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A General Equilibrium Model with Capital and an Exhaustible Resource

by N. V. Long and Hans-Werner Sinn

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Optimal taxation and economic depreciation: A general equilibrium model with capital and an exhaustible resource

NGO VAN LONG and HANS-WERNER SINN*

1. Introduction

The study of the taxation of natural resources has typically been of a partial equilibrium nature. Exceptions to this general observation include Kemp and Long (1980, essay 17) and Sinn (1980) which serve as a basis on which the present paper is built.

The main objectives of this essay are to demonstrate that some received results in the partial equilibrium normative theory of resource taxation are incorrect, and to explore the effects of various taxes in a general equilibrium model which encompasses earlier models as special cases.

Economists have long debated about the efficient taxation of natural resources and capital goods, but so far little agreement has been reached on the matter. The following quotation from Auerbach (1982, p. 355) describes not unfairly the state of the art:

> There are few problems in tax analysis which have generated as much study and discussion among economists as the question of how to formulate "neutral" tax incentives for investment. This concentration

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of research effort may be traced to the importance and relevance to policy design of the issues under investigation. In this light, it is especially distressing to the economist and government planner alike that no consensus has been reached concerning the proper approach to take when adjusting taxes. On the contrary, authors continue to analyze the problem of investment incentives using distinct criteria, each calling markedly different tax schemes neutral. In each case, satisfaction of the neutrality criterion is argued to lead to an efficient allocation of capital, but this cannot be simultaneously true for different criteria.

The main reason for diverging results in taxation theory is that authors typically do not fully specify the underlying model in a general equilibrium framework, and therefore their claims that their proposed tax rules would bring about an efficient allocation of resources often cannot be easily assessed.

In this essay we are concerned with the problem of optimal taxation in the resource sector given that capital income in other sectors is taxed according to predetermined, immutable rules. In most Western economies these rules are essentially those of Schanz, Haig and Simons (see Goode (1977) for details), which require that interest income from financial investment and the returns from real investment be taxed where, concerning the latter, debt interest and economic depreciation have to be tax deductible.

The problem we pose is a second-best problem of taxation. This is not a new problem. It has been studied by various authors, but no concensus has been reached. A major problem in the existing literature has been the failure to define production efficiency in an intertemporal framework. Authors often equate their definitions of neutrality with efficiency, or postulate neutrality as a "principle". (See Auerbach (1982) for further discussion.) In the context of an economy with natural resources, Garnaut and Clunies Ross (1979) and Swan (1976) both argue in favour of neutrality, even though they disagree concerning the neutrality of certain proposed tax rules. Swan (1976) upholds the "principle of neutrality" based on economic depreciation, and argues that economic depreciation in the mineral industry should be tax deductible in the same way as in other industries. Dasgupta, Heal and Stiglitz (1980) and Dasgupta and Heal (1979) claim that economic depreciation (defined as the "decrease in the value of the oil field") should be subtracted from the value of the gross returns to the oil company:

> This "depletion allowance" would be equivalent to what has been called *true economic depreciation* in the context of durable capital goods. It would provide an appropriate measure of net income and would, at the same time, be non-distortionary, provided that interest income is taxed (Dasgupta, Heal and Stiglitz (1980, p. 159)).

The idea of taxing the resource sector according to the Schanz–Haig–Simons rules (as summarized above) might seem at first appealing in the light of the theorem on economic depreciation independently formulated by Johansson (1961, esp. pp. 148n, 211n; 1969) and Samuelson (1964), for this theorem says that with true economic depreciation and with a given market rate of interest the values of the mines, as well as the value of all investment projects in other sectors, are independent of the tax rate, thus ensuring that the so-called "intersectoral efficiency condition" in taxation theory is satisfied. However, while "intersectoral efficiency" is certainly desirable in a first-best world with no other distortions, it is completely unclear whether it is a desirable goal in a world where the taxation of interest income distorts the consumption-saving decisions on the part of households.

In the present essay we show that, indeed, this is not generally the case. We demonstrate that, under certain conditions, it is not desirable to allow the mining firm to deduct economic depreciation (defined as the decrease in the value of the mine), and we identify the source of the error made by those who advance the general claim that "there is no bias in extraction pattern" if the tax allowance is "on the true economic depreciation of the deposit" (Dasgupta and Heal, p. 371).

True economic depreciation is in some sense the negative of "true capital gains". We shall try to clarify the precise relationship between these two concepts and show the implications of our results for the desirability (or undesirability) of capital gains taxation.

In addition to the economic depreciation issue we also briefly consider other forms of efficient taxation, such as a tax on a dividend payout and a specially designed production-based royalty.

2. Second-best taxation and the undesirability of the economic depreciation rule

In this section we construct a simple model which contradicts the assertion made by Dasgupta and Heal (1979), Dasgupta, Heal and

Stiglitz (1980), and others, concerning the supposedly efficient tax rule based on true economic depreciation. We also propose a second-best tax rule, which will be formulated in proposition 2.2.

Since our model is a general equilibrium one, with consumers and producers solving intertemporal maximization problems, our argument will be long and, in places, tedious. Readers who are mainly interested in our findings and not so much inclined to follow the technical steps may find it more useful to read proposition 2.1 and the ensuing discussion at the end of section 2, where a common sense account of the findings will be given.

2.1. *The structure of the economy*

For simplicity, we consider an economy consisting of three interrelated sectors. The first sector, called the Ricardian sector, uses labour (L_R) to produce a Ricardian good which can be consumed or invested. The second sector is the "manufacturing sector", producing manufactured consumption goods by means of capital (K) and labour (L_M), the capital good being produced by the Ricardian sector. The last sector is called the "extractive sector". It uses labour (L_E) to extract natural resources which are directly consumed. We assume for simplicity that the first and third sectors draw labour from a common pool, while the manufacturing sector uses specialized labour, so that, in equilbrium,

$$L_R + L_E = \bar{L}_C; \qquad L_M = \bar{L}_M,$$

where $\bar{L}_C$ and $\bar{L}_M$ are fixed supplies of the two types of labour. Thus, the three consumption goods compete for resources either directly or indirectly (in the case of the manufacturing sector, via its demand for capital goods which are produced by labour in the Ricardian sector).

The production function in the manufacturing sector is given by:

$$Q_M = F(K, L_M),$$

where F is homogeneous of degree one and has all the usual neoclassical properties.

The output of the extractive sector is given by:

$$Q_E = (1/b) L_E,$$

so that the cost of extracting one unit of the extractive good is b units of the Ricardian good. The output of the Ricardian good is:

$$Q_R = \bar{L}_C - L_E = \bar{L}_C - bQ_E.$$

We assume that the economy is competitively organized. For each sector there is one representative firm. All three firms are owned by a representative household which, in addition to the wage income, receives dividends and interest income. All agents are endowed with perfect foresight and take the price paths as exogenously given in their individual optimization problems.

Money in this economy is simply a unit of account, there is no stock of real balances. Nominal prices are denoted by $q_i(t)$ (i = R, M, E) and nominal wages by $W_i(t)$ (i = R, M, E). We will write $W_C \equiv W_R = W_E$.

There is a uniform capital income tax at the rate γ which is applied to the interest income received by households, and to company income (whether retained or distributed). In other words, the personal and the company tax systems are fully integrated. (In section 3 the effect of an additional tax on dividends is considered.)

The Ricardian sector and the manufacturing sector are taxed according to the Schanz–Haig–Simons rules which require the deductibility of debt interest and economic depreciation. The tax treatment of the extractive sector is the subject of our discussion. Labour income is not taxed.

By its very definition the Ricardian firm has no intertemporal optimization problem to solve and hence does not require a formal analysis. Obviously, it neither generates profits nor a tax revenue. The problem of the household, the manufacturing firm, and the extractive firm, however, need explicit consideration.

2.2. *The problem of the household*

Households hold assets in the form of bonds or shares. It is assumed that each bond is a promise to pay a stream of interest $\langle r(t)\rangle$, where $r(t)$ is the market rate of interest at time t. Thus, the price of a bond is unity, and there are neither capital gains nor losses in bond holding.

Each individual maximizes the discounted stream of utility,

$$\text{(P1)} \quad \int_0^\infty [U_M(C_M) + U_E(C_E) + U_R(C_R)] \exp(-\rho t)\, dt,$$

subject to the constraint that the value of his consumption plus the value of his asset accumulation equals his after-tax income:

$$\sum q_i C_i^d + \dot{B} + \sum Z_j \dot{S}_j = (1-\gamma) r B + \sum D_j S_j + W_C \bar{L}_C + W_M \bar{L}_M, \quad (1)$$

where

C_i^d = planned purchase of the ith good, i = E, R, M,
B = the quantity of bonds the individual plans to own,
Z_j = price of a share of the jth firm,
S_j = number of shares of the jth firm the individual plans to own,
r = the rate of interest,
γ = the tax rate on interest income,
D_j = dividend per share of the jth firm (net of income tax),
W_i = nominal wage rate (i = C,M),
ρ = the rate of utility discount ($\rho > 0$),
q_i = price of the ith good.

In addition to constraint (1), we also impose the following non-negativity constraints:

$$S_j(t) \geq 0, \quad (2)$$

and

$$\sum S_j(t) Z_j(t) + B(t) \geq 0. \quad (3)$$

In words, the individual is not allowed to hold negative quantities of shares (shortselling is ruled out), and his net borrowing cannot exceed the value of his shares.

Assuming that (P1) has an interior solution (a solution with $C_i^d(t) > 0$, i = E, M, and strict inequality holding for (2) and (3)), the consumer's optimal paths of consumption and asset accumulation must satisfy the following conditions:

$$(\dot{Z}_j + D_j)/Z_j = (1-\gamma) r, \quad (4)$$

$$U'_R(C_R(t))/q_R(t) = U'_E(C_E(t))/q_E(t) = U'_M(C_M(t))/q_M(t) \quad (5)$$

and

$$U'_i(C_i(t)) \exp(-\rho t) / U'_i(C_i(0)) = q_i(t) \exp[-(1-\gamma) r t] / q_i(0). \quad (6)$$

Condition (4) is the usual arbitrage condition: the capital gain plus dividend per share is equated to the opportunity cost of holding shares (the after-tax return on bond holding). Condition (5) is the static efficiency condition, that the marginal utility per dollar spent on the ith good at time t be equated to the marginal utility per dollar spent on the jth good at time t. Condition (6) is the intertemporal counterpart of condition (5): that the marginal rate of substitution between dated goods be equated to their relative costs. Defining

$$\lambda(t) = U'_i(C_i(t))/q_i(t),$$

we can write (6) in the alternative form:

$$\dot{\lambda}/\lambda = \rho - (1-\gamma) r,$$

or

$$[C_i U''_i / U'_i](\dot{C}_i / C_i) = \rho - (1-\gamma) r + (\dot{q}_i / q_i). \quad (7)$$

Equation (4) can be integrated to yield:

$$Z_j(s) = \int_s^\infty D_j(t) \exp\{-(1-\gamma)[R(t) - R(s)]\} \, dt, \quad (8)$$

where

$$R(t) \equiv \int_0^t r(t') \, dt'. \quad (9)$$

In obtaining (8), we have assumed that share prices do not explode to infinity, or, more precisely, that:

$$\lim_{t \to \infty} Z_j(t) \exp[-(1-\gamma) R(t)] = 0. \quad (10)$$

2.3. *The problem of the manufacturing firm*

We now turn our attention to the problems of the firms. In line with Fisher's separation theorem, it seems reasonable to assume that each firm seeks to maximize $Z_j(0)$, the wealth of existing shareholders.

At this stage, it is convenient to choose the Ricardian good as the numeraire; thus:

$$q_R(t) = 1. \quad (11)$$

Assume that the tax laws define the income or profit of the manufacturing firm as:

$$Y_M = q_M(t) F(K, L_M) - W_M L_M - r B_M - \delta q_R K, \quad (12)$$

where B_M is the firm's nominal stock of debt (which is the same as the real stock of debt in terms of the Ricardian good), and δ is the rate of physical depreciation.

Let

T_M = tax payments,
$\dot{B}_M$ = additional finance obtained from the sale of new bonds,
$Z_M\dot{S}_M$ = additional finance obtained from the sale of new shares.

Total dividend payments are given by:

$$D_M(t)S_M(t) = q_M F(K, L_M) - W_M L_M - rB_M - T_M + \dot{B}_M + Z_M\dot{S}_M - q_R I, \tag{13}$$

where $I(t)$ is the firm's purchases of investment goods. We assume that the tax laws require that $D_M S_M$ be non-negative and not greater than Y_M if the latter is positive.

For simplicity, in this section we assume that the company tax rate is the same as the tax rate on interest income received by individuals, and that there are no other taxes, so that

$$T_M = \gamma Y_M. \tag{14}$$

It is well known that under this assumption firms will be indifferent between debt financing and equity financing. Thus, we may set:

$$\dot{S}_M = 0; \qquad S_M(t) = S_M(0). \tag{15}$$

Using (11)–(15), the firm's objective can be written as:

$$\text{(P2)} \quad \max_{L_M, \dot{B}_M, I} \int_0^\infty [(1-\gamma)(q_M F(K, L_M) - W_M L_M - rB_M) + \gamma\delta K - I + \dot{B}_M]\alpha(t)\,\mathrm{d}t,$$

where

$$\alpha(t) \equiv \exp[-(1-\gamma)R(t)]. \tag{16}$$

The maximization is subject to:

$$\dot{K} = I - \delta K, \tag{17a}$$

$$K(0) = K_0 \text{ given}, \qquad B_M(0) \text{ given}, \tag{17b}$$

and

$$\lim_{t\to\infty} B_M(t)\alpha(t) = 0. \tag{18}$$

Condition (18) states that the firm cannot indefinitely service its debt by contracting more debt. Condition (18) is implied by the requirement that dividend payout be not greater than income.

Now from (9) and (16):

$$\int_0^t [\dot{B}_M - (1-\gamma)rB_M]\alpha(t')\,\mathrm{d}t' = B_M(t)\alpha(t) - B_M(0). \tag{19}$$

Using (18) and (19), problem (P2) can be re-written as:

$$\text{(P2}'\text{)} \quad \max_{I, L_M} \int_0^\infty [(1-\gamma)(q_M F(K, L_M) - W_M L_M) + \gamma\delta K - I]\alpha(t)\,\mathrm{d}t$$

subject to (17a). The Hamiltonian of (P2′) is:

$$H = \alpha(t)[(1-\gamma)(q_M F(K, L_M) - W_M L_M) + \gamma\delta K - I] + \psi(I - \delta K).$$

Along an interior solution, it is necessary that:

$$\alpha(t) = \psi(t), \tag{20}$$

$$q_M F_L = W_M, \tag{21}$$

and

$$\dot{\psi}_M = \delta\psi_M - \alpha(t)[(1-\gamma)q_M F_K + \gamma\delta]. \tag{22}$$

From (20) and (22):

$$(1-\gamma)r(t) = -\dot{\psi}_M/\psi_M = (1-\gamma)(q_M F_K - \delta), \tag{23}$$

which is basically the Johansson–Samuelson neutrality result.

2.4. *Taxing the extractive sector: A second-best problem*

Let us pause here and study the steady state of our economy under the assumption that there are no natural resource deposits. We assume for simplicity that the government uses the tax revenue to purchase manufacturing goods and distributes them to individuals. (One may think of "free books" distributed to school children.) This assumption is made because it is not our purpose to study the problem of optimal provision of public goods. Another simplifying assumption that will be adopted is that $U_M(C_M)$ and $U_E(C_E)$ are strictly concave and increasing functions, and that $U_R(C_R)$ is linear in C_R, so that by a suitable choice of units:

$$U_R'(C_R) = 1. \tag{24}$$

Using (7), (24), and the normalization given by (11), we obtain the condition determining the rate of interest:

$$r(t) = \rho/(1-\gamma), \quad \text{all } t, \tag{25}$$

provided that $C_R > 0$.

The steady-state equilibrium can be characterized by the following equations:

$$q_M^* = U_M'(C_M^*), \tag{26a}$$

$$C_M^* = F(K^*, \bar{L}_M), \tag{26b}$$

$$q_M^* F_K(K_M^*, \bar{L}_M) - \delta = r = \rho/(1-\gamma), \tag{26c}$$

$$C_R^* = \bar{L}_C - I^* = \bar{L}_C - \delta K^*. \tag{26d}$$

Assume that the economy is initially in a steady-state equilibrium, and that suddenly S resource deposits are found. Given that the rate of capital income tax γ is an immutable feature of the economy, the question we want to ask is whether, on efficiency grounds, the "true economic depreciation" of deposits should be allowed as a tax deduction.

At first sight, one might be tempted to answer the above question in the affirmative, as did Dasgupta and Heal (1979), Dasgupta, Heal and Stiglitz (1980), and many others who advocate "inter-sectoral neutrality". The argument for "inter-sectoral neutrality" typically runs as follows. In the absence of taxation, at each point of time the inter-temporal rates of transformation are equated, i.e. the rates of return on all assets are equalized, so that

$$q_M F_K(K_M, L_M) - \delta = r = (\dot{q}_E - b\dot{W}_E)/(q_E - bW_E), \tag{27}$$

where the right-hand side of (27) is the rate of return from leaving the resource underground. In the presence of capital income taxation, since the first equality in condition (27) remains satisfied (see eq. (23)), it is argued that efficiency requires that the second equality in (27) be satisfied also.

The above argument rests on the presumption that the theorem on second best does not apply in this case. A close inspection of the properties of the present model suggests that the argument for inter-sectoral neutrality may be faulty. For the consumer's marginal inter-temporal rate of substitution is no longer equated to the producers' marginal intertemporal rates of transformation when there is capital income taxation. This is reflected in the consumer's equilibrium condition (25).

We now set out to prove that in the context of our model, given that the presence of the tax rate γ is an immutable feature of the economy, it is better not to allow extractive firms to deduct economic depreciation from their taxable incomes.

Assume that the true economic depreciation is tax deductible in the extractive sector. The tax liability of the extractive firm is:

$$T_E = \gamma[(q_E - b)Q_E(t) - A(t) - rB_E(t)], \tag{28}$$

where $A(t)$ is the firm's true economic depreciation and B_E is its stock of debt. Since the value of the firm is

$$V(X(t), t) = (q_E(t) - b)X(t) \tag{29}$$

(where $X(t)$ is remaining stock at time t), the true economic depreciation is

$$A(t) = -\mathrm{d}V/\mathrm{d}t = -\dot{X}(q_E - b) - \dot{q}_E X \tag{30}$$

$$= Q_E(t)(q_E - b) - \dot{q}_E X. \tag{31}$$

The extractive firm's stream of dividend pay-out is:

$$D_E(t) = (q_E - b)Q_E - T_E - rB_E + \dot{B}_E. \tag{32}$$

Using (28), (31), and (32):

$$D_E(t) = (q_E - b)Q_E - \gamma\dot{q}_E X - r(1-\gamma)B_E + \dot{B}_E. \tag{33}$$

By the same reasoning which led from (P2) to (P2′), the last two terms in (33) can be omitted and hence the firm's maximization problem can be written as

$$\text{(P3)} \quad \max_{Q_E} \int_0^\infty [(q_E - b)Q_E - \gamma\dot{q}_E X]\,\alpha(t)\,\mathrm{d}t,$$

where $\alpha(t)$ is given by (16) and where

$$\int_0^\infty Q_E(t)\,\mathrm{d}t \leqslant X_0, \qquad Q_E(t) \geqslant 0. \tag{34}$$

Transforming the integral constraint in (34) into the differential form,

$$\dot{X}(t) = -Q_E(t), \qquad X(0) = X_0,$$

$$\lim_{t\to\infty} X(t) \geqslant 0, \qquad Q_E(t) \geqslant 0, \tag{35}$$

we obtain the Hamiltonian:

$$H(t) = \alpha(t)[(q_E - b)Q_E - \gamma\dot{q}_E X] - \mu(t)Q_E. \tag{36}$$

The necessary conditions are:

$$(q_E - b)\alpha(t) - \mu(t) \leq 0 \quad (=0, \quad \text{if } Q_E(t) > 0), \tag{37}$$

$$\dot{\mu} = -\partial H/\partial X = \gamma\alpha(t)\dot{q}_E. \tag{38}$$

Along a positive extraction path, condition (37) yields:

$$\dot{q}_E/(q_E - b) = (\dot{\mu}/\mu) - (\dot{\alpha}/\alpha). \tag{39}$$

Using (37), (38), and (39), we obtain:

$$\dot{q}_E/(q_E - b) = r(t). \tag{40}$$

Thus, if the true economic depreciation is an allowable tax deduction, the inter-sectoral neutrality condition (27) will hold (recall that $W_E(t) = q_R(t) = 1$). The path of consumption of the extractive good can be obtained using (40), (5), (24), and (25):

$$U''_E(Q_E)\dot{Q}_E/(U'_E - b) = \rho/(1-\gamma). \tag{41}$$

Given our simplifying assumptions, it is clear that the manufacturing sector remains in its steady state described by (26a)–(26d).

We now show that the time path of consumption of the extractive good, as given by (41), is inferior to the outcome of the alternative tax regime which does not allow extractive firms to deduct true economic depreciation from the taxable incomes. Under this alternative tax regime, the stream of dividend payout by the representative extractive firm is:

$$D_E(t) = (1-\gamma)(q_E - b)Q_E(t) - r(1-\gamma)B_E + \dot{B}_E, \tag{42}$$

so that the firm's problem is:

$$\text{(P4)} \quad \max_{Q_E} \int_0^\infty (1-\gamma)(q_E - b)Q_E(t)\alpha(t)\,\mathrm{d}t,$$

subject to (35).

In this case, along a positive extraction path (with $Q_E(t) > 0$ for all t), it is necessary that rent rise at the net rate of interest:

$$\dot{q}_E/(q_E - b) = -\dot{\alpha}/\alpha = (1-\gamma)r(t). \tag{43}$$

Since $U_E = q_E$, the consumption path is given by:

$$U''_E(Q_E)\dot{Q}_E/(U'_E - b) = (1-\gamma)r(t) = \rho. \tag{44}$$

It remains to show that the consumption path given by (44) is superior to that given by (41). Since in both cases the paths of consumption of the manufacturing goods are identical, it suffices to show that (44) is the solution of the following centralized maximization problem:

$$\text{(P5)} \quad \max \int_0^\infty [U_E(Q_E) + U_R(Q_R)]\exp(-\rho t)\,\mathrm{d}t$$

subject to (35) and

$$Q_R = \bar{L}_C - \delta K^* - bQ_E. \tag{45}$$

It is a routine matter to see that (P5) yields condition (44).

To summarize our result, we state the following proposition:

Proposition 2.1. Under the assumptions of the model, it is suboptimal to allow extractive firms to deduct the economic depreciation from their taxable incomes, although capital income in the rest of the economy is taxed according to the Schanz–Haig–Simons rules.

The economic common sense behind our result is that since consumers equate the marginal rate of time preference to the net rate of interest, $(1-\gamma)r(t)$, while the allowance of economic depreciation in the manufacturing sector makes producers equate the net marginal product of capital with the gross rate of interest, $r(t)$, it is not necessarily desirable to achieve inter-sectoral neutrality. To allow true economic depreciation allowance in the extractive sector would induce that sector to choose an extraction path which equates the rate of return on holding the resource with the gross rate of interest, $r(t)$. This would result in too rapid an extraction path, since $r(t)$ is greater than the equilibrium rate of time preference, $(1-\gamma)r(t)$.

The assertion that "economic efficiency requires that some depletion allowance be provided" (see Dasgupta, Heal and Stiglitz (1980, p. 160)), is, in general, incorrect. More generally, "inter-sectoral neutrality", which is advocated by many authors, should not be accepted – without qualification – as a desirable criterion for judging tax rules.

Our model relies on the separability of the utility function and the partial separability of the production structure. Perhaps in a model where these restrictions are removed, there would be a trade-off between intersectoral neutrality on the one hand, and the equality between the rate of time preference and the rate of increase of rent on the other hand.

It is clear from our model that an efficient second-best taxation is a tax on the real cash flow of the mining firm, which at the same time allows the tax deductibility of the interest the mining firm pays to its creditors. Note that this tax is not the same as the Brown tax which is the optimal first-best tax in the absence of taxes on other sources of capital income, and which requires that debt interest be non-deductible from the tax base (see Brown (1948) and Garnaut and Clunies Ross (1979)). Thus we can state:

Proposition 2.2. An efficient second-best tax on the extractive firm is a tax on real cash flow where the tax rate equals that on interest income and interest is tax deductible.

3. The effect of other taxes

In this section we examine the effects of some other forms of taxation, using the model developed in the preceding section.

3.1. *A tax on capital gains in the extractive sector*

True economic depreciation allowance is in fact a form of capital gains tax, if capital gains are defined as the negative of the true economic depreciation. Another form of capital gains tax is a tax at the rate $\gamma > 0$ on the increase in the value of the existing stock, ignoring the fact that the stock is being depleted at the rate $Q_E(t)$. This form of taxation is considered in Sinn (1980, sections 4.5 and 4.6). If it is assumed that debt interest is deductible to ensure an interior financial equilibrium of the firm, the representative extractive firm's tax liability is:

$$T_E(t) = \gamma(\dot{q}_E X - rB_E). \tag{46}$$

Inserting (46) into (32) again gives eq. (33) for the dividend payout. As a result, this form of taxation is equivalent to a tax on profit with true economic depreciation.

The economic reason for this equivalence is that true economic depreciation is equivalent to the taxation of unrealized capital gains, $\dot{q}_E X - Q_E(q_E - b)$, and that the increase in the value of the existing stock, $\dot{q}_E X$, is the sum of unrealized and realized capital gains, where the latter equals the net revenue from current extraction, $Q_E(q_E - b)$.

From proposition 2.1 it follows that, given the assumptions of the present model, it is suboptimal to supplement a Schanz–Haig–Simons tax applied to capital income in general by a tax on realized and unrealized capital gains in the resource sector.

3.2. *An additional tax on dividends*

It has been shown that a tax on the real cash flow of the mining firm (with debt interest being tax deductible) is efficient in the second-best sense. But this is not the only efficient form of taxation.

Another tax with this property is a tax on the dividend payout by the mining firm. Such a tax has been suggested by the Meade Committee (1978) for corporations in general and has been studied by King (1974), Auerbach (1979), Bradford (1981), and Sinn (1982) in various contexts. Assume that the efficient profit tax considered in section 2.4 is levied and let γ^* denote the additional tax for corporate distributions. Then, instead of (42), the dividend payout of the mining firm is:

$$D_E(t) = (1-\gamma^*)[(1-\gamma)(q_E - b)Q_E - r(1-\gamma)B_E + \dot{B}_E], \tag{47}$$

and the firm's maximization problem becomes

$$\text{(P6)} \quad \max_{Q_E, \dot{B}_E} \int_0^\infty (1-\gamma^*)[1-\gamma)(q_E - b)Q_E - r(1-\gamma)B_E + \dot{B}_E]\alpha(t)\,\mathrm{d}t$$

subject to (35) and

$$\lim_{t\to\infty} B_E(t)\alpha(t) = 0. \tag{48}$$

Since the term $(1-\gamma^*)$ is a constant it obviously does not affect the solution of the optimization problem. Moreover, because of (19) and (48), the value of the integral does not depend on the time path of debt. Thus, the firm is indifferent between paying dividends and reducing its stock of debt. Hence the solution of (P6) is identical to that of (P4). It follows that the tax on the distributions of the mining firm is efficient, given the structure of our model and given an immutable Schanz–Haig–Simons tax on other sources of capital income.

3.3 *The effects of a sales tax and/or a production-based royalty on the extractive firms*

Production-based royalities and sales taxes are of great practical importance. We therefore study the question of how such taxes should be designed from the point of view of second-best efficiency.

Assume that extractive firms have to pay $\mu_E(t)$ dollars per unit of extraction, and that the royalty payments $\mu_E(t)Q_E(t)$ can be offset against income tax. Then the firm's dividend payout is:

$$D_E(t) = (1-\gamma)(q_E - b)Q_E - r(1-\gamma)B_E + \dot{B}_E - (1-\gamma)\mu_E(t)Q_E. \quad (49)$$

Clearly, $\mu_E(t)$ can also be interpreted as a per-unit sales tax, in which case $q_E(t)$ is the price gross of tax and $q_E(t) - \mu_E(t)$ is the price net of tax. Alternatively, define

$$P_E(t) = q_E(t) - \mu_E(t), \quad (50)$$

and define $\theta(t)$ by

$$q_E(t) = [1 + \theta(t)]P_E(t), \quad (51)$$

then

$$\mu_E(t) = [\theta(t)/(1+\theta(t)]q_E(t), \quad (52)$$

so that any equilibrium gross price path $q_E(t)$ which results from the imposition of a per-unit sales tax path $\mu_E(t)$ can also be obtained by imposing an ad valorem sales tax at rate $\theta(t)$, where $\theta(t)$ is suitably chosen so that (52) is satisfied.

Under the assumption of zero extraction cost, Kemp and Long (1980, essay 17, pp. 207–208), and Sinn (1980, section 4.2) have shown that a constant ad valorem tax rate $\theta \leqslant 1$ has no effect on the extraction path and hence no effect on the gross price path $q_E(t)$. In that special case, $\mu_E(t)$ rises at the net rate of interest:

$$\dot{\mu}_E/\mu_E = -\dot{\alpha}/\alpha = (1-\gamma)r(t). \quad (53)$$

Condition (53) is also necessary and sufficient for the neutrality of the per-unit sales tax path $\mu_E(t)$ in the more general case where extraction cost is non-zero, and in fact even when the average extraction cost b is dependent on the remaining stock $X(t)$. If b is stock-independent, the proof of this proposition is simple (see Dasgupta and Heal (1979, p. 364), for an arbitrage type of argument). We now offer a more general proof which allows for the possibility that $b = b(X(t))$.

In the absence of the tax $\mu_E(t)$, the Hamiltonian of the firm's maximization problem is:

$$H_0 = \alpha(t)(1-\gamma)[q_E(t) - b(X)]Q_E(t) - \mu_0(t)Q_E(t), \quad (54)$$

where $\mu_0(t)$ is the shadow price of the resource deposit. If $Q_E^*(t) > 0$ until the exhaustion date T_0, then the optimal path is characterized by the conditions:

$$\alpha(t)(1-\gamma)[q_E(t) - b(X)] = \mu_0(t), \quad (55)$$

$$\dot{\mu}_0(t) = \alpha(t)(1-\gamma)b'(X)Q_E, \quad (56)$$

and

$$\mu_0(T_0) \geqslant 0, \qquad X(T_0) \geqslant 0, \qquad \mu_0(T_0)X(T_0) = 0. \quad (57)$$

In the presence of the sales tax path $\mu_E(t) \neq 0$, the Hamiltonian is:

$$H_1(t) = \alpha(t)(1-\gamma)[q_E(t) - b(X) - \mu_E(t)]Q_E(t) - \mu_1(t)Q_E(t), \quad (54')$$

and the counterparts of (55)–(57) are:

$$\alpha(t)(1-\gamma)[q_E(t) - b(X) - \mu_E(t)] = \mu_1(t), \quad (55')$$

$$\dot{\mu}_1(t) = \alpha(t)(1-\gamma)b'(X)Q_E, \quad (56')$$

and

$$\mu_1(T_1) \geqslant 0, \qquad X(T_1) \geqslant 0, \qquad \mu_1(T_1)X(T_1) = 0. \quad (57')$$

Clearly, the necessary and sufficient conditions for the time paths $q_E(t)$ and $b(X(t))$ to be the same in both cases are:

$$\alpha(t)\mu_E(t) = \text{constant} = \alpha(0)\mu_E(0), \quad (58)$$

$$0 \leqslant \mu_1(t) = \mu_0(t) - \alpha(t)\mu_E(t)(1-\gamma). \quad (59)$$

In other words, if the sales tax path $\mu_E(t)$ is such that

$$\mu_0(T_0) - \alpha(T_0)\mu_E(T_0)(1-\gamma) \geqslant 0,$$

and if $\mu_E(t)$ rises at the rate $(1-\gamma)r(t)(\equiv -\dot{\alpha}(t)/\alpha(t))$, then the sales tax is only a tax on pure rent. In the special case where the deposit is not exhausted, $\mu_0(T_0) = 0$ and hence $\mu_E(t) = 0$ for all t.

From (52) and (58), an ad valorem sales tax is neutral only if the proportional rate of change of $\theta(t)/[1+\theta(t)]$ equals

$$\chi(t) \equiv (1-\gamma)r(t) - (\dot{q}_E/q_E),$$

which is different from zero if extraction cost is positive.

4. Concluding remarks

The basic point of this essay, which goes far beyond the natural resource problem, is to raise doubt on the applicability of the fundamental Johansson–Samuelson theorem of taxation theory. Too much has been claimed by some authors when referring to this theorem.

The false interpretation seems to originate from Samuelson himself, for he claimed that his theorem implied the desirability of economic depreciation and the taxation of all kinds of capital gains. This claim is justified in a very limited sense only. It is certainly true that economic depreciation ensures the inter-sectoral neutrality of a general income tax. However, inter-sectoral neutrality is only desirable in a first-best world where the consumer's saving decision is not distorted, i.e. where the right volume of the overall stock of resources is transferred to the future. In the presence of an interest income tax, which is a crucial assumption underlying the Johansson–Samuelson theorem, this condition is not met because the interest income tax clearly distorts saving decisions.

The second-best taxation problem which is studied in this essay and to which the Johansson–Samuelson theorem is often applied is whether saving in the form of natural resources should be penalized, given that the penalization of saving in the form of capital goods is an immutable fact. Most authors implicitly suggest that the solution to this problem is to penalize saving in the form of natural resources, too. This amounts to telling the farmer to kill his cow when his sheep has died. The present approach, instead, recommends to keep the cow alive, i.e. not to discourage the preservation of natural resources through true economic depreciation allowances or the taxation of capital gains, even though too few capital goods of other kinds are left to future generations.

We do not deny that our recommendation rests on the special assumption of a separable utility function. However, this assumption, albeit special, is not at the extremes, but is rather somewhere in the middle of the spectrum of possibilities. If cows and sheep are complements, then one may conjecture that the optimal policy for the farmer is to kill the cow (i.e. a tax system that discourages the conservation of resources may be appropriate). If, on the other hand, cows and sheep are substitutes, there is an even stronger reason for prolonging the life of the cow, and resource conservation should be encouraged. Perhaps, rather than deducting economic depreciation from the tax base, it might be better to add it to the tax base in this case.

The analysis in this essay was conducted without imposing a government revenue constraint. We assumed that the tax revenue is used to buy manufactured goods for distribution to private consumers, but we did not require that the taxation of the resource sector bring about a given present value of tax revenue. The reason is that we wanted to study the problem in the way it was posed by Dasgupta, Heal and Stiglitz, in order

to check the validity of their findings. Our basic result, that true economic depreciation allowance is suboptimal, stays unchanged if such a revenue constraint is imposed. For, by a suitable choice of the dividend tax rate γ^*, as studied in section 3.2, we can attain the target revenue without changing the extraction path, provided of course that the tax burden is sufficiently low to be compatible with positive share prices of mining firms.

All of this shows how little is known about the structure of dynamically efficient tax systems. There has been a decade of intensive work in the static theory of optimal taxation, but it seems obvious to us that basic results achieved are not directly transferrable to dynamic economies by a mere reinterpretation of variables. Interest income, depreciation allowances, capital gains taxation and the like are aspects to which there are no counterparts in static models. Hopefully, the next decade will be devoted to a discussion of the numerous problems in dynamic taxation theory that are yet to be solved.

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