Coal Transport and Coal Market Integration

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The coal market is characterized by a competitive market allocation system distributing coal from fixed supply regions to fixed demand regions with geological, environmental, and transport capacity constraints. Considerable success in coal market forecasting has been recorded using linear programming models. These models have a natural extension to the evaluation of coal transport policy. Careful interpretation of the optimal solution and dual variables of an integrated coal transport and coal market model can be used to examine two specific issues: the determination of transport rates that are negotiated between parties having substantial market power, and the social costs and benefits associated with relieving potential transportation bottlenecks in coal delivery. This paper defines the appropriate linear programming model in some detail and shows how it is used to investigate these issues.

Planners and policymakers in government and industry are evaluating the impacts of accelerated domestic coal development. The price and availability of coal depend on the interactions of coal supply and demand and coal transportation (1,2). The extent to which coal can be utilized depends on a host of current decisions and plans affecting demand, supply, and transport. Because the costs and risks of a particular energy policy are substantial, there is a clear and present need to predict as accurately as possible the consequences of alternative strategies.

Many public policies are directed toward transition to coal. With this transition come important coal transport issues including the determination of transport rates and the optimal expansion of coal transport facilities. In 1976, western coal production was approximately 20 percent of total production. Under assumptions of accelerated development and compliance with Environmental Protection Agency sulfur regulations, our studies indicate that western production will increase to 50 or 60 percent of production in 1985. Under these assumptions western production will more than double by 1985 and eastern production will continue to increase (3).

The increased demand on the nation's coal transport system represented by future coal development is quite substantial. Coal movements out of the West will be made primarily on a rail system that has been untested in carrying the magnitude of traffic envisioned. Eastern coal production, especially from the low-sulfur fields in middle Appalachia, will depend on a rail system that currently requires revitalizing trackage and spur lines.

Viewed in these terms the importance of coal transport issues is obvious. There are questions of optimal location and feasibility of transport capacity expansion, and there is the related problem of whether rail rate determination mechanisms will occur in such a way that coal and other energy resources will be optimally allocated (4, p. 531).

Unfortunately, many important decisions affecting coal supply and transport are being made with less than adequately certain predictions of the future costs of using coal. Both national energy policy and the capital expansion plans of the private sector require assumptions about future prices and availabilities of fuel supplies. Recognizing this situation, researchers are working to understand energy markets in general and coal supply and coal transport in particular.

An impressive payoff of coal supply research has been the development of mathematical programming models of the coal market. Several independent research efforts have validated the use of linear programming methods to represent the national coal market for forecasting minemouth prices and regional production (5,6,7). Some recent modeling efforts have focused on coal transportation capabilities and rate determination (8,9,10). Coal supply is exogenous in these coal transport studies, just as forecasts of coal transport rates are exogenous in the coal market models. Our experience suggests a large payoff for study of coal transport problems by means of integrated coal market and coal transport models.

This paper describes the structure of such an integrated model and discusses how the model can be used to address the issues of rate determination and coal transport capacity. This model is a generalization of the Charles River Associates (CRA) regional coal price forecasting model developed for the Potomac Electric Power Company (PEPCO). The CRA-PEPCO coal price model is recognized as one of two models providing the first concrete starting points for sophisticated coal supply analysis (7). Although the generalized model would be costly to solve as a linear programming model directly in the form specified here, the model could be transformed to a simpler structure or decomposed for computational efficiency.

MODEL SPECIFICATIONS

The CRA model of coal market behavior is indicative of a class of models developed to analyze coal allocation problems. These models represent the spatial competition of coal markets and are designed to forecast minemouth prices and coal production by region. Transport between supply and demand regions is treated in a zonal aggregate fashion. Thus the detail of the models is not suitable for accurately forecasting delivered prices or interregional flows. On the other hand, models used to investigate transport bottlenecks, such as the Manalytics study (10), have used a detailed description of the coal transport network, distributing prespecified production and consumption over the network. To investigate rate determination and evaluate the cost of bottlenecks, an integrated model reflecting the impacts of both minemouth price and transport rates and costs is needed.

Conceptually, this integrated model has the same structure as the CRA model used for price forecasting. The level of transport detail is greatly increased to include rail, water, and pipeline networks. The objective of the integrated model is to forecast minemouth prices and transport flows using the criterion of minimizing delivered costs of coal (minemouth coal price plus transport rates). In this section, we describe the existing CRA coal model and its extension to a fully integrated model. In subsequent sections we describe the use of the integrated model in studies of rate determination and capacity expansion.

CRA COAL MARKET MODEL

To estimate coal market clearing prices, a linear programming model of regional coal demand and supply is defined. This model simulates the activity of a competitive market and finds the equilibrium set of prices and coal flows among regions for any given forecast year. The model assumes that, subject to generation requirements, utilities will minimize the cost of fossil fuel. The cost of coal includes extraction, transport, and desulfurization costs. The cost of other fossil fuels, such as oil, includes port-of-entry costs and transportation costs to the utility. The model allows for the possibility that some plants can switch among fuels. Supply from each region is represented as a function that associates the coal available with forecast extraction costs.

Because coal is available at fixed locations and varies in quality, prices of coal at the mine include rents reflecting location or quality advantages as well as extraction costs. Modeling the minemouth price of coal thus requires determining, for the output level, both the extraction costs and location and quality rents. Although extraction costs (intermediate and long-range) at a given location for various output levels can be modeled independently of the regional distribution of demand, the locational and quality rents are determined by transportation costs and the location and types of coal demanded. Thus, modeling minemouth coal price is facilitated by using a geographically disaggregate coal model that reflects the location of coal supply and demand, types of coal demanded, and coal transportation costs.

The model incorporates, for any time period, the competing demands for regional coal supply, the heterogeneity of coal resources, coal supply response, user requirements for various coal attributes, and demand response. The equilibration process of the model thus accounts for the trade-offs among coal supply-and-demand locations by considering extraction costs (supply price without rents), coal transport costs (line-haul rates, loading and unloading), coal processing costs (scrubbing, cleaning), and demand. The equilibration process also accounts for the dynamic effects of coal resources development—openings and shut-downs—by linking static single-period models.

Model in Current Form

The general form of the CRA model, used to forecast minemouth prices, is shown below. [The models presented in this paper are based on customary units; therefore SI units are not given.]

$$\min_{X,Y} \sum_{m=1}^{M} \sum_{i=1}^{I} \sum_{j=1}^{J} (e_{im} + t_{ij}^c + c_{ij}^c) X_{imj} + \sum_{j=1}^{J} (r + t_j^o) Y_j \qquad (1)$$

$$\sum_{m=1}^{M} \sum_{i=1}^{I} b_i^c X_{imj} \geq d_j^c \qquad \forall_j \qquad (2)$$

$$\sum_{m=1}^{M} \sum_{i=1}^{I} b_i^c X_{imj} + b^o f Y_j \geq d_j^{co} + d_j^c \qquad \forall_j \epsilon J^Y \qquad (3)$$

$$\sum_{j=1}^{J} X_{imj} \leq s_{im} \qquad \forall_{i,m} \qquad (4)$$

$$X_{imj}, Y_j \geq 0 \qquad \forall_{i,mj} \qquad (5)$$

where

d_j^c = utility demand for coal (measured in Btu) in region j;
d_j^{co} = utility demand for coal or oil (measured in Btu of coal) required to meet demand in region j;
s_{im} = tons of coal available in deposit i at extraction cost e_{im};
c_{ij}^c = costs, if any, of desulfurizing coal obtained from deposit i for use in j (if the coal quality is such that the coal cannot be used at j, this cost will be a large number or the variable X_{imj} will not be included in the model);
e_{im} = extraction cost per ton for coal in region i, supply increment m;
r = base cost per barrel of oil;
t_{ij}^c = cost per ton of transporting coal from deposit i to region j;
b_i^c = Btu per ton of coal extracted from deposit i;
b_o = Btu per barrel of oil;
f = ratio of Btu of coal required per kilowatt hour to Btu of oil required per kilowatt hour;
X_{imj} = tons of coal transported from deposit i, supply increment m, to region j; and
Y_j = barrels of oil used in region j.

The objective function minimizes the resource cost of supplying coal and oil to coal-burning plants. The demand regions and supply regions represent sulfur-location combinations (e.g., coal with less than 0.6 lb sulfur/million Btu located in coal-producing district 1). The coal and oil supplied must satisfy demand for fuels from coal-burning plants, including plants that could convert from coal to oil. Point estimates of this demand by region measured in Btu of coal are specified as constraints. Coal supply functions are defined as step functions describing the tons of coal available in each region, s_{im}, at specified marginal extraction costs, e_{im}.

The model generated for each forecast period reflects the assumptions specified by the user. Both the structure of the model and the supply and demand estimates may be affected by these assumptions. For example, assumptions about compliance to sulfur regulations affect the amount of low-sulfur coal demanded and consequently the values of d_j in certain regions j. If the price of oil is such that some utilities might find it economical to switch to oil in the forecast period, and if it is possible for oil to be used by the utility, then Equation 3 is included in the model; otherwise it is excluded.

If demand region j is a low-sulfur region and desulfurization technology is available in the region, then the model includes a variable for coal drawn from high-sulfur region i to region j with a desulfurization cost of c_{ij}^c; otherwise c_{ij}^c is zero. Assumptions about mandated conversions to coal, utility load growth, and nuclear penetration affect demand estimations d_j^{co} and d_j^c.

A transportation network based on existing rail movements links supply and demand regions. Transportation costs between regions reflect the initial rate structure and the cost of transportation inputs including fuel, labor, and capital. Coal supply regions are aggregates of coal-producing districts or states. In the intermediate run (1-3 years), coal supply reflects the historically observed responsiveness of coal output to market prices as well as trends in productivity and costs of coal-mining inputs. Over the intermediate run, coal output does not respond quickly to changes in demand, and consequently price swings can be relatively dramatic.

Long-range supply functions are based on a geostatistic representation of reserves by sulfur content and on prediction of productivity and input factor costs and cover the period after 3 years when coal-mining capacity can adjust to perceived changes in demand. The geostatistical representation of reserves allows the model to forecast the effects of depletion on coal prices. The effects of technological change and input costs (labor, materials, and capital) are forecast using an econometric model of the production function for coal mining.

Coal demand by utilities is based on 10-year projections made by utilities and on expected econometric trends in utility fuel consumption beyond 10 years. Forecasts are made initially for each reliability council and are then allocated to the demand regions in the model (areas served by utility plants); coal consumption among sulfur categories is predicted. The model has the capability of analyzing utility trade-offs between coal and oil. Varying assumptions about trends in load growth, sulfur regulation compliance, coal-oil switching, and growth in nuclear generation—factors affecting coal demand—can be modeled.

Nonutility demand by end-use sectors is forecast for each coal-producing region using econometric models linked to macroeconomic activity. The end-use sectors include metallurgical, export, retail, and other mining and manufacturing activities.

Forecasting Minemouth Prices and Production

Minimizing extraction costs, transport costs, and desulfurization costs, subject to a fixed demand, results in solution variables that estimate the market clearing prices and production of a competitive market. In particular, the minemouth price per ton for the coal in a particular supply region, assuming a competitive coal market, is estimated as the sum of the marginal extraction cost and rent for the marginal unit of coal produced in that region. The location and quality rents at a supply point are estimated by shadow prices in the model. The extraction costs are inputs to the model. The economic rent per ton is estimated as the shadow price of a supply constraint for the supply region-coal type. The market clearing minemouth price for a region can be estimated as the sum of the shadow price and extraction costs for any supply increment in the region that supplies coal in the model solution. These market clearing prices are specific to the sulfur-coal quality combinations modeled in the region and are associated with the regional coal output predicted by the model.

INTEGRATED COAL MARKET AND TRANSPORT MODEL

As a structure for exploring issues of rail rate determination and capacity expansion, we present the coal market and transport model below:

$$\min_{X,Y,H,V} \sum_{m=1}^{M} \sum_{i=1}^{J} \sum_{j=1}^{J} (e_{im} + c_{ij}^{c})X_{imj} + \sum_{k=1}^{K} \sum_{i=1}^{I} \sum_{j=1}^{J} t_{kij}H_{kij} + \sum_{j=1}^{j} (r + t^{o})Y_j \qquad (6)$$

$$\sum_{m=1}^{M} \sum_{i=1}^{I} b_i^c X_{imj} \geq d_j^c \qquad \forall_j \qquad (7)$$

$$\sum_{m=1}^{M} \sum_{i=1}^{I} b_i^c X_{imj} + b^o f Y_j \geq d_j^{co} + d_j^c \qquad \forall_j \xi J^Y \qquad (8)$$

$$\sum_{j=1}^{J} X_{imj} \leq s_{im} \qquad \forall_{i,m} \qquad (9)$$

$$\sum_{k=1}^{K} H_{kij} - \sum_{m=1}^{M} X_{imj} = 0 \qquad \forall_{i,j} \qquad (10)$$

$$\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} H_{kij}\delta_{akij} - V_a = 0 \qquad \forall_a \qquad (11)$$

$$V_a \leq n_a \qquad \forall_a \qquad (12)$$

$$X_{imj}, Y_j, V_a, H_{kij} \geq 0 \qquad (13)$$

where

- d_j^c = utility demand for coal (measured in Btu) in region j;
- d_j^{co} = utility demand for coal or oil (measured in Btu of coal) required to meet demand in region j;
- s_{im} = tons of coal available in deposit i at extraction cost e_{im};
- c_{ij}^c = costs, if any, of desulfurizing coal obtained from deposit i for use in j (if the coal quality is such that the coal cannot be used at j, this cost will be a large number of the variable X_{imj} and will not be included in the model);
- e_{im} = extraction cost per ton for coal in region i, supply increment m;
- r = base cost per barrel of oil;
- t_{kij} = cost per ton of transporting coal from deposit i to region i on path k between i and j;
- b_i^c = Btu per ton of coal extracted from deposit i;
- b^o = Btu per barrel of oil;
- f = ratio of Btu of coal required per kilowatt hour to Btu of oil required per kilowatt hour;
- X_{imj} = tons of coal transported from deposit i, supply increment m, to region j;
- Y_j = barrels of oil used in region j;
- H_{kij} = tons of coal transported from deposit i to region j on path k (note k must connect i and j);
- V_a = tons of coal transported on link a of the network;
- δ_{akij} = a 0, 1 variable, 0 if link a is on path k, 0 otherwise; and
- n_a = maximum volume of coal that can be transported on link a.

This model represents the coal market behavior in Equations 7-9 and a coal transport network in Equations 10-12. The objective function incorporates a choice of paths between origin i and destination j.

In this model, flows along alternative paths between destinations i and j are represented by variables H_{kij}. Since paths between various origins and destinations may share links, the volume on a link V_a is the sum of volumes on all paths containing this link. Bottlenecks occur when these constraints cause flows to take greater than minimum cost paths or prohibit flows.

The implementation of a transport model requires definition of transport costs, links, and capacities appropriate to the use of the model. Links can represent line-haul, loading, and unloading facilities. In most cases where market behavior is analyzed, transport rates should be used, although in an application discussed later in this paper, we use transport costs for some links in identifying potential rates.

Construction of rail line-haul capacity constraints requires knowledge of how many trains can be handled over a given link. Train scheduling, rail trackage, and conditions must be considered. The capacity definitions reflect an implicit service level. For some problems, it would probably be useful to define transport capacities associated with several service or congestion levels and relate these service levels to demand. The definition of capacity for coal transport also requires defining the effect of other commodities shipped over the track on available capacity.

When volume on a link reaches a capacity constraint (i.e., Equation 11 is an equality for some a), the shadow price on the equation represents the value of increasing the capacity by one unit. This price represents the value to coal transport users of relaxing this capacity constraint.

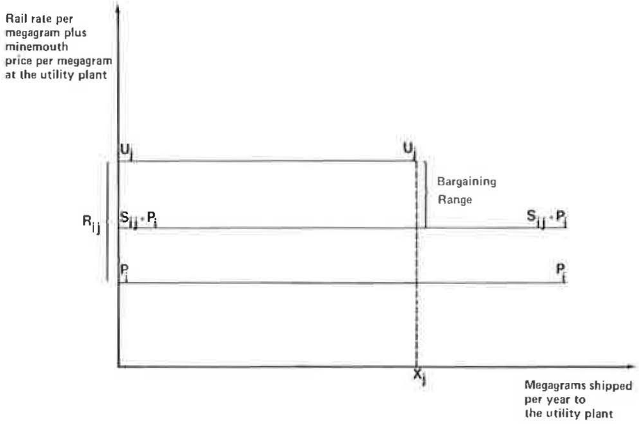
RAIL RATE DETERMINATION

Unit train rates are negotiated between large coal purchasers and railroads; these negotiations depend on the relative market power of the parties. Unit train rates, which bear no relationship to conventional single-rail carload rate structures, are determined by a variety of factors, primarily minimum train load, annual minimum weight, and origin and destination points.

The relative market power between consumers and railroads tends to be particularly important in setting rates for new rail services. Once a freight rate structure is established, ex parte rate increases sanctioned by the Interstate Commerce Commission tend to reflect changes in factor input costs.

Currently an important issue relating to the delivered cost of coal is the establishment of rail rates for coal shipments eastward from the western coal fields. These rates for western coal shipments will be a crucial factor in western coal production. Rates of early unit train shipments out of the West were promotional and do not necessarily reflect competitive relationships that would hold as western coal production expands or as alterna-

Figure 1. Rent determination for utility and railroad rate bargaining under constant returns to scale.



tive railroad lines or transportation modes are introduced.

The incremental cost as perceived by the railroad sets a minimum level for the rate the railroad will accept, but the rates actually charged depend on the elasticity of demand for rail transportation services at a particular destination point. This elasticity of demand depends on the substitutes for rail as the transport mode and for coal as a fuel. The extent of competition for coal traffic, particularly from water-based modes, has been very important in the history of rail rates. The availability and cost of alternative fuels have also determined initial rail rates. Alternative sources of coal are another factor affecting elasticity of demand.

Among recent studies that estimate empirical relationships between rail rates and the determinants of transport cost, two studies consider effects of substitutes directly. Charles River Associates (8, pp. 62-64) and Martin Zimmerman (9) have separately estimated regression models using 1970 unit train rates based on negotiating behavior. Implicit in these investigations is a conceptual framework that views both the railroad and the purchaser as having market power. In such a situation, classical economic price theory does not yield deterministic solutions for rates and volume except under arbitrary behavioral assumptions. In the case of setting unit train rates, the parties determine how economic rents at the destination point will be divided between them.

To illustrate this point, Figure 1 presents the indeterminate range for rate-setting behavior. Assume that P_i is the minemouth price of coal at source i and U_j is the minimum delivered price of an alternative fuel-transport mix at point j. Further assume that the minemouth price and transport cost does not change with volume used at j and that alternative fuels require the same plant costs. Then, S_{ij}, the long-range marginal cost of transport between locations i and j, is the minimum rate railroads will accept in the long-range period and R_{ij} is the maximum rate the consumer would accept. The actual rate will fall somewhere between these two values.

In a previous study, CRA estimated the rate usually agreed upon as a function of S_{ij} and the share of coal among other fuels used by a utility operating company (8). The theory behind this specification was that the higher the share of coal, the greater the difference between $S_{ij} + P_i$ and U_j and, consequently, the greater the difference of the actual negotiated rate from $S_{ij} + P_i$. That is, railroads negotiated higher rates when coal was less threatened by alternative utility fuels, all other factors held constant. Zimmerman updated this approach by setting U_j equal to the delivered cost of an alternative fuel (9). Thus, his specification makes rates a function of the difference between U_j and $S_{ij} + P_i$ and of cost factors, S_{ij}. He found that rates were higher the more U_j differed from $S_{ij} + P_i$.

Both works indicate that an econometric model of rates is appropriate using the theory expressed in Figure 1. The simplified form of the model is

$$N_{ij} = f[U_j - (S_{ij} + P_i), S_{ij}] \qquad (14)$$

where N_{ij} equals the negotiated rate. From these studies, there appears to be at least a statistical regularity in the way utilities and railroads divide up the per ton rent, $U_j - (S_{ij} + P_i)$, existing at the time the rate is established.

However, these models are not entirely appropriate for predicting future rates that will be made in response to large western coal shipments. Their major problem is that they are based on coal's competition with alternative fuels to provide rate ceilings. Given that the prices of other fossil fuels are currently high and are expected to remain so for the foreseeable future and that supplies are risky, these prices no longer determine the rate ceiling in most regions. Instead, competition among various coal sources will be the mechanism by which railroad rate ceilings are formed. A coal market and transport market model such as that specified earlier could be used to determine the bargaining range for establishing rates between specified origins and destinations.

ESTIMATING BARGAINING RANGES

The coal market and transport model provides an optimal coal distribution among coal supply and demand regions based on minimum transport and extraction costs subject to resource availability constraints. In the long run (over 5 years) minemouth prices will tend to average cost per megagram of new mines because capacity is assumed to adjust. This means that the delivered price of the assigned allocation of coal to a demand region will be the unconstrained minimum sum of transportation cost plus minemouth coal price from a unique supply region. Typically, this will establish a unique transport mode to serve the origin and destination pair. To use the model to aid in determining N_{ij}, cost over routes where rates are not yet established will equal long-run marginal cost, S_{ij}, and on routes where rates are established will equal existing rates. The predicted delivered prices will equal $P_i + S_{ij}$, over routes where rates are not yet established, and will equal P_i plus the existing rate on routes where rates are established. The minimum rate is t_k on the selected path. We now show how this solution is used to determine N_{ij}.

The maximum rate the consumer would accept, U_j in Figure 1, can be estimated from the model outputs. This is done by noting that the marginal delivered cost from an alternative supply point using an alternative transport mode to the point of interest is the sum of the minemouth price forecast by the model and the transport cost or established rate on the minimum cost path to the demand node. The minimum of these alternative delivered costs establishes the upper limit, U_j; this would be the consumer's next best alternative. This assumes that the consumer has no independent effect on coal prices.

The difference between the U_j and $P_i + t_{kij}$ taken from the model solution is the minimum value for the variable in Equation 14. If all transport costs except the market under consideration are established rates, then this difference is the exact value of the variable. This value is of interest to railroads and utilities in rate negotiations because it is the economic rent they are attempting to capture. It can be used by analysts attempting to forecast new rates. In particular, the value can be used in an estimated equation (similar to

Equations 1-5) to project an established rate on the basis of historical evidence of the fraction of rent distributed between railroads and consumers.

When numerous rates are to be established, this procedure also applies as long as the maximum rate is based on an established rail rate, not cost. If the upper-bound U_j is based on transport cost of an alternative fuel supply, it may be lower than the upper bound resulting after all rate negotiations are completed.

It is interesting to note that since rates always fall between U_j and $P_i + t_{kij}$, the coal allocation of the model solution will still be optimal under the new rates. That is, the introduction of the rate structure will change minimum delivered prices to a demand region but not the ranking of delivered prices from potential supply regions (although delivered prices may be the same).

The transport capacity bottlenecks should be carefully considered in this analysis. In establishing rates, it is likely that unconstrained capacity is used. The estimation of Equation 14 must be consistent with the model assumption. If appropriate, the model can be run without capacity constraints.

TRANSPORT CAPACITY EXPANSION

Numerous questions concern expansion of coal transport facilities. Among the issues are whether alternative modes should be introduced (e.g., coal slurry) and where bottlenecks on rail lines should be released.

Ideally, we would like to identify the benefits of increasing transport capacity and compare these to the costs of providing the increased capacity. If the costs are less than the benefits, then the capacity should be constructed. If there is a choice of modes to serve the pair, the least costly mode should be constructed.

The coal transport and market model can be used to identify transport bottlenecks in each year and to study the benefits to coal users of increasing coal transport capacity. (Note that under this treatment, other commodity users have first priority on the system, and benefits are valued in terms of their impact on coal prices. If all commodities were considered simultaneously, the benefits might be valued somewhat differently.) Benefits over an appropriate time horizon should be compared with the costs of increasing capacity. It is important to look at a significantly long time horizon because transport modes are capital intensive and because policies and adjustments in the coal market are likely to shift coal production areas through time.

To illustrate how, in any given year, bottlenecks could be identified and benefits studied, consider the coal market and transport model. The model run with the existing transport network, capacity and coal transport rates, and likely coal supply and demand scenarios will result in an allocation of coal to routes.

Bottlenecks in loading, unloading, or line-haul facilities can be identified as links where constraints (see Equation 12) are binding; that is, equations of this form will hold at equality.

Usually, a positive shadow price will be associated with the binding constraint. This shadow price will reflect the value to coal users of relaxing the constraint one unit. The shadow prices represent the social benefit in money terms of changing each capacity constraint, one at a time. These benefits apply only if the single bottleneck is removed. Consequently, the shadow prices can be used to summarize the social cost-benefits of removing each bottleneck alone.

To tabulate the benefits of removing several bottlenecks simultaneously requires a parametric analysis. In general, the effect of removing several constraints simultaneously can be explored by finding the optimum allocations for different capacity levels. The difference in the value of the objective functions of two cases is the benefit to users of the incremental capacity, assuming the transport rates would be the same with the expanded capacity.

To see if expansion at a bottleneck is cost-effective, one would compare the time stream of shadow prices against the cost of building an additional unit of capacity. If the discounted shadow prices exceed the costs, then the capacity should be constructed. Units of capacity should be added up to the point where the discounted stream of shadow prices is less than the discounted costs. As units of capacity are added, new shadow prices must be computed. Operationally, the implementation of such a procedure requires care in the definition of capacity, transport units, and construction costs. Means of increasing capacity by operations and capital need to be treated.

In general, the careful interpretation of the optimum solution, including the dual variables, extends the power of this tool from forecasting to cost-benefit analysis. Obviously, a linear programming representation of the coal market and transport network requires making assumptions about the behavior of the coal allocation system. We feel these assumptions are not restrictive; the most important modeling issues involve being careful to represent the market and transport sector as realistically as possible within the mathematical programming framework.

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