Using spatial equilibrium models to analyze transportation rates: an application to steam coal in the United States

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Abstract

This paper uses the implications of Samuelson’s spatial equilibrium model to analyze transportation rates for steam coal delivered to electric utilities in the United States. The analysis indicates that transportation rates declined in every year but two since railroads were substantially deregulated in 1980. While some utilities may have experienced some rate increases, coal-fired electric utilities as a whole have clearly benefited from lower transportation rates, and economic welfare has increased. The methodology in this study may be used in other instances where reliable data on transportation rates are not available, but data on delivered prices are available. © 1999 Elsevier Science Ltd. All rights reserved.

1. Introduction

Spatial equilibrium models have wide applicability in transportation economics. Takayama and Labys (1986) provide a review of the many ways in which such models may be formulated. The initial model of Samuelson (1952) relies on supply and demand functions in each of several spatially separated markets to determine the delivered price and quantity traded in each market. If trade in the good takes place between two regions, then in equilibrium delivered prices in the two regions differ by the amount of transportation rates. An important corollary of this result is that while changes in delivered prices within each region may depend on any number of supply and demand factors, changes in the variation of delivered prices between regions depend only on changes in the transportation rate.

This paper uses the implications of Samuelson’s model to analyze the current controversy regarding transportation rates for steam coal delivered to electric utilities in the United States. Section 2 discusses existing studies of coal transportation rates in the United States, and briefly
reviews some existing applications of spatial equilibrium models to transportation rates. Section 3 uses data on the variation of delivered prices to analyze transportation rates for steam coal delivered to electric utilities since railroads were substantially deregulated in 1980. This methodology can be applied to any number of situations where reliable data on transportation rates are not available, but data on delivered prices are. Section 4 presents the conclusions.

2. Literature review

The economic benefits of railroad deregulation are well established. Winston (1985, 1993), Kahn (1990), Hahn and Hird (1991), and Viscusi et al. (1995, pp. 553–574) all provide reviews of this literature. However, controversy continues regarding whether electric utilities have shared in the benefits of deregulation through lower rates for coal transportation. Mehring (1985), Atkinson and Kerkvliet (1986), Dunbar and Mehring (1990), Winston et al. (1990, p. 28) and others, using data primarily from the first few years after deregulation, argue that coal-fired electric utilities did not necessarily share in the benefits, and may have faced higher railroad rates. Dalton and Redisch (1990), MacDonald (1994), Wilson (1994), USDOE (1995) and others, usually using somewhat more recent data, argue that reduced costs, contracting, and innovation brought about by deregulation, along with competition from other modes, reduced railroad coal transportation rates.

Each of these previous analyses of coal transportation rates have suffered from a variety of shortcomings. First, each of these analyses was based on a subset of movements, in some cases only from a single state. Second, all of the earlier studies and some of the later ones were based on only a few years of data, and may not have captured all of the effects of deregulation. Third, almost all of the studies relied on either the Interstate Commerce Commission’s Carload Waybill Sample, or the Department of Energy’s Coal Transportation Rate Data Base (CTRDB). Both of these sources have shortcomings. The Carload Waybill Sample, a stratified sample of railroad movements, is known to understate unit train movements of coal prior to 1981 (Wolfe and Linde, 1997), and overstate railroad revenues since 1986 (Wolfe and Linde, 1997). The CTRDB, a survey of coal supply contracts and transportation-related data, contains enough information to calculate revenue per ton for only 31% of coal shipments (USDOE, 1991b, pp. 56,59), and contains no data on municipalities, cooperatives, Federally owned utilities, or spot market purchases. Lastly, all of these studies overestimate the transportation costs actually incurred by electric utilities, since they do not take into account substitution of other rail carriers, other transportation modes, or other coal sources for existing transportation service. This failure to account for all the alternatives a purchaser uses is known as substitution bias. Diewert (1998, pp. 49–51) provides a current and detailed discussion.

Spatial equilibrium models have been used for some time to analyze grain transportation rates. Adam and Anderson (1985), Babcock et al. (1985), Fuller et al. (1987), and MacDonald (1989) provide just a few examples. Applying Samuelson’s model, these studies generally calculate transportation rates as the difference between country elevator bid prices and terminal elevator delivered prices. Since data are available on both origin and destination prices, there is no need in any of these grain studies to calculate the standard deviation of delivered prices. There do not appear to be any examples of spatial equilibrium models applied to coal transportation rates.
3. Analysis

3.1. The United States steam coal market

In 1996 the United States produced 1,057 million tons of coal, of which 862 million tons (82%) was steam coal delivered to electric utilities (USDOE, 1997b, pp. 3, 35). Almost 65% of steam coal consumed by electric utilities is delivered to its final destination by rail, 16% by water, and 19% by truck, tram, conveyor, or slurry pipeline (USDOE, 1997a). In many cases more than one mode of transportation is used in a given movement. In 1996 approximately 81% of steam coal consumed by electric utilities was produced under supply contracts (USDOE, 1997b, pp. 35, 36). In 1987 approximately 84% of steam coal consumed by electric utilities was delivered under transportation contracts (USDOE, 1991b, p. 56).

Different types of steam coal can have different characteristics, including heat, water, ash, or sulfur content, which may affect the delivered price per ton. Stigler (1964) illustrates how products with different characteristics can be analyzed as a homogeneous product by including adjustment costs in the relevant demand or supply functions. The regional demand and supply functions used in this analysis were therefore defined in terms of the price per million British Thermal Units (BTU) of energy that meets appropriate environmental requirements. Higher or lower heat content would affect the delivered price per ton of coal, but would not affect the delivered price per BTU. Coal with higher ash or sulfur content per BTU would impose higher disposal or environmental costs on utilities that burn such coal. The demand function of a utility for BTUs of energy that meet disposal and environmental requirements would then be reduced by the per-BTU cost of disposing of ash or meeting appropriate environmental requirements.

Electric utilities purchase coal both on the spot market and under long-term contract. Coal supply and transportation contracts specify the source, chemical composition, monthly and annual quantities, method of transportation, and duration of the contract. In addition, the contracts generally contain formulas to determine the amount that the utility is to pay for supply and transportation of the coal at any point in the contract (Joskow, 1987; MacDonald, 1994). While the pricing formulas may not adjust perfectly to unanticipated changes in supply or demand, utilities have been successful in renegotiating coal supply and transportation contracts so that contract prices and rates more accurately reflect current market conditions (Joskow, 1988, 1990; MacDonald, 1994). For these reasons it is appropriate to consider coal produced or delivered under long-term contract as part of the analysis.

3.2. A spatial equilibrium model

Suppose that two regions of the United States produce and consume a homogeneous commodity, BTUs of energy from steam coal. Prior to trade, supply and demand conditions in the two regions are given by

\[ D^1 = D^1(P_1, E^1, I^1), \quad D^1_{P_1} < 0, \quad D^1_{E^1} > 0, \quad D^1_{I^1} > 0, \]  \hspace{1cm} (1)

\[ S^1 = S^1(P_1, T^1), \quad S^1_{P_1} > 0, \quad S^1_{T^1} > 0, \]  \hspace{1cm} (2)
\( D^2 = D_1^2(P_2, E_2, I_2), \quad D_{P_2}^2 < 0, \quad D_{E_2}^2 > 0, \quad D_{I_2}^2 > 0, \quad (3) \)

\( S^2 = S_2^2(P_2, T_2), \quad S_{P_2}^2 > 0, \quad S_{T_2}^2 > 0, \quad (4) \)

where \( D^1, D^2 \) are the quantity demanded in regions 1 and 2; \( S^1, S^2 \) the quantity supplied in regions 1 and 2; \( P_1, P_2 \) the price of the goods in regions 1 and 2; \( E_1, E_2 \) the price of a substitute good in regions 1 and 2; \( I_1, I_2 \) the income in regions 1 and 2; and \( T_1, T_2 \) are the production technology in regions 1 and 2. The subscripts on the demand and supply functions indicate partial derivatives of those functions with respect to the variable in the subscript. All demand and supply functions are assumed to be continuous and have continuous partial derivatives with respect to all variables.

When trade takes place, total shipments of the commodity must equal total receipts

\( (D^1 - S^1) + (D^2 - S^2) = 0. \quad (5) \)

If trade takes place between the two regions, then in equilibrium there are no profits from further trade so that

\[
P_2 = P_1 + R
\]

(6)

where \( R \) is the transportation rate from region 1, the net producing region, to region 2, the net consuming region.

This generalized model has six endogenous variables \((D^1, D^2, S^1, S^2, P_1, \text{ and } P_2)\), and seven variables that are assumed to be exogenously determined \((E_1, E_2, I_1, I_2, T_1, T_2, \text{ and } R)\). The equilibrium regional prices reflect the effect of all of these exogenous factors.

The total change in price in region 1 due to all factors can be found by taking total differentials of the system of Eqs. (1)–(6) and solving for \(dP_1\).

\[
dP_1 = -D_{E_1}^1 dE_1 + D_{E_2}^2 dE_2 - (D_{I_1}^1 dI_1 + D_{I_2}^2 dI_2) + (S_{T_1}^1 dT_1 + S_{T_2}^2 dT_2) - (D_{P_2}^2 - S_{P_2}^2) dR
\]

\[
(D_{P_1}^1 - S_{P_1}^1) + (D_{P_2}^2 - S_{P_2}^2)
\]

(7)

Similarly, \(dP_2\), the total change in price in region 2 due to all factors is

\[
dP_2 = -(D_{E_1}^1 dE_1 + D_{E_2}^2 dE_2) - (D_{I_1}^1 dI_1 + D_{I_2}^2 dI_2) + (S_{T_1}^1 dT_1 + S_{T_2}^2 dT_2) + (D_{P_1}^1 - S_{P_1}^1) dR
\]

\[
(D_{P_1}^1 - S_{P_1}^1) + (D_{P_2}^2 - S_{P_2}^2)
\]

(8)

Eqs. (7) and (8) illustrate that changes in delivered prices within each region are the result of changes in any number of exogenous factors such as the price of substitute energy, income, supply conditions, and transportation rates. The denominators of both equations are the Walrasian stability condition (which has a negative sign), indicating that an increase in either delivered price reduces excess demand in that region (Henderson and Quandt, 1971, p. 134). In the numerators, an increase in the price of substitute energy in either region \((E_1, E_2)\) increases delivered prices in both regions. An increase in income in either region \((I_1, I_2)\) also increases delivered prices in both regions. An improvement in supply technology \((T_1, T_2)\), such as increased production from lower-cost strip mines, decreases delivered prices in both regions. Similarly, a reduction in supply which may, for example, result from introduction of costly safety regulations, increases delivered prices in both regions. Lastly, an increase in transportation rates \((R)\) decreases prices in region 1, the net producing region, and increases prices in region 2, the consuming region.

The variation of prices between the two regions is defined as

\[
\Delta = P_2 - P_1.
\]

(9)
The total change in the variation of prices between regions is the difference in the two differentials,

\[ d\Delta = dP_2 - dP_1. \tag{10} \]

Substituting Eqs. (7) and (8) into Eq. (10) results in

\[ d\Delta = \frac{(D^1_{P_1} - S^1_{P_1})dR + (D^2_{P_2} - S^2_{P_2})dR}{(D^1_{P_1} - S^1_{P_1}) + (D^2_{P_2} - S^2_{P_2})}. \tag{11} \]

This further simplifies to

\[ d\Delta = dR. \tag{12} \]

Eq. (12) illustrates that changes in the variation of delivered prices between any two regions depend only on changes in the transportation rate. The intuition of this result can best be seen through the zero-profit equilibrium condition in Eq. (6). Since, in equilibrium, the difference in delivered prices between the two regions is exactly equal to the transportation rate, changes in the variation of delivered prices between regions depend only on changes in the transportation rate. Therefore, differences in delivered prices between regions can be used to assess changes in transportation rates.

3.3. Data

Data on the delivered price of coal per BTU are reported by USDOE (1997b, p. 35). These data, in turn, are based on information contained in the Federal Energy Regulatory Commission Form 423, *Monthly Report of Cost and Quality of Fuels for Electric Plants*. The delivered price data include all coal received by all coal-fired electric utility plants with greater than 50 megawatt generating capacity, and have been published in a number of different sources since at least 1969. In 1996 these facilities accounted for over 98% of coal-fired electricity generating capacity in the United States (USDOE, 1996), and an even greater percentage of coal-fired electricity generation. This data set therefore represents a complete census of delivered prices for essentially all coal received by electric utility plants over a period of almost 30 years. USDOE provides a further description of this data set (cf. USDOE, 1991a, pp. iii, 233–236).

The United States Department of Energy’s multi-state regions USDOE (1997b) were used as the basis for analysis. These regions are listed in Table 1. Prices were calculated on an annual basis for each region from 1969 to 1996 in order to provide sufficient information on price trends before and after railroad deregulation in 1980. Current dollar prices per BTU were converted to constant 1996 prices using the implicit price deflator for Gross Domestic Product (Executive Office of the President, 1997, p. 304).

The use of delivered price data provides substantial advantages over previous analyses. First, the delivered price data cover essentially all coal received by electric utilities. The analysis is based on population values, which are known with certainty, not sample statistics, which are subject to sampling error. The use of delivered price data therefore provides a more reliable indication of rate movements than previous studies based on a subset of shipments. Second, the delivered price
data are available for a significant number of years both before and after deregulation, providing a more complete picture of rate movements than studies based on only a few years of data. Third, the delivered price data do not rely on the CTRDB or Carload Waybill Sample, again providing a more complete and accurate representation of rates than previous studies. Lastly, since the delivered price data cover essentially all coal received by electric utilities, they do not suffer from the substitution bias inherent in other studies which do not consider all forms of substitution.

Fig. 1 shows annual observations of delivered coal prices per BTU in each of the nine regions from 1969 to 1996. Regional prices are expressed as a percentage of the ton-weighted national mean. While regions change somewhat in their relative rankings, there appears to be a general tendency of regional prices to converge toward the national average over the period. Regions with higher than average delivered prices, such as New England, generally trended downward over time. Regions with lower than average delivered prices, such as the West South Central and Mountain regions, generally trended upward over time. Other regions tended to exhibit fairly tight variation about the national average, especially in more recent years. There is relatively little within-year variation in delivered coal prices since seasonal variations can readily be anticipated and coal can easily be stored.

The variation in regional prices across all regions was measured using the standard deviation of delivered prices per million BTU from the ton-weighted mean,

\[ s = \sqrt{\frac{\sum_{i=1}^{9} t_i(P_i - \bar{P}_w)^2}{\sum_{i=1}^{9} t_i}} \]  

(13)
where the ton-weighted mean is
\[ \bar{P}_w = \frac{\sum_{i=1}^{9} t_i P_i}{\sum_{i=1}^{9} t_i}, \]  
(14)

\( P_i \) is the delivered price in region \( i \), and \( t_i \) is the tonnage delivered to region \( i \).

Using the standard deviation as a measure allows the variation to be expressed in the same units as the original prices. The standard deviations in this analysis are for the entire population of steam coal deliveries to electric utilities. They are *population values*, which are known with certainty, not sample statistics, which are subject to sampling error. If shippers received lower constant dollar transportation rates since railroad deregulation in 1980, then the standard deviation should have declined since that time.

### 3.4. Empirical results

The results of this calculation are shown in Fig. 2. The ton-weighted standard deviation of regional prices, in 1996 dollars per million BTU, is shown on the vertical axis, and the years are shown on the horizontal axis. The standard deviation was low in the late 1960s and early 1970s, but rose rapidly in 1974, as oil price increases raised both transportation costs and the demand for steam coal transportation. This suggests that transportation companies in this period of regulation were successful at raising their rates in response to increased demand for steam coal transportation. The standard deviation declined slightly over the period from 1975 to 1978, and was virtually unaffected by oil price increases in 1979 and 1980. During this period of regulation, rates paid by coal-fired electric utilities held steady or declined, but remained at almost double their
pre-1974 levels. From 1981 onward the standard deviation of delivered prices declined steadily. With the exception of 1981 (when railroads attempted to recoup fuel price increases incurred in 1979 and 1980) and 1993 (when flooding disrupted much of the nation’s coal transportation system), the standard deviation of delivered prices, and hence the transportation rates paid by coal-fired electric utilities, declined in every year since railroad deregulation in 1980. By 1996 the standard deviation of delivered prices, and hence transportation rates paid by coal-fired electric utilities, was less than half of what it was in 1980, and slightly less than it was in 1970. These results are consistent with those of other studies showing a decline in railroad coal transportation rates since railroads were substantially deregulated in 1980.

The data are not sufficiently detailed to permit a determination of how much of the decline in rates was due to any particular mode, carrier, or geographic source. However, since the share of coal delivered by rail to electric utilities increased from 58% in 1980 to 65% in 1996 (USDOE, 1981, 1997a), railroad rates must have been an important factor in declining transportation rates for coal-fired electric utilities as a whole, and must at least have declined relative to other modes. Nor can we conclude that the decline in rates was due solely to rail deregulation, since other contemporaneous factors may have played a role. While it is possible that some utility customers did experience some rate increases, coal-fired electric utilities as a whole have clearly benefitted from lower transportation rates since 1980. These lower rates translate into increased economic welfare, though it is not possible to determine the magnitude of the increase without additional data.

**4. Conclusion**

Previous studies of railroad coal transportation rates suffer from a variety of shortcomings. This paper uses the implications of Samuelson’s spatial equilibrium model to analyze the current
controversy regarding transportation rates for steam coal delivered to electric utilities in the United States. The key feature of this analysis is that while changes in delivered prices within each region depend on a number of supply and demand factors, changes in the variation of delivered prices between regions depend only on changes in the transportation rate.

Data on the variation of delivered price per million BTU of energy were used to analyze the change in coal transportation rates for steam coal delivered to electric utilities by all modes over the period from 1969 to 1996. The data indicate that transportation rates for steam coal delivered to electric utilities declined in every year but two since railroads were substantially deregulated in 1980. Transportation rates in 1996 were less than half of what they were in 1980, and slightly less than they were in 1970. While it is possible that some utilities did experience some rate increases, coal-fired electric utilities as a whole have clearly benefitted from lower transportation rates over the period, and economic welfare has increased.

The methodology in this study might well be used to analyze transportation in developing countries or any other instance where reliable data on transportation rates are not available, but data on delivered prices are available.

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