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Robert F. Conrad*

Variable Rate Severance Taxes: Impact and Incidence

INTRODUCTION

This paper analyzes two issues. First, the paper will address incentives, both positive and negative, related to variable rate output taxes. A simple economic model of mining operations allows an examination of the incentives created by two types of such taxes introduced recently by different states. This analysis shows that these taxes may affect the time profile of extraction, the level of investment, and the quantity of economically recoverable reserves. Second, the paper will address the incidence of variable rate output taxes. The extent to which incentives are realized will be determined by the ability of the mine operators to shift the tax either forward to consumers through higher prices, or backward to labor or to owners of the natural resource base. Thus, the issues of incentives and incidence appear to be linked. This paper will argue that, while in the short-run, states may not substantially affect the behavior of mining operations by changing the tax structure, the long-run incidence of the tax may ultimately fall on the owners of the resource base within the jurisdiction (which might be the state itself).

An Economic Model of the Mine.[1]

From an economic perspective, the mine operator seeks to maximize the present value derived from extracting and processing reserves. While profit maximization is the assumed objective of any type of supplier, two characteristics distinguish the mining problem from other forms of economic activity. First, the quantity of geological reserves within a given property is exogenously determined and thus outside the mine operators control. This fact forces the mine operator to make intertemperal tradeoffs with regard to the time path of extraction. Reserves extracted today will increase current revenue, but at a cost of lost revenues in the future. Thus, the operator must calculate the opportunity cost (the user cost) of

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1. The model described below has been developed extensively elsewhere. *See* R. Conrad, Taxation and the Theory of the Mine (1978) (unpublished doctoral thesis in University of Wisconsin at Madison library); R. CONRAD AND R. HOOL, GRADE VARIATION, ENDOGENOUS RESERVES AND THE THEORY OF THE MINE (1979), and R. CONRAD AND R. HOOL, TAXATION OF MINERAL RESOURCES (1980) for a complete description.

foregone future extraction in order to maximize the present value of the mine.[2]

Second, every mineral deposit is unique. The fault structure, depth, and type of overburden for each deposit will determine, in part, the type of technology employed and the level of costs. In addition, the quality of the reserves varies across (and in non-petroleum mines varies within) deposits.[3] These facts have two consequences. First, the operator must determine which qualities (i.e., grades) of ore to extract and when to extract them. The mine operator must also determine the level of economically recoverable reserves. The cost structure and time path of prices may dictate a cut-off grade below which extraction of the geological reserve is unprofitable. The uniqueness of each deposit results in a second consequence; variability of the cut-off grade in accordance with price changes. Both the short-run and long-run supply curves for the firm and the entire industry are upward sloping. Increases in price lower the cut-off grade and increase extraction from a particular mine. Also, new mines will open at higher prices and further increase supply.

In order to analyze these factors, the following simple model will be used. Profit in any time period (t) is defined as:

$$(1) \quad \pi_t = P_t \sum_{g=1}^{G} \alpha_g X_{tg} - C(X_t ; \theta)$$

where:

P_t = Price of output in time t

X_{tg} = Reserves of type (grade) g extracted and processed in time t.

α_g = Proportion of X_{tg} sold (i.e., the grade of g)

$X_t = \sum_{g=1}^{G} \alpha_g X_{tg}$ = Total output in time t

C_t = Total cost of extraction and processing in time t.

X_t = Total extraction in time t.

θ = Vector of geological factors affecting costs

G = Number of grades of ore in the deposit

Note that in this form, the miner extracts a linear combination of different

2. For a complete definition of user cost, *see* A. SCOTT, THE THEORY OF THE MINE UNDER CONDITIONS OF CERTAINTY (1967).

3. *See* L. THOMAS, AN INTRODUCTION TO MINING (1973) for a description of the variations and how they affect the technology and cost.

ores, each with a different value, i.e., $P_t\alpha_g$ is the value (marginal revenue) of ore g in period t. The fact that reserves of each grade are finite in the deposit implies:

$$(2)\quad R_g \geq \sum_{t=o}^{T} Xtg \qquad \forall g = 1, \ldots G.$$

i.e. the miner is constrained by the amount of reserves of each grade. With this notation, the operator confronts the problem of choosing the quantity of ore of each grade for extraction in each period so as to maximize the present value of the mine, i.e.

Choose X_{tg} for $\forall$ t,g so that

$$(3)\quad PV = \sum_{t=o}^{T} \frac{P_t \sum_{g=1}^{G} \alpha_g X_t - C(X_t)}{(1 + r)^t}$$

where: r = discount rate is a maximum subject to the constraint in (2).

Briefly, the analytical solution to the problem requires that the discounted marginal profit from extraction in any period of a particular grade be "at least as great" as the discounted marginal profit derived from extracting that grade in any other period, i.e.[4]

$$(4)\quad \frac{P_t\alpha_g - C'_{Xt}}{(1 + i)^t} \geq \frac{P_j\alpha_g - C'X_j}{(1 + i)^j} \forall j \neq t.$$

This condition simply means that the firm will only choose to extract a particular grade when the discounted marginal profit covers the opportunity cost of extracting it at some other date. Higher grade reserves always yield higher current revenue. The quantity of high grades, however, is finite. Clearly, the firm would choose to take the best grades when their contribution to discounted profits is the greatest. The model considered here can show that the best grades will be extracted in the periods with the highest discounted prices until the best grades are exhausted.[5] This result implies that the firm will order the grade selection profile according to the ranking of discounted prices until exhausted, then the next best grade is extracted.

Finally, the miner must determine the quantity of economically re-

4. A formal proof of this proposition is in CONRAD & HOOL (1979), *supra* note 1.

5. *Id.* For an engineer's perspective of this type of rule, *see* Walduck, *Justification of the Concept of High-Grading in Metal Ore Bodies—A Dissenting View*, 1374 MINING MAG. 65 (1976).

coverable reserves. He must determine the cut-off grade. In the current model, the cut-off grade is defined as:[6]

$$(5) \quad \alpha_g^* = \frac{C'_k}{P_k}$$

where: k = period of lowest discounted price for which there is positive extraction.

At this grade, marginal profit is zero and extracting any grade below α_g^* will only result in a decrease in both current and discounted profit.[7] For example, consider the case where all prices are constant in nominal terms. In this case, the grade selection profile will be a decreasing function of time. Less ore will be extracted and processed in the future than in the early periods and extraction will stop (and the mine will close) when the firm reaches the grade yielding marginal revenues equal to the minimum of the average cost curve.

In summary, the operator must determine the quantity of reserves and the grades of ore to extract in any period, and the quantity of economically recoverable reserves (those above the cut-off grade). These determinations are made by relating the geological characteristics of the deposit to the economic environment. Clearly the value of the reserve base (the present value), given its geological structure, is sensitive to economic parameters. For instance, an increase in price will increase the present value for two reasons. First, those reserves that would have been extracted at a lower price are now more valuable. Second, the cut-off grade is decreased, which increases the quantity of economically recoverable reserves. On the other hand, increases in cost will decrease the present value by increasing the cut-off grade and decreasing the value of those ores which are extracted.

Incentives Created by Variable Rate Taxes[8]

Various states in the U.S. have introduced several variable rate taxes. Two of these taxes will be analyzed here: 1) Per Unit taxes which change

6. For numerical examples of these rules, *see* Conrad (1978), *supra* note 1; CONRAD & HOOL (1979), *supra* note 1, and Conrad, *Mining Taxation: A Numerical Introduction*, 36 NAT'L Tax J. 443 (1980).

7. Cut-off grade calculations are much more complicated. Lane describes these factors in more detail in *Choosing the Optimum Cut-off Grade*, 59 Q. COLO. SCHOOL OF MINES 811 (1964).

8. The analysis of this section is based on an article in process by Conrad and Hool, *Grade Variation, Endogenous Reserves and Mining Taxation*, J. of PUB. ECON. (forthcoming); Peterson, The Long-Run Dynamics of Mineral Taxation (1976) (unpublished manuscript, The University of Maryland), and M. GILLIS, TAXATION AND MINING (1976).

in relation to some price index (Colorado,[9] North Dakota,[10] and New Mexico—oil and gas[11]). 2) Ad valorum put out taxes with rates that change due to changes in price (New Mexico—uranium[12]).

Per Unit Variable Taxes

This tax is based on the tonnage of output ($T/ore) and is related to some price index that may change through time. For instance, the North Dakota Coal Severance Tax[13] increases by one-cent for 1% change in the Wholesale Price Index. This tax decreases the net-of-tax price received by the firm in each period by a fixed amount, i.e.

$$(6) \quad P_{et} = P_t - T_t$$

where: P_{et} = Net of Tax Price

T_t = Severance Tax in Period t.

Discounted profit in any period is now:

$$(7) \quad \pi_t = \frac{(P_t - T_t) \sum_{g=1}^{G} \alpha_g X_{tg} - C'(X_t)}{(1 + i)^t}$$

Generally, this type of tax will have two effects. First, it will increase the cut-off grade, since:

$$(8) \quad \alpha_g = \frac{C'_k}{P_k - T_k} > \alpha^* g = \frac{C'_k}{P_k}$$

where: C' = minimum of the average cost

This means that less reserves are now economically recoverable and thus the life of the mine will tend to be shorter.[14] Second, the tax may intertemporally reallocate the smaller economically recoverable base between the periods for which extraction is positive. To see this, recall that the operator will extract the best grades when the discounted prices are higher. The introduction of the tax may change the ranking because:

9. For a description of current tax policy in the states, *see* CONRAD AND HOOL (1980), *supra* note 1, and Stinson, State Taxation of Mineral Deposits and Production, Rural Development Report #2; USDA (1978).

10. *Id.*

11. *Id.*

12. *Id.*

13. *See* Link, *Political Constraints and North Dakota's Coal Severance Tax*, 31 NAT'L TAX J. 263 (1978) for a discussion of how this tax developed.

14. This is known as tax induced "high-grading." *See* GILLIS, *supra* note 8, for details.

$$(9)\quad \frac{P_t}{(1+i)^t} \geqslant \frac{P_j}{(1+i)^j}$$

does not imply that

$$(10)\quad \frac{P_t - T_t}{(1+i)^t} \geqslant \frac{P_j - T_j}{(1+i)^j}$$

unless

$$(11)\quad \frac{P_t}{(1+i)^t} - \frac{P_j}{(1+i)^j} \geqslant \frac{T_t}{(1+i)^t} - \frac{T_j}{(1+i)^j}$$

This condition is clearly satisfied when the tax rises at the rate of interest (since the right hand side of (11) is zero), but in other cases it will depend on how prices move through time in relation to how the tax changes.[15] Indeed, real prices (even nominal prices) could fall through time while the tax is rising.

Finally, the tax may change total extraction in each period. The direction could be from the future to the present or present to future depending on how the tax changes in each period. Generally, extraction will increase in periods with a relatively lower real tax burden. The current structure of these taxes in practice means this reallocation will be from the present to the future because the tax changes are usually smaller than the change in the index used. As noted above, the North Dakota tax increases one cent for every 1% rise in the Wholesale Price Index. Thus, for any reasonable discount rate (including inflation), the tax will fall in real terms causing a reallocation from the present to the future. Note, however, that this reallocation to the future pertains only to the lower level of economically recoverable reserves. The net effect on the mine life will depend on how many reserves are lost relative to the deferred extraction of recoverable reserves induced by the tax.

Variable Ad Valorum Taxes Which Are a Function of the Price

This type of tax is defined as a certain percentage of the selling price with the marginal rate increasing as a function of the nominal price. Discounted profit in any period is now defined as:

$$(12)\quad \pi_{2t} \quad \frac{(1-\beta(P_t)) \sum_{g=1}^{G} \alpha_g X_g - C(X_t)}{(1+i)^j}$$

where: $\beta_t(P_t)$ = average tax rate with $\beta_t' p_t > 0$.

15. For a discussion of "exponentially" increasing taxes, *see* Peterson, *supra* note 8, and Burness, *On Taxation of Nonreplenishable Natural Resources*, 3 J. ENVT'L ECON. & MGMT. 289 (1976).

Assuming competitive behavior, the tax rate is exogenous. Like the per unit tax, this tax clearly increases the cut-off grade, reducing economically recoverable reserves, since:

$$(13)\quad \overline{\alpha} = \frac{C'k}{(1-\beta\ (P_k))P_k} > \alpha^*g = \frac{C'k}{P_k}$$

The rates of these taxes are a function of the price of the resource. Thus difference in discounted prices would tend to be smaller than in the no tax case. This implies that the remaining reserves (those above the cut-off grade) would be extracted in a more even manner (variations in production through time might not be as great). Finally, the ordering of the grade selection profile may change. In order to see this note:

$$(14)\quad \frac{P_t}{(1+i)^j} > \frac{P_j}{(1+i)^j}$$

will imply

$$(15)\quad \frac{(1-\beta(P_t))\ P_t}{(1+i)^j} > \frac{(1-\beta(P_j))\ P_j}{(1+i)^j}$$

if and only if:

$$(16)\quad 1 < \frac{P_t}{P_j}(1+i)^{j-t} > \frac{1-\beta(P_j)}{1-\beta(P_t)}$$

This condition will generally hold in practice with one exception. If $P_t > P_j$, then the right hand side of (16) is greater than one. Then, condition (16) could be violated if the change in the tax rate is sufficiently large. To see this, suppose that in t = o, P_o = 100 and in t = 1, P_1 = 101. If the discount rate were 10%, the left hand side of (16) would be equal to 1.111. If the royalty rate at 100 were 10%, but doubled to 20% on prices greater than 100 the right hand side of (16) would be 1.125, which would violate the condition. Thus, in this case the answer depends on how much the the tax rate changes with respect to nominal prices: the greater the change in tax rates, the greater the likelihood that a change in the grade selection and extraction profiles will result.

III. SHIFTING AND INCIDENCE

World markets determine the time path of prices of most minerals. Tax policy, however, is made by political subdivisions of these markets. When a particular state increases the tax burden on mineral operations, two

things generally happen. In the short-run, the producer will attempt to shift the tax by increasing the price. "Pass-through" clauses in contracts may enable him to do this in the short-run. Nevertheless, contracts do expire and they can be broken. Thus consumers will begin to look for alternative sources of supply or begin to substitute with another input. Clearly consumers would be willing to pay up to the new price level for an alternative source. If the consumers can get an alternative for less than the new price, then they will have every incentive to seek the alternative source.

If consumers are successful, even in part, in finding alternative sources, then the price to the producer will not increase by the amount of the tax and the results of the last section will hold: cut-off grades will rise, and extraction profiles will change. In the longer run, the producer, knowing that the net-of-tax return to invested capital is now lower, will attempt to lower costs by shifting the tax back on to owners of the resources themselves. If the producer owns the mineral rights by prior contract, he can do very little in the short-run to shift the tax. At lower prices, however, he clearly will not be willing to pay the same amount for mineral rights in the future. Thus, if the producer's efforts to shift the tax to landowners meet resistance, capital will leave the region. Investment and exploration activity in the area will decrease with a corresponding increase in these activities in other jurisdictions until the net of tax return to capital is equal between the jurisdictions. The mobility of capital and labor over time thus suggests which factor bears the long-run incidence of the tax: the landowner who would have had his reserves developed (or developed more completely) if the tax had not been imposed.[16]

In order to understand this process, consider the following example.[17] Suppose there are two regions that supply a given resource: State A, and the rest of the world. In any time period, equilibrium requires that supply will equal demand, i.e.

$$D = S_a + S_w \quad (17)$$

where: D = Quantity demanded in the market

S_a = Supply from A

S_w = Supply from the rest of the world.

The "net" demand for A's product is then:

16. *See* McClure, Jr., *Economic Constraints on State and Local Taxation of Energy Resources*, 31(3) NAT'L TAX J. 275 (1980); Gillis and McClure, Jr., *The Incidence of World Taxes on Natural Resources, With Special Reference to Bauxite*, 65 AM. ECON. REV. 2 (1975); and A. ATKINSON & J. STIGLITZ, LECTURES IN PUBLIC ECONOMICS (1980) for a discussion of incidence with immobile factors.

17. This analysis is based on A. HARBERGER, TAXATION AND WELFARE (1974).

(18) $S_a = D - S_w$

Graph I depicts this situation. The right hand side of the panel shows D and S_w. The left hand panel shows A's supply curve and A's *net* demand curve. The net demand curve is derived by calculating the excess demand at each price for $D - S_w$ and plotting the difference on the left hand panel. In the absence of taxation, the price that each producer receives and the price the consumers pay will be equal. This equality is shown as P on Graph I, where A supplies S_a, W supplies S_w and by definition $S_a + S_w = D$.

Now suppose the government of A imposes a tax of $T/ton. The producer in A will attempt to shift the tax forward by increasing the price. Thus, the supply curve for A will shift to the left from S_a to $\bar{S}_a$ on Graph I. If there is any elasticity in A's net demand curve and A's supply curve is less than perfectly elastic, then at least part of the tax will be borne by the factors of production in A. This result is shown on Graph I where the world price is now Pw, but the price the producers in A receive is only $P\bar{s}$. Output in A falls to $\bar{S}_a$, W's output rises to $\bar{S}_w$, and equilibrium is defined by $\bar{S}_a + \bar{S}_w = \bar{D}$. Note that producers in W have been made better-off. In effect, they have received a "wind-fall" from the change in A's tax policy. The burden of the tax is thus borne by all consumers and the producers in region A. Consumers bear an amount equal to the area P Pw AE on the left panel in Graph I, while producers in A bear an amount equal to the area P $P\bar{s}$ EC (with the sum of these two areas $P\bar{s}$ Pw AC being equal to the tax revenue). The share of the tax burden borne by consumers and producers is known to be inversely proportional to the elasticities of supply and demand:

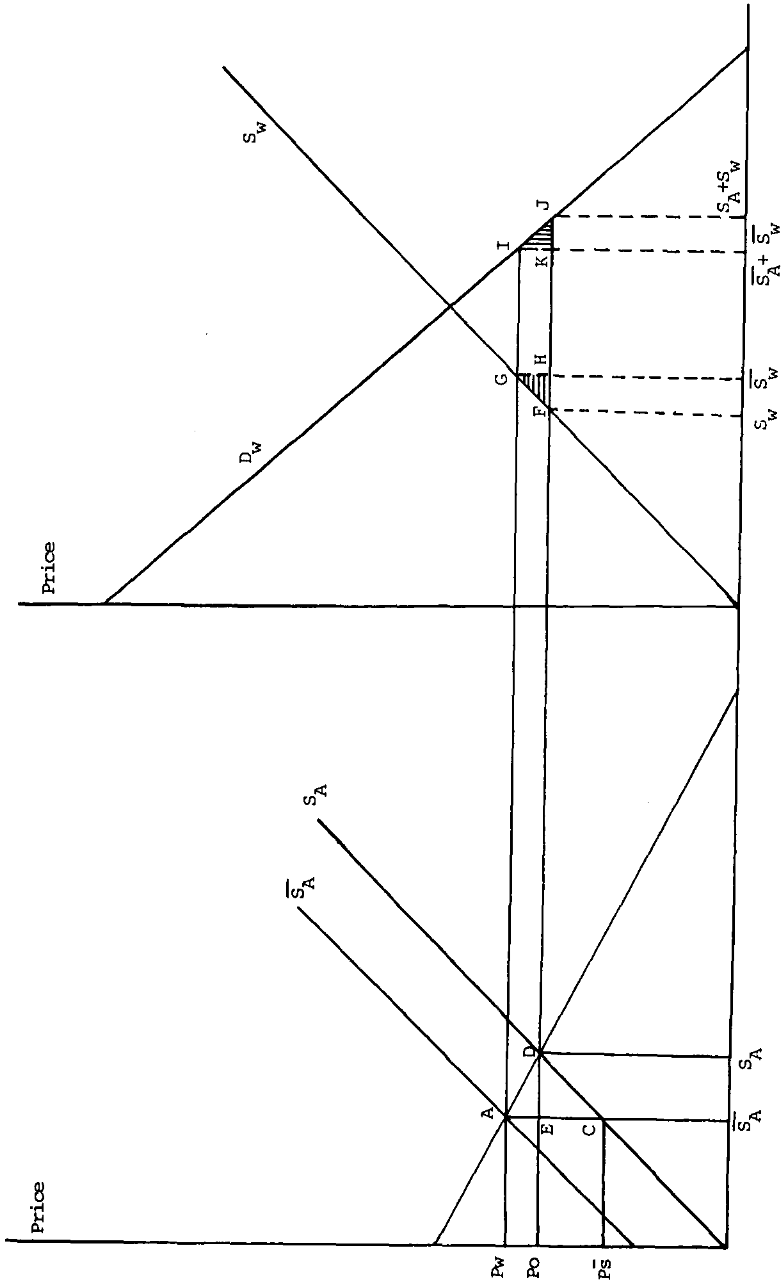
$$(19) \quad \frac{\text{P Pw AE}}{\text{P E P}\bar{\text{s}}\text{C}} = \frac{\epsilon_{SA}}{\epsilon_{DA}}.$$

In this case the elasticity of demand for A's output is equal to:

$$(20) \quad \epsilon_{DA} = \frac{D}{S_a}\epsilon_D - \frac{S_w}{S_a}\epsilon_{SW}$$

where: D = Total quantity demanded
S_A = Supply of A
ϵ_D = Elasticity of the demand curve
S_W = Supply of W
ϵ_{SW} = Elasticity of supply from W.

Thus, the smaller the share of A's output, the greater the supply elasticity of W; and the greater elasticity of aggregate demand, the larger will be


Price
Price
D_w
S_w
S_A
$\overline{S}_A$
A
C
D
E
F
G
H
I
J
K
Pw
Po
$\bar{P}s$
S_A
$\overline{S}_A$
S_w
$\overline{S}_w$
$\overline{S}_A + \overline{S}_w$
$S_A + S_w$

GRAPH 1.

the share of the tax borne by the factors in A. In the short-run each factor may bear part of the burden. In the longer run, however, the burden will be borne by the factor that is least able to move to another jurisdiction, the reserves which are left in the ground.

Finally, note that the introduction of the tax has created a welfare cost[18] equal to the area ACD. The loss in consumer surplus (AED) results for two reasons. First, consumers are paying more and getting less. The portion of the welfare loss attributable to this reason equals the area IJK on the right panel. Second, factors are used inefficiently in W due to its increased output. The area FGH on the right panel represents the portion of the welfare loss attributable to inefficiency. Thus, ADE = FHG + IJK. The lower part of the welfare triangle (EDC) represents the loss in producer surplus in A resulting from the tax. The introduction of the tax thus decreases both the welfare of A's suppliers and the welfare of all consumers (to the benefit of suppliers in W).

In summary, the ability of a given jurisdiction to permanently shift the burden of the tax outside its region is small. There are too many sources of supply, and increasing prices will bring them forth. Possibly the best example of this type of result has been the recent experience of OPEC. The price increases which occurred in the 1970s imposed a severe burden on the entire world. This "tax" created "wind-falls" for non-OPEC producers, and producers of alternative energy sources such as coal. The recent increase in drilling activity in non-OPEC countries and the development of new coal deposits and other forms of alternative energy sources bear witness to the fact that there is a positive supply elasticity in the rest of the world. This elasticity, combined with the decrease in oil imports, has begun to stabilize world prices, increase the total supply,and decrease the transfer of wealth to the OPEC countries.

IV. CONCLUSION

Much of the public debate over natural resource policy in general and mining taxation in particular has focused on the depletable nature of mining activity. The amount of "geological" reserves within a certain jurisdiction truly are finite and inelastically supplied. Nevertheless, tax policy cannot be made solely on this basis because the level of mineral activity and the quantity of "economically" recoverable reserves are not inelastically supplied either in the short- or long-run. Rather, mining activity will respond to the economic environment just like any other type

18. This assumes the demand and supply curves in Graph I are income compensated. Welfare cost or efficiency cost is a measure of the dollar value of the deduction in economic welfare which results from an artificially induced change in relative prices.

of economic activity. Tax policy should be made with a full awareness of the incentives created by it. Otherwise, a state or other jurisdiction may introduce taxes which gain tax revenue in the short-run but at the cost of long-term gains which would have accrued by a larger and more prolonged level of investment.