partial factor tax are the elasticities of substitution in production. Extending the model to allow for three primary factor aggregates (e.g. resources, capital and labor), we move from one elasticity of substitution per sector to nine Allen partial elasticities of substitution.3/ Thus empirical results

---

3/ In a separate paper (Hertel, 1981a), the author has worked with a three factor model to derive a qualitative expression for changes in the wage-rental ratio in response to partial factor subsidies on the resource input. This work indicates the important role plated by the relative sizes of the Allen partial elasticities of substitution between capital and resources on the one hand and labor and resources on the other.

soon become the only practical alternative.

IMPLEMENTING THE MODEL

Model Structure: The qualitative results cited above are quite useful in guiding us so that we may capture the essential general equilibrium implications of alternative resource pricing decisions while retaining a computationally tractable model. In defining the sectors of such a model we note that it is important to identify substantial differences in out-of-state tradeability of commodities, factor intensity, as well as factor substitutability. In this paper these distinctions will be illustrated using three sectors. They will represent resource extensive/tradeable (T), resource extensive/non-tradeable (N), and resource intensive/tradeable (I) commodities respectively.[4] Factors in the model are delineated to facilitate consideration of supply response, interstate mobility and substitutability. Three primary factors of production are utilized here: capital (K), labor (L), and resources (R).[5] Intermediate goods are also an important component of the empirical problems discussed above (e.g. primary metals and chemicals in the case of New York). Inclusion of the latter leaves us with six factors in each of three productive sectors.

There are both theoretical and empirical issues involved in specifying the production functions employed in this model. Current data availability, particularly at the state level, forces us to resort to input-output tables in accomodating intermediate goods.[6] Clearly the attendant assumption of fixed

---

[4] Finer distinctions may be introduced by adding more sectors. This does not complicate the model conceptually, it merely increases the computational effort required to solve the model.

[5] Any of these broad factors can be further disaggregated for purposes of a particular application. In the case of New York's hydroallocation problem, the "resource" input becomes an energy aggregate. The assumption of two-stage optimization (Fuss, 1977) permits energy to be further broken down into electricity, natural gas, petroleum and coal inputs.

[6] In those cases where recent I-O tables are not available for the state, national production technology may be imposed on the economy at a very disaggregate level, followed by aggregation using employment data to arrive at the appropriate sectoral composition (Boisvert and Bills, 1976).

technological coefficients is unacceptably restrictive for the full production structure. For example, qualitative results referred to above indicate the important role played by the elasticities of substitution among primary factors in determining the incidence of alternative subsidy schemes. Therefore we employ the concept of a primary factor aggregate: $N_i = N^i(R,K,L)$ which exhibits constant returns to scale. This may be estimated using a flexible functional form (e.g. translog) which permits a wide range of factor substitutability. Thus we have the following production structure for a given sector (e.g. I):

$$I = \min[N^I(R_I, K_I, L_I),\ 1/a_{II}I_I,\ 1/a_{TI}T_I,\ 1/a_{NI}N_I].$$

Proceeding with the simple three sector aggregation described above, we may now introduce a complete general equilibrium model. This is presented below.

(A) Intensities and Prices

(1)-(3) $P_j = a_{Rj}P_R + a_{Kj}P_K + a_{Lj}P_L + a_{Tj}P_T + a_{Nj}P_N + a_{Ij}P_I$

(4)-(12) $a_{ij} = \partial c_j(P_R, P_K, P_L)/\partial P_i$ $i = R, K, L$ a_{Tj}, a_{Nj}, a_{Ij} constant;
$j = T, N, I$ P_T, P_I exogenous.

(B) Commodity Demands

(13)-(16) $D_i = D^i(P_T, P_N, P_I, P_R, P_R\bar{R} + P_K\bar{K} + P_L\bar{L})$; $i = I, T, N, R$

(C) Accounting

(17)-(22) $(\bar{R}, \bar{K}, \bar{L}, T, N, I)'$ = intermediate demands + final demands + net exports (TE and IE).

Equations A describe the relationships between intensities and factor prices. These are independent of output levels in this constant returns to scale economy. The first three conditions reflect competitive commodity markets (zero profits).[7] The next nine equations describe the relationships between variable input-output coefficients and primary factor prices. Cost minimization by

---

[7] Alternative assumptions about the determination of output levels and prices in selective sectors, are possible, in which case profits and losses are permitted and the relevant zero-profit condition is dropped. (See for example Hertel, 1981b.)

firms in all three sectors implies that these a_{ij}'s will equal the partial derivative of each sector's unit cost function with respect to the appropriate factor price.

The relationship between equilibrium prices and intensities on the one hand, and production, consumption and net export levels on the other, depends on the degree to which state prices are determined exogenously (by the rest of the nation). In particular, if we fix three prices (e.g. prices of tradeable commodities and capital) we can solve for the endogenous prices and intensities (equations A) independently of output levels. This is an illustration of Samuelson's Non-Substitutability Theorem (1966). If we fix one additional price, equations A will be overdetermined and we will force the economy to specialize, as one of the tradeable sectors is driven out of business. In the case of our simple model, we will assume fixed factor supplies with only p_T and p_I (tradeable prices) being dictated exogenously. This leaves us with four unknown prices and only three equations. Thus intensities and prices _will_ depend on levels. The equations in section B comprise the commodity demand conditions. Note that some of the resource is delivered directly to final demand. Finally we have the market clearing conditions which provide us with six equations and only five unknowns. This balances the discrepancy in section A, leaving us with a total of 22 simultaneous equations in an equal number of unknowns.

Numerical Specification -- Calibration vs. Econometric Estimation: Before proceeding with our simple illustration, a brief discussion of some of the major issues involved in the numerical specification and solution of applied general equilibrium models is in order. The first attempts at this sort of modelling (e.g. Fullerton _et al_., 1978) utilized a technique which is known as calibration of the model. The researchers assumed (1) that the economy, as observed at some point in time, was in equilibrium, and (2) that the behavior of individual actors in this neoclassical economy could be adequately modelled using fairly simple functional forms for utility and production functions. For example, if the economy is assumed to be Cobb-Douglas, then a unique set of parameters may be inferred from the "equilibrium" observations. If it is CES, then independent estimates of the elasticities of substitution are required. Because of the arbitrary nature the "equilibrium" assumption, the reliability of a calibrated model in predicting the impact of sector-specific policy interventions has been justifiably questioned.

This author prefers to utilize the information in historical observations via econometric estimation of the relevant parameters in the model. Clearly there is no guarantee that the resulting equilibrium will reproduce observed prices and quantities. As such, the model is most helpful in understanding changes in the composition of a given level of economic activity, as opposed to forecasting macroeconomic aggregates. Ideally, estimation should take account of the simultaneity inherent in the entire model (Mancur and Whalley, 1981). This is rarely feasible and one is forced to resort to "piecemeal" estimation.

There are two sets of concerns which we confront in attempting to solve such a model. The first has been dealt with at length in the literature on general equilibrium theory, and involves questions of existence and uniqueness of an equilibrium. At this stage our model is fully neoclassical and this should satisfy the necessary conditions for existence. However, uniqueness of this equilibrium cannot be guaranteed and must be considered on a case by case basis. Secondly, we face the computational problem of solving a large, nonlinear system of equations (presuming that an equilibrium does exist). Alternative solution strategies and algorithms are detailed in Adelman and Robinson (1978, Appendix B). In the illustration below, Newton's Method is successfully employed to solve the model at very little computational cost.

An Illustration: By way of illustration let us assume that the primary factor aggregation functions are Cobb-Douglas, as is the aggregate utility function. Table I provides a complete set of parameter values for such an economy. Note that the resource intensive sector (I) is also extremely capital intensive (e.g. primary metals and chemicals in New York's hydropower problem). The non-tradeable sector (e.g. services) is the most labor intensive, while the tradeable, resource extensive sector lies somewhere in between. Two alternative scenarios are examined. The first is the baseline (no subsidy) case, where each sector is charged the same price for the resource. The second case illustrates what happens when the resource intensive sector is charged one-half the price paid for the resource by the other two sectors and consumers. Both the partial, and the general equilibrium implications of this factor subsidy are examined. The former are the direct result of assuming the supply of primary factors to sector I is perfectly elastic. This prevents the subsidy scheme from affecting factor returns elsewhere in the economy.

Table II presents the simulation results. The first round effects of the partial factor subsidy stem from the change in relative factor prices facing sector I. Because the primary factor aggregate is Cobb-Douglas the resource input substitutes equally well for both capital and labor. Holding P_K and P_L constant, this results in equiproportional (19%) drops in the intensity with which capital and labor are used. This is where the partial equilibrium analysis ends, since it assumes that state factor prices are unaffected by sector I's factor demands. Our general equilibrium model captures the second round effects which occur as sector I bids the limited resource input away from other uses. Subsequent rises in the unsubsidized cost of R to other sectors induces them to employ it less intensively.

TABLE I. PARAMETERS IN THE ILLUSTRATIVE ECONOMY.

Primary Factor Shares
(Share of the Cobb-Douglas aggregate)

		Sector I	Sector T	Sector N
Primary Factor	K	.6	.3	.15
	L	.1	.6	.8
	E	.3	.1	.05

Budget Shares

T : .5
N : .35
I : .1
E : .05

Interindustry Table
(Fixed a_{ij}'s)

		(To) T	N	I
(From)	T	.2	.3	.4
	N	.2	.1	.1
	I	.05	.02	.01

Fixed Factor Supplies: $\overline{K} = \overline{L} = 100$, $\overline{E} = 65$; Exogenous Prices: $p_T = p_I = 2.7$

TABLE II. SIMULATION OUTPUT - EQUILIBRIUM VALUES FOR ENDOGENOUS VARIABLES.

Prices and Intensities

	No Subsidy	Partial Equilibrium Subsidy	Partial Equilibrium (% change)	General Equilibrium Subsidy	General Equilibrium (% change)
P_K	0.52	0.52	(0)	0.59	(+13)
P_L	0.72	0.72	(0)	0.63	(-13)
P_K/P_L	1.38	1.38	(0)	1.07	(-23)
P_R	0.59	0.59	(0)	0.99	(+67)
P_{RI}	0.59	0.295	(-50)	0.495	(-16)
P_N	2.36	2.36	(0)	2.28	(-3)
a_{KI}	1.59	1.28	(-19)	1.41	(-12)
a_{LI}	0.19	0.15	(-19)	0.22	(+16)
a_{EI}	0.69	1.21	(+75)	0.84	(+22)
a_{KT}	0.91			0.81	(-11)
a_{LT}	1.31			1.51	(+15)
a_{ET}	0.26			0.16	(-39)
a_{KN}	0.36			0.30	(-17)
a_{LN}	1.39			1.49	(+7)
a_{EN}	0.11			0.06	(-46)

Levels

		No Subsidy	General Equilibrium Subsidy	General Equilibrium (% change)
Output	I	36.83	50.82	(+38)
	T	30.86	20.88	(-32)
	N	37.72	38.46	(+2)
Consumption	I	2.98	3.03	(+2)
	T	29.82	30.31	(+2)
	N	24.10	25.35	(+5)
	E	27.35	16.73	(-39)
Net Exports	I	31.19	45.46	(+46)
	T	-31.19	-45.46	(-46)

The foregoing discussion considered only prices and intensities. However, the partial factor subsidy also has an impact on output levels and hence the composition of the state's economy. In particular, production in sector I expands at the expense of output in the other tradeable sector (T). Since the former is extremely capital intensive, its growth places additional demands on the state's capital market, with the opposite being true for labor. The net result is that the equilibrium price of capital rises by 13%, while the price of labor falls by 13%. This change in the wage-rental ratio is one example of the general equilibrium incidence implications of resource pricing which are not captured in a partial equilibrium setting. Additional dimensions of the incidence issue may be addressed upon further disaggregation of the model.

The change in relative factor prices is reflected in the new equilibrium factor intensities. As a result of the subsidy scheme, capital is used less intensively in every sector, while labor intensities have all increased. The latter result stands in marked contrast to our partial equilibrium prediction that labor intensity in sector I would drop by 19%. The partial equilibrium predictions for sector I's resource intensity were also significantly in error, as they did not account for the fact that the price of the fixed resource (P_R) would be bid up by 67%.

In sum, this paper has demonstrated the feasibility and possible benefits of a general equilibrium approach to state-level natural resource allocation problems. Empirical application of such a model requires, at a minimum, further disaggregation of sectors and factors of production, introduction of flexible functional forms for producer and consumer behavior, consideration of variable factor supplies, as well as critical examination (and possible relaxation) of the assumptions of perfect competition. The value of the proposed methodology will ultimately be determined by the degree to which such efforts are successful.

REFERENCES

Adelman, I. and S. Robinson (1978), Income Distribution Policy in Developing Countries, Stanford Press, Stanford, California.

Boisvert, R. N. and N. L. Bills (1976), A Non-Survey Technique for Regional I-O Models, Cornell University, Department of Agricultural Economics, Research Paper 76-19.

Castle, E. N., M. M. Kelso, J. B. Stevens, and H. H. Stoevener (1981), "Natural Resource Economics, 1946-75" in L. R. Martin ed. A Survey of Agricultural Economics Literature vol. 3, University of Minnesota Press, Minneapolis, Minnesota.

Dyson, J. (1981), Allocation of Hydroelectric Power, Report to the Governor and the Legislature of the State of New York from the Chairman of the Power Authority, PASNY, New York, N.Y.

Fullerton, D., J. B. Shoven, J. Whalley (1978), "General Equilibrium Analysis of U.S. Taxation Policy", in 1978 Compendium of Tax Research, Office of Tax Analysis, Department of the Treasury.

Fuss, M. A. (1977), "The Demand for Energy in Canadian Manufacturing", Journal of Econometrics 5, 80-116.

Harberger, A. C. (1962), "The Incidence of the Corporation Income Tax", Journal of Political Economy 70, 215-240.

Hertel, T. W. (1981), The Pricing of Publicly Controlled Natural Resources: A General Equilibrium Approach, term paper, Cornell University.

Hertel, T. W. (1981b), Dissertation Prospectus, Cornell University.

Jones, R. W. (1965), "The Structure of General Equilibrium Models", Journal of Political Economy 73, 557-572.

LeVeen, E. P. and R. N. Stavins (1981), Institutional Impediments for More Efficient Use and Allocation of Irrigation Water in the West, Public Interest Economics (West), Berkeley, California.

Mansur, A. and J. Whalley (1981), "Numerical Specification of Applied General Equilibrium Models: Estimation, Calibration, and Data", CSIER Working Paper no. 8106C, University of Western Ontario, London, Canada.

McLure, C. E. (1970), "Taxation, Substitution and Industrial Location", Journal of Political Economy 78, 112-132.

Mieszkowski, P. M. (1966), "The Comparative Efficiency of Tariffs and Other Tax-Subsidy Schemes as a Means of Obtaining Revenue or Protecting Domestic Production", Journal of Political Economy 74, 587-599.

Samuelson, P. A. (1966), "Abstract of a Theorem Concerning Substitutability in Open Leontief Models" and "A New Theorem on Nonsubstitution" in J. E. Stiglitz ed. The Collected Scientific Papers of Paul A. Samuelson, vol 1, Chapters 36 and 37, MIT Press, Cambridge, Massachusetts.