The Navigation Economic Technologies Program

September 1, 2005

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TRANSPORTATION MARKET EQUILIBRIUM

A Theoretical Approach

US Army Corps of Engineers®

IWR Report 05-NETS-P-05

Navigation Economic Technologies

The purpose of the Navigation Economic Technologies (NETS) research program is to develop a standardized and defensible suite of economic tools for navigation improvement evaluation. NETS addresses specific navigation economic evaluation and modeling issues that have been raised inside and outside the Corps and is responsive to our commitment to develop and use peer-reviewed tools, techniques and procedures as expressed in the Civil Works strategic plan. The new tools and techniques developed by the NETS research program are to be based on 1) reviews of economic theory, 2) current practices across the Corps (and elsewhere), 3) data needs and availability, and 4) peer recommendations.

The NETS research program has two focus points: expansion of the body of knowledge about the economics underlying uses of the waterways; and creation of a toolbox of practical planning models, methods and techniques that can be applied to a variety of situations.

Expanding the Body of Knowledge

NETS will strive to expand the available body of knowledge about core concepts underlying navigation economic models through the development of scientific papers and reports. For example, NETS will explore how the economic benefits of building new navigation projects are affected by market conditions and/or changes in shipper behaviors, particularly decisions to switch to non-water modes of transportation. The results of such studies will help Corps planners determine whether their economic models are based on realistic premises.

Creating a Planning Toolbox

The NETS research program will develop a series of practical tools and techniques that can be used by Corps navigation planners. The centerpiece of these efforts will be a suite of simulation models. The suite will include models for forecasting international and domestic traffic flows and how they may change with project improvements. It will also include a regional traffic routing model that identifies the annual quantities from each origin and the routes used to satisfy the forecasted demand at each destination. Finally, the suite will include a microscopic event model that generates and routes individual shipments through a system from commodity origin to destination to evaluate non-structural and reliability based measures.

This suite of economic models will enable Corps planners across the country to develop consistent, accurate, useful and comparable analyses regarding the likely impact of changes to navigation infrastructure or systems.

NETS research has been accomplished by a team of academicians, contractors and Corps employees in consultation with other Federal agencies, including the US DOT and USDA; and the Corps Planning Centers of Expertise for Inland and Deep Draft Navigation.

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A Theoretical Approach

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Abstract

The mainstay of the spatial modeling used by ORNIM is the Samuelson and Takayama-Judge model (S-TJ model) of trade between regions. Basically, a product is produced in different regions with different demand and supply conditions. Transportation causes price differences between the regions to be arbitraged in equilibrium, so that prices differ across regions by the transportation costs whenever trade occurs. In this model, all markets are competitive and the regions themselves are fixed. Transportation can and has entered the model through the addition of a fixed transportation price or through the addition of a demand and supply function for transportation. Each of these are considered in this paper with an eye towards evaluating policy actions to improving the transportation sector when both market power and endogenous regions are present. The main objective is to allow for market power and endogenous regions in the canonical models of trading regions, in the tradition of Samuelson and Takayama-Judge.

Keywords: Spatial equilibrium, transportation, market power, oligopsony, monopsony, transportation oligopoly, welfare, Samuelson and Takayama-Judge models, vertical structure, double marginalization.

1 Introduction

In this paper, we set out a template for addressing market power in the spatial context and evaluating the welfare consequences. Our starting point is a simplification of the classic spatial model of Samuelson (1952) and Takayama and Judge (1964), to which we add market power in the transportation industry and in the regional markets (through purchase agents - or "grain elevators" for concreteness.) In the Samuelson and Takayama-Judge models (S-TJ models), there is a set of regions trading a good. Each region is endowed with a set of demand and supply functions. If the markets are completely separated (i.e., no trade is allowed, or else is prohibitively costly), markets are cleared in the usual way in equilibrium. That is, demand and supply functions are equated for each region to give equilibrium prices and quantities. However, more generally, transportation provides a mechanism to arbitrage regional differences in supply and demand. The S-TJ model is easily adapted to this setting through the addition of an exogenous transportation price or through the derivation of transportation demand and the addition of transportation supply. This allows the welfare consequences of improvements to the transportation infrastructure to be explicitly identified.

We consider two major issues related to equilibrium and welfare measurement of different policies. The S-TJ model rests on competitive markets. However, there are many sources through which market power can and has entered the trade between regions. In our progression, we first model the case where transportation firms are so small they take prices as given and they compete in a "world" market. This forms a case for which we derive the demand for transportation services. Since, in many settings, transportation is provided by a single supplier, we modify the price-taking assumption and allow for monopoly power in the transportation sector. As a further refinement we then adapt the model to allow for market power among transportation firms. This leads to a monopsony setting which combined with a monopoly transportation sector leads to very inefficient market outcomes emanating from "double marginalization". These initial models are monopoly/monopsony models, in the subsequent sections, the model is adapted to allow for Cournot competition both in transport and the grain elevators. The S-TJ model adapted to modeling imperfect competition concludes with a discussion of the beneficiaries of improvements to the transportation sector. Such an issue is tantamount import in the formation of policies that affect trade between a foreign and domestic sector. The general result we find is that the larger the number of "local" markets, the more rents are captured by foreign consumers.

The model developed is a very special case of the S-TJ framework. In section 4, the more standard S-TJ framework is presented wherein market prices are connected through an equilibrium. In particular, the prices in each region depend on the flows to and from other regions. The model is first worked out for the case of separated markets. Transportation is then added with a fixed price per unit and the quantity transported (quantity demanded) is derived. To this model, we add the supply of transportation and consider alternative market structure assumptions.

The second major issue addressed rests with the region fixity assumption of S-TJ models. In some settings, this approach is perfectly reasonable assumption. The assumption requires there is a bordering effect such that individual suppliers in one region cannot substitute to another region. The models of sections 3 and 4 provide useful benchmarks to consider the likelihood that, in some settings, there are important substitution effects. To develop the case in which there are substitution effects requires the development of a full-fledged spatial model. This model is developed in section 5, for the competitive case and adapted to allow for market power among both grain elevators and transportation suppliers. Section 6 concludes the paper with a comparison between the S-TJ models and the results from the full spatial model.

This research is of central import to evaluating the welfare effects of transportation infrastructure improvements. Such improvements include the development of rail line/terminal capacity and waterway capacity. In recent years, the latter has been of considerable interest to the Army Corps of Engineers (ACE). ACE maintains U.S. waterways. The waterways include a system of locks and dams that make river navigable. Most of the locks and dams were built more than 50 years ago and have obsolesced with time. Redesigns and replacements require considerable sums. In evaluating whether to improve a waterway through lock investment, ACE must consider from an array of alternative restructuring plans and consider the welfare benefits from the alternatives. They use a variety of models that have been criticized by the National Research Council (NRC) of the National Academy of Sciences and others. The criticisms largely focus on forecasting methods and on the treatment of demands in their simulation models. The later is of particular relevance to this paper in that the assumptions in the ACE models can be related to a S-TJ type setup. Further, the NRC recommended that ACE more directly consider the role of space and market alternatives in their modeling efforts. This research pertains directly to the consideration of space and the presence of market power in the grain elevator and transportation sectors. The general findings presented in the last section point to differences in welfare consequences measure in the class of S-TJ models and a full spatial model.

2 Fixed World Price

We begin our analysis with a case of trade from one region to a market. For the discussion, the market is labeled a "world" market which could be considered a region in the S-TJ setting.[4] In this model, we suppose that the world price is given exogenously to individual transportation firms, and then we consider market power of the individual transportation firm. The assumption of a fixed price can be also interpreted as the situation facing a transportation firm that has market power in the local market from which it transports, but is a small player in the global market. In this case, the transportation firm will be modeled

[4] Another interpretation is to understand this world price as say the price in New Orleans, which is the point of shipment to farther marketplaces. We shall derive how local conditions in markets upstream translate into quantities supplied to the Port of New Orleans as a function of world price (i.e., the price in New Orleans). This analysis will basically give us a supply curve (measured at the Port, and in terms of the price there), that together with an analogous demand curve will render this price endogenous. We take a short-hand (black-boxed) version of this world demand at the end of this Section. A detailed analysis of the ingredients to the demand curve, from all the disparate ports of call for shipments leaving the Port, would follow parallel lines to those developed in this paper for the supply side.

anyway as taking the world price as fixed, but this device is instrumental in generating a world supply which can be in turn used as input to generate a world price endogenously by integrating up over a large number of transportation firms that have no effective power in the world market, even though they do have market power in the local markets from which they transport. In the sequel, we also consider the case in which the transportation firm has market power in the world market. The general structure is quite intricate insofar as we can treat different degrees of market power upstream and downstream. That is, for example, we can have relatively few transportation firms in the local production regions, but if there are many transportation firms in the world market as a whole, they do not have much market power there (on the world price) since they are so many, comprising transportation firms transporting from many different regions. However, this sketch may be a little misleading insofar as the exercise of market power on the local markets can nonetheless cause significant distortions on the world market (as compared to a benchmark case of perfect competition).

We first present the supply side, from which the demand for transportation services is generated. We can then use this to determine the actions of a transportation firm with market power. The simplest case to address is one in which there is a monopoly transportation firm. As we shall see, this transportation firm behaves analogously to a monopsonist in the local market. This behavior is, therefore, congruent with the idea of local grain elevators which buy up produce from local producers. They then have access to a competitive transportation technology and can use their market power directly in the buying market. An third set-up we investigate is a monopsonistic elevator buying up grain from local producers. It then can transport to the final market, but it faces a transporter with market power. Thus, this situation gives rise to a chain of monopolies vertical externality double marginalization problem. We then allow for intermediate degrees of competition in the transport market.

Throughout this and the next Section, we have a virtually "spaceless" economy to the extent that producers remain attached to their local transportation points. In later Sections we use a full spatial model to address this point.

3 Small transportation firms in the world market

We first consider the case where transportation firms are so small relative to the world supply that they effectively take the world price as fixed. This analysis also does enable us to later endogenize this price that is being taken as given, just as standard economic analysis of demand and supply views each individual as too small to knowingly have an influence on the outcome, and so can be reasonably described as a price-taker. We deal with the material in the following order, and show various equivalences along the way. We first set up the supply side, and consider a single local market, with a world price that local agents take as given at a distant location. From this we derive the demand for transportation. We then assume a monopoly transportation firm and derive the price this monopolist will set for transportation. Next, we consider a grain elevator in conjunction with a competitive supply for transportation, and then we put both together.

3.1 Deriving the demand for transportation

The first step is to describe the primitive market conditions and derive the demand for transportation.

Suppose that the world price is fixed (or rather, treated as such by the participants in the local market). Let its level be $\bar{p}$. Furthermore, let the local supply for the agricultural commodity under analysis be

$$S\left(p_s\right) = p_{s\alpha}$$

where $p_{s\alpha}$ is the supply price (or "producer price") which is that price received by the local participants, and $S\left(.\right)$ is the quantity supplied at the given price, p_s, which takes here the simplest linear form. We shall also write the inverse supply as $p_{s\alpha}(Q)$, which is the supply price that induces a quantity supplied of Q.

We suppose, initially, that there is no local demand for the commodity and so all the output produced must be sold on the world market at destination price $\bar{p}$.[5] However, the local produce has to arrive at the world marketplace, and doing so involves costly transportation via a transportation intermediary that may apply its mark-ups in order to generate profit for itself from its transportation business.[6]

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[5] Recall we take this world market as synonymous with demand and supply conditions at some intermediate point in the supply chain; for concreteness (in the current context especially) the Port of New Orleans.

[6] A major motivating example for the analysis is agricultural production, which, being

The demand for transportation services is then given as the quantity of shipments that the local suppliers wish to send as a function of the price charged for making a shipment. Clearly, if the price were $\bar{p}$ or more, no shipments would be made since it would cost more than it was worth to farmers, even if they were willing to supply at zero price. At the other extreme, a zero transport cost implies a supply response of $S(\bar{p}) = \bar{p}$ which is the maximum possible. Since the supply curve is linear, the demand for transportation services is then also linear between the two extreme points just derived. More formally, let w be the price charged for transportation one unit from the supply point to the destination (world market). Then the demand for transportation as a function of w is $T(w) = \bar{p} - w$, which we can write in inverse form as $w(T) = \bar{p} - T$ to denote the demand price for a quantity T of transportation services. This derivation is illustrated in Figure 1: the top panel gives the supply curve at local prices: netting this from the world price yields the demand for transportation services in the lower panel.

INSERT FIGURE 1.

Demand for transportation services derived from supply of goods and world price.

extremely land intensive, necessarily occurs in the hinterland. Locations for other natural resources are determined by nature and geography (e.g., where the coal veins are). However, locations for some commodity types are more footloose: firms must decide where to locate facilities. The current analysis can also be helpful for endogenizing such location choices, as well as dealing with their implications for market equilibria in the commodities they product. For example, locations will depend typically on transport facilities and costs of shipping both inputs and outputs. Whether inputs or outputs get a higher weighting in the choice depends on whether the product is weight-losing or weight-gaining (in the parlance of economic geography. The importance of the transport net is clear from the locations of factories near major roads, railways and rivers.

More general transportation functions are derived in a similar manner: other examples are treated below.

3.2 Monopoly vs. competition in the transportation sector (and capacity constraints)

Suppose first that transportation is perfectly competitive. We can describe equilibrium in the transportation market from equating supply and demand for transportation. The demand curve was derived above. The simplest case to describe for the supply side is when the transporting firms have equal and constant costs per unit transported. Accordingly, let the cost of transportation be $\bar{w}$, and so this is the supply price of transportation (and the supply curve is totally elastic at this price). Then the equilibrium amount of produce transported is $T_\alpha(\bar{w}) = \bar{p} - \bar{w}$ and this is the amount of regional supply. Equivalently, the domestic supply price, in terms of the rate received by domestic producers per unit produced at the transportation terminal, is $p_{s\alpha} = \bar{p}_\alpha - \bar{w}$. Clearly, a transport rate reduction raises the price received by domestic producers and so increases the amount produced and transported. If the world price is fixed (equivalently, think of the transport cost improvement as pertaining solely to the local market), then all the transport cost improvement is captured as rents by the local producers. The welfare gain is illustrated in Figure 2.

INSERT FIGURE 2. Welfare gain (accruing to producers) from reduction in cost of transportation from $\bar{w}_1$ to $\bar{w}_0$.

If the transport sector is subject to a capacity constraint, there is a limit to the amount that can be transported. Call the capacity constraint $\bar{T}$, representing the maximal amount of transportation on the local link. If capacity is above $T(\bar{w})$, then the constraint is not binding. So suppose that instead $\bar{T} < T(\bar{w})$. Then the amount transported is just $\bar{T}$ and all rents from transport cost improvements (assuming that these do not relax the capacity constraint) accrue to transportation firms - there is no benefit to local producers, who continue to receive a producer price of $p_s = \bar{T}$. The welfare gain is illustrated in Figure 3.

INSERT FIGURE 3. Welfare gain from reduction in cost of transportation from $\bar{w}_1$ to $\bar{w}_0$: accruing to transporters. Here w is the equilibrium price of transportation services.

Suppose now that the transportation sector is controlled (at least on the local route) by a monopolist controlling transportation and able to set a transportation price per unit. The monopoly calculus trades off the mark-up charged over the cost with the volume of shipments (the cost is retained as $\bar{w}$ in the analysis that follows). Following this logic, the monopolist's objective is to render $(w - \bar{w})\, T(w)$ as large as possible, where this profit is the product of the mark-up and the volume transported. The monopolist is to choose w, the price it charges per unit transported. With a linear demand, the solution is geometrically apparent (and can also be readily checked algebraically from the first-order condition). The optimal price is half-way between the cost, $\bar{w}$, and the transportation demand intercept, $\bar{p}$. Hence, the monopoly price charged, w_m, is $\frac{w+p}{2}$. Recall that this is the amount charged for transportation: the domestic producers receive a price of $\bar{p}$ per unit once the shipments arrive on the world markets. Hence, the net price received by the producers is the latter minus the former, or $\bar{p} - \left(\frac{w+p}{2}\right) = \left(\frac{p-w}{2}\right)$. This, given the linear supply function, is also the amount of local production: see Figure 4.

INSERT FIGURE 4. Monopoly transporter and associated surpluses.

Any transportation cost improvement (reduction in $\bar{w}$) is then split equally between the monopoly transporter and the local producers, in the sense that half the cost reduction is passed on as a lower transportation price. This elicits a supply response that is only half that which would arise under a fully competitive market.

INSERT FIGURE 5. Welfare gains and distribution of surpluses from reduction in cost of transportation from $\bar{w}_1$ to $\bar{w}_0$.

Figure 5 illustrates the division of the gains from reducing the transportation cost. First, the monopoly price falls, resulting in a surplus gain to producers of $a + c$ in the Figure. The rest of the gain accrues to the monopoly transportation firm in terms of higher profit; first because of the lower cost on existing units (the term e) and furthermore in terms of extra profits on the higher output. Profits rise by $(d + e + f) - a$: the (a) was transferred to producers though. Equivalently, the social gain is $(c + d + f)$ (the social value of the extra production at the new higher output level) and the (e) that represents the lower cost on existing units.

3.3 A monopsony grain elevator and competitive transportation

Oftentimes, grain is bought up by elevators and then shipped down-river. This arrangement arguably puts the elevator in a position of market power vis-a-vis the local producers. As a first benchmark, suppose that transportation is perfectly competitive (we deal with market power in this context below). There is an important relation between this scenario and that of a monopoly transportation firm facing a competitive supply, i.e., without the intermediary. Namely, the market outcome is *identical* in terms of amounts transported.

The set-up for this case is as follows. The grain elevator acts as a monopsonist by setting the producer price that the producers will receive. It then accesses the competitive transportation sector to transport the commodity (at rate $\bar{w}$ per unit transported) out to the world market, where the good is sold at price $\bar{p}$ per unit. The elevator then effectively faces a net value of $\bar{p} - \bar{w}$ per unit that it induces supplied from the producers, and it earns a mark-up of this minus the price it has to pay suppliers. It also accounts for the volume of supply it generates in its choice of price to the producers. Therefore, it faces the problem of maximizing $(\bar{p} - \bar{w} - p_s)\, p_s$, which is the product of the mark-up it earns and the induced quantity supplied. Using the logic of the above monopoly analysis, the price it will set is midway between zero and $\bar{p} - \bar{w}$, i.e., the price received by suppliers is $p^m_{s\alpha} = (\bar{p} - \bar{w})/2$. The latter price is also, given the one-to-one output-to-price relation assumed in the supply curve, the quantity transported in equilibrium. This solution and its derivation are illustrated in Figure 6.

INSERT FIGURE 6. Monopsony Grain Elevator.

The outcome above is equivalent to monopoly in the transport sector, the solution described in the preceding sub-section. That is, a monopsonist buying up the good from suppliers and transporting competitively is equivalent in terms of output and producer surplus to a monopoly on the transportation sector. It is also noteworthy that this equivalence result is not specific to linear supply, etc., but holds as a general property. It is a useful result to bear in mind for the rest of the analysis.

3.4 A monopsony grain elevator and a transport monopoly: the double marginalization problem

The equivalence breaks down if the elevator and transporter are both monopolies. Indeed, this market structure can lead to very inefficient market outcomes. Basically, this inefficiency arises because each monopolist applies its own margin to extract profit. This is known as the double marginalization problem (the usual context is upstream-downstream manufacturing relations).[7] In the current context, it works as follows.

Think of the transportation monopolist as choosing a mark-up for its transportation services, and taking into account that the grain elevator also uses its monopsony power in the local supply market. If the transport rate is w, we know from the previous sub-section that the elevator chooses a price for the competitive suppliers as $(\bar{p} - w)/2$, which is the quantity supplied. Understanding this relation between the rate it charges and the quantity that is

[7] See Tirole (1988, Ch. 4) for an exemplary modern treatment. The forthcoming Handbook of Industrial Organization (third volume, forthcoming) brings Tirole's text up to date.

transported, the transport sector operator then chooses the transport rate to maximize $(w - \bar{w})\left((\bar{p} - w)/2\right)$. The solution to this problem is to choose a rate $w^* = (\bar{p} + \bar{w})/2$. The grain elevator then applies its own margin to further increase the mark-up grabbing monopoly distortion and the price received by the competitive suppliers is then $\left(\bar{p} - \left[(\bar{p} + \bar{w})/2\right]\right)/2 = \frac{\bar{p} - \bar{w}}{4}$ which is fully one quarter of the competitive outcome, and one half of the outcome under either a monopoly transporter alone or a monopsony in the local supply market alone. This successive application of mark-ups, therefore, can be very inefficient. Paradoxically, perhaps, the exercise of market power may ultimately help domestic firms (those with the market power) to retain rents from transport cost improvements that would otherwise go to foreign consumers (see more details below on this).

3.5 Cournot competition in transportation

We looked above at a comparison between monopoly and competition among transportation firms, before going on to look at market power of the grain elevator. We now return to the case of competition at all levels apart from the transportation market, and consider the cases intermediate to pure monopoly and perfect competition, namely oligopoly.

Suppose that there are n competing transportation firms. We follow the standard "work-horse" Cournot model of imperfect competition, by supposing that each transportation firm recognizes the strategic interaction of the small group in the industry. Each rationally anticipates the quantity transported by the other transportation firms and maximizes its own profit accordingly. In doing so, each realizes full well all its competitors are doing likewise.

To find this equilibrium, denote by $q_{i\alpha}$ the quantity transported by transportation firm i. Then the total quantity transported is $q_{i\alpha}$ and the price received for transportation is determined in the following manner. Recall that $T(w) = \bar{p} - w$, which we can write in inverse form as $w(T) = \bar{p} - T$, where T is the total quantity shipped. Hence $T = \Sigma q_i$, and the Cournot assumption has firms recognizing through this relation their individual influence on the price w for transportation in the market.

The profit of transportation firm i can then be written as

$$\begin{aligned} \pi_i &= [w(T) - \bar{w}]\, q_{i\alpha} \\ &= [w(\Sigma q_j) - \bar{w}]\, q_{i\alpha} \end{aligned}$$

where the first term is the mark-up over the price paid for transportation and the last one is the quantity transported by i. The first-order condition to the problem is then

$$\frac{\partial \pi_{i\alpha}}{\partial q_{i\alpha}} = [w(\Sigma q_j) - \bar{w}] + w'(\Sigma q_j)\, q_{i\alpha}$$

which is interpreted as follows. The first term on the RHS is the extra revenue from transporting one more unit of the good; the second term is loss on existing units transported. The latter is the product of the amount by which the market price falls to induce an extra unit to be transported ($w'(\Sigma q_j)$), and the individual transportation firm's volume of shipments.

In the case of the particular linear supply function used above (which implies the transportation demand function is $w = (\bar{p} - \Sigma q_j)$), the first-order condition reduces to

$$\frac{\partial \pi_{i}}{\partial q_{i}} = [\bar{p} - \sum q_{j} - \bar{w}] - q_i;$$

setting equal to zero and summing over all n transportation firms gives a relation

$$n\,[\bar{p} - \sum q_{j} - \bar{w}] = \sum q_j (= T),$$

or

$$T = \frac{n}{n+1}[\bar{p} - \bar{w}].$$

The gratifying properties of this relation are that the amount of transportation is the monopoly amount, $T = \frac{1}{2}[\bar{p} - \bar{w}]$, for $n = 1$, and it tends to the competitive level, $T = [\bar{p} - \bar{w}]$, as n gets large. Moreover, the convergence is "monotonic": the more competitors, the larger is the amount of production. Nonetheless, although the total is increasing with the number of transportation firms, the size of each individual firm (that is, the amount it transports) is decreasing. That amount is $\frac{1}{n+1}[\bar{p} - \bar{w}]$, which is decreasing in n. Thus, more competitive markets involve smaller transportation firms but with a greater total output shipped.

3.6 Cournot competition among grain elevators, competitive transportation

Just as we did above for a single monopoly in the transport sector, and a single monopoly in buying up the product, we can think of a vertical structure with different degrees of market power at the two levels. For example, we can model several grain elevators buying grain (and taking into account their monopsony power on the supply of agricultural produce), and faced with a monopoly (or an oligopoly) in the transportation sector. This enables us to describe various degrees of market power. The double marginalization problem of vertical structure will still remain, though it will be muted in the presence of more competition at either level.

3.7 Endogenous world price and foreign rents

One dimension of interest regards who benefits from transportation improvements. The models above take the world price as given and parametric. This is of interest in its own right for some commodities,. However, for others, the actions of many small production areas aggregate into a significant economic force, and world prices are then affected. Who earns how much extra surplus from a transportation improvement depends on various demand and cost elasticities, as well as market structure in the various sub-markets along the way.

To illustrate the general approach, suppose first that all markets are competitive. There are $m\alpha$ supply regions, and for simplicity, they all face the same conditions (same distance from the final market, same supply relation). As a function of the world price, $p_{w\alpha}$ (which therefore replaces $\bar{p}$ in the analysis above), each will supply to the world market a quantity $p_{w\alpha} - \bar{w}$. This means that the total quantity supplied at world price $p_{w\alpha}$ is $m\,(p_{w\alpha} - \bar{w})$.

Now suppose the world demand is given as $D_{w\alpha} = \Sigma_{\ w\alpha} - p_w$. Equating world demand and supply yields $_{w\alpha} - p_{w\alpha} = \Sigma m\,(p_{w\alpha} - \bar{w})$, or $p_{w\alpha} = \Sigma \frac{_w + mw\alpha}{m+1}$. The associated shipment from each local market is this amount less $\bar{w}$ (from the local supply curves), i.e., $\frac{_w - w}{m+1}$: the total amount shipped is $m\alpha$ times this, or

$\frac{m(^{-}{}_{w} - w)^{-}}{m+1}$, and we can immediately verify that this equals world demand at the price $p_{w\alpha} = \Sigma \frac{{}_{w} + mw}{m+1^{-}}$.[8]

A transport improvement (fall in $\bar{w}$) now reduces the world price by an amount $\frac{m}{m+1^{-}}$ per dollar reduction. Note that this means that the larger the number of local markets, then the greater the benefits to the foreign consumers. In particular, with very competitive markets, foreigners will capture nearly all the rents.

Consider now the domestic regions. Since the equilibrium supply price is $\frac{{}_{w} - w}{m+1}$, a transport improvement (fall in $\bar{w}$) now raises the individual supply prices by an amount $\frac{1}{m+1^{-}}$ per dollar reduction. The more local regions there are, the more rents are captured by the foreign consumers.

4 Trading Regions

We now describe the S-TJ set-up when there are trading regions, and each may have both a domestic (or local) demand and supply. Transportation, if not too costly, allows trade to occur between such regions and causes price differences between regions to be arbitraged. To illustrate, suppose, there were no transportation costs. The prices in the regions then must be the same in equilibrium. No difference can be sustained because goods would flow from any low price region to a higher price one if transportation is costless. With costly transportation, differential prices will reflect transportation costs: transportation will arbitrage excessive price differences between the regions. In what

[8] World demand at price $p_{w\alpha} = + \frac{w + mt\alpha}{m+1^{-}}$ is ${}_{w\alpha} - p_{w\alpha} = + \frac{{}_{w} m - mt\alpha}{m+1^{-}}$, which is the expression given in the text for the total amount shipped (world supply).

follows we start by generating demand for transportation and the competitive solution to the model. The solutions under various market power assumptions follow along similar lines to those in the previous Section.

4.1 An Illustrative Example - Prohibitive Transportation Costs

Consider a simple example of two regions with linear demand and supply functions given by:

$$D_1 = \Sigma_1 - p_1$$

$$D_2 = \Sigma_2 - p_2$$

$$S_1 = p_1$$

$$S_2 = p_2$$

where the subscripts represent two different regions, 1 and 2. Suppose that $_2 > \alpha_1$: since supply parameters are the same, trade will flow from Region 1 to Region 2, Accordingly, we can think of 1 as the "supply region" and 2 as the "demand region". In this case, if there is trade, then it will flow from the low demand region (1) to the high demand region (2).

However, if trade costs are too high, then autarky prevails and each market clears independently of the other. It is straightforward to find the equilibrium without trade as

$$p_1^* = \frac{1}{2}\alpha_1, \quad p_2^* = \frac{1}{2}\alpha_2, \quad D_1^* = S_1^* = \frac{1}{2}\alpha_1; \quad D_2^* = S_2^* = \frac{1}{2}\alpha_2$$

.

In this simple model, the prices and quantities (both produced and sold) in the high demand region (2) are greater.

4.2 Transportation Costs and the Demand for Transportation

Transportation arbitrages price differences across regions. The point is most simply illustrated with zero transportation costs. The equilibrium can then be found by equating excess demand to excess supply. The excess demand equations are simply the residual demands for each region. Obviously, if the equilibrium price under trade is greater than α_1 demand in region 1 is zero. This will hold as long as α_2 is large enough relative to α_1. Equilibrium then is determined in market 2, which is supplied by both Region 1 and Region 2 suppliers. Excess demand in Region 2 is simply $ED = \alpha_2 - 2p_2$, which is then set equal to excess supply from Region 1 suppliers, which is simply equal to p_1 as long as price is high enough that domestic demand in 1 is crowded out. That is, given that it is assumed that α_2 is sufficiently high relative to α_1 so that demand is zero in 1, excess supply is simply Region 1's supply function. Since transportation costs are zero, $p_1 = p_2$ and so $ES = p_1 = p_2$. The equilibrium prices and quantities under trade then are:

$$S_1^* = S_2^* = p_1^* = p_2^* = \frac{1}{3}\alpha_2, \quad D_1^* = 0, \quad D_2^* = \frac{2}{3}\alpha_2;$$

and this outcome holds as long as

$$_2 \geq 3\Sigma_1.$$

If $_2$ is lower than $3\Sigma_1$ (but still retaining the assumption that it exceeds $_1$), then Region 1 consumers consume some of the good, and the rest is exported. We can find the outcome using the same technique as above, equating excess demand and excess supply. Region 2's excess demand function is just the same, $ED = \Sigma_2 - 2p_2$, and costless transportation again implies perfect price arbitrage, so that $p_1 = p_2$. What changes is Region 1's excess supply function, which now needs to account for domestic consumption eating into domestic production. Thus $ES = 2p_1 - {}_1$, which is simply domestic supply minus domestic demand. Pulling these equations together yields the equilibrium prices and quantities under trade as:

$$S_1^* = S_2^* = p_1^* = p_2^* = \Sigma\frac{_1 + \Sigma_2}{4\Sigma}, \quad D_1^* = \Sigma\frac{3\Sigma_1 - {}_2}{4\Sigma}, \quad D_2^* = \frac{3\Sigma_2 - {}_1}{4\Sigma};$$

which holds as long as

$$_2 \in [{}_1, 3\Sigma_1].$$

Transportation, however, is costly. Let w represent the cost per unit of of the good transported. For now, consider the case of one mode providing transportation from Region 1 to Region 2. The excess demand and excess supply equations above still apply to the case of costly transportation, but transportation can no longer arbitrage prices to be the same. Instead, arbitrage implies that price differences cannot exceed the transport cost. That is, the prices are linked by the constraint $p_2 \leq p_1 + w$. If there is trade in equilibrium, this holds with equality (so $p_2 = p_1 + w$) and differential prices simply reflect the cost of getting the good transported to the demand region. On the other hand, if prices are closer together than w ($p_2 < p_1 + w$) there can be no trade since arbitrage cannot be profitable. The equilibrium types then are like the ones we have already described: if transport costs are too large, the autarkic equilibrium prevails. For lower costs, there is trade, and the supply region will export its total production only if its domestic demand is weak relative to that in the demand region.

The autarky regime is the simplest to describe. As we showed above, autarky prices are $p_1^* = \frac{1}{2}\alpha_1$ and $p_2^* = \frac{1}{2}\alpha_2$, so that autarky attains as long as the price difference is less than the transportation cost. Equivalently, $\alpha_2 - \alpha_1 \leq 2w$ means there will be no trade.

In the case of lower transport cost but weak demand in the supply region, then demand in the low demand Region 1, is zero. To characterize this case, we equate excess demand and excess supply so $\alpha_2 - 2p_2 = p_1$ and use the price difference equation $p_2 = p_1 + w$. Solving out yields $p_1^* = \frac{\alpha_2 - 2w}{3}$ and $p_2^* = \frac{\alpha_2 + w}{3}$. Each region's domestic production equals its domestic supply, and quantity consumed in Region 1 is zero, while in Region 2 it is given by the demand curve as $D_2^* = \frac{2\alpha_2 - w}{3}$. For this regime to be pertinent, we require $p_1^* \geq \alpha_1$ otherwise there would be positive consumption in the supply region.

This condition is $\alpha_2 - 2w \geq 3\alpha_1$. Notice that the quantity transported from 1 to 2 is the full quantity produced in 1, namely $\frac{\alpha_2 - 2w}{3}$, which expression forms the demand for transportation, and is a decreasing function of w.

For low transport cost and relatively strong Region 1 demand, not all Region 1's production will be exported. Equating excess demand and excess supply in this case implies that $\alpha_2 - 2p_2 = 2p_1 - \alpha_1$, and again the price difference equation $p_2 = p_1 + w$ holds. Solving these equations gives $p_1^* = \frac{\alpha_1 + \alpha_2 - 2w}{4}$ and $p_2^* = \frac{\alpha_1 + \alpha_2 + 2w}{4}$; once again, these are also the respective expressions for the domestic supplies, S_1^* and S_2^* respectively. The quantities consumed are $D_1^* = \frac{3\alpha_1 - \alpha_2 + 2w}{4}$ and $D_2^* = \frac{-\alpha_1 + 3\alpha_2 - 2w}{4}$ respectively.[9] From the first of these, it is clear that we need the condition $3\alpha_1 + 2w > \alpha_2$ to hold in order for D_1^* to indeed be positive. The quantity transported in this case is given by $T = \frac{(\alpha_2 - \alpha_1)}{2} - w$.

The result of both cases are similar. Specifically, as demand in the excess demand region grows, quantities transported increase and as the transportation rate increases, quantities transported fall. In the second case, as demand in the excess supply region grows (i.e., α_1 increases) less is transported.

The model to this point has treated as exogenous the cost of providing transportation. When there is market power in the transportation sector, the transportation companies use the demand for transportation to extract rents, analogous to the previous section's analysis.

[9] It is readily checked that total production equals total consumption, i.e., $S_1^* + S_2^* = D_1^* + D_2^*$ $(= \frac{\alpha_1 + \alpha_2}{2})$.

5 A Full Spatial Model

The analysis above has treated regions simply as points in space connected by transport costs, without regard to the fact that production of most agricultural commodities is quite land intensive. This is especially important because transportation costs typically comprise a large fraction of the selling price for agricultural goods. The geography of production and the transportation network are then crucial determinants of the market equilibrium.

We suppose that geography (and fixed costs) restrict the number of river terminals to be few, and we further assume the rail terminals are located at the same points as the river terminals (see Anderson and Wilson, 2005, for a discussion of these assumptions). Then each shipper (farmer) has to choose which terminal to ship from and which mode to use once there (rail or river). Truck transport is used to reach the terminal, distance is measured via the "block-metric," and truck transportation costs $t\alpha$ per unit distance per unit trucked. Suppose for the moment that each farmer is assigned to the closest "pool" – we relax this assumption below. The importance of the assumption now though is that it generates demands for the barge transportation exactly of the form analyzed above, namely demands that are linear in the price of the barge transportation to the final port, the rate $w_{i\alpha}$ above. The geography of the hinterland production and the fixed region assumption are shown in Figure 7.

INSERT FIGURE 7. Agricultural gathering area for fixed region constrained to be coincident with pool latitudes.

Note that the area farmed rises linearly with reductions in the barge rate; moreover, the transportation demand for each pool is independent of the barge rates charged at any other pool (see Anderson and Wilson, 2005). This means that the full linear demand analysis of Section 2 above, with its full market structure implications, apply directly to this case. It therefore forms an important benchmark by allowing for market structure within a specifiable full geographic framework while at the same time enabling the analyst to break into two parts the effects of market structure in the S-TJ framework and then allowing for a richer geographical structure.

The above structure follows if no "lock-jumping" is allowed (in tandem with the S-TJ implicit assumption to this effect). The linear demand assumption IS consistent with a spatial market, albeit a restricted version thereof. Suppose now instead that farmers are permitted to choose the terminal (and mode) that minimizes costs of transportation. Figure 8 shows the geographical structure of terminals along the river, and also how the market boundaries between demand areas change with barge rates in other pools.

INSERT FIGURE 8. Endogenous Pool Markets and Barge Rates.

For simplicity, suppose in the development below that agricultural produce entails no production costs – the object of interest is the transportation sector for the moment, and costs can readily be added once the ideas here are understood.[10] Figure 9 illustrates the catchment areas for agricultural produce when choices are fully endogenous to the model.

[10] As noted below, this causes no extra difficulty.

INSERT FIGURE 9. Endogenous Markets and Catchment Areas.

The first task is to determine the latitudes that delineate markets. By equating the costs of trucking plus barge from a location along the river-side, we find the following relation:

$$\hat{y}_{i\alpha} = \frac{y_{i\alpha} + y_{i-1}}{2} + \frac{w_{i\alpha} - w_{i-1}}{2t\alpha}.\alpha$$

Clearly, the analogous relation applies to the upper boundary, just by replacing indices of pools, so:

$$\hat{y}_{i+1} = \frac{y_{i+1} + y_{i\alpha}}{2} + \frac{w_{i+1} - w_{i\alpha}}{2t\alpha}.\alpha$$

Hence, these are the upper and lower boundary levels, as per Figures 8 and 9 above. However, we also need to deal with the extensive margin within these latitudes, as per the lozenge shape illustrated in Figure 9. Given it was just assumed that the production cost is zero (it would suffice to just net it from $\bar{p}$, as long as it is independent of location), we have the following expression for the extensive margin at any given latitude, y:

$$\bar{p} = w_{i\alpha} + t\,|y - y_i| + tx\alpha$$

As is apparent from Figure 9, this expression covers two cases, that are broken down as follows. First, for $y > y_i$, we have

$$x = \frac{\bar{p} - w_{i\alpha}}{t\alpha} + y_{i\alpha} - y,\alpha$$

while for $y\alpha \leq y_i$, we have

$$x = \frac{\bar{p} - w_{i\alpha}}{t\alpha} + y - y_i.\alpha$$

Given the above analysis, we can now write out demand as (assuming a constant density across space of agricultural production):

$$
\begin{aligned}
D_{i\alpha} \;=\; & \int_{y_{i\alpha}}^{\frac{y_{i+1}+y_i}{2}+\frac{w_{i+1}-w_i}{2t}} \left[\frac{\bar{p}-w_{i\alpha}}{t}+y_{i\alpha}-y_\alpha\right] dy\alpha \\
& + \int_{\frac{y_i \;\; y_{i-1}}{2}+\frac{w_i-w_{i-1}}{2t}}^{y_i} \left[\frac{\bar{p}-w_i}{t\alpha}+y-y_{i\alpha}\right] dy.\alpha
\end{aligned}
$$

The first of these constitutes the area above $y > y_{i\alpha}$ (i.e., $y > y_{i\alpha}$) and up to the upper latitude of the catchment area, while the second is the area below y_i, and down to the lower latitude.

Now, we are interested in the shape of this demand function: it is rather cumbersome (although straightforward) to write it out, but it is also simpler to identify its fundamental form and identify parameters of the base form as necessary. In particular, it is shown in the Appendix that the demand function is a quadratic function. One interesting (and decidedly non-trivial) property of the demand is that markets are chain linked. Namely, demand at each pool depends on the barge prices at neighboring pools, which in turn depend on prices above and below them. This property implies that all markets are affected if there is a change in any one of them: equilibrium prices will adjust according to the chain structure. For example, a change in the market structure or in the transportation cost at any one pool has implications for all (although the effects dampen with distance: the largest effects are felt in the immediately neighboring pools. This property in turn implies that the welfare effects of transportation changes are wide-reaching and quite intricate.

6 Appendix

First note that (using Leibnitz' rule)

$$\frac{dD_i}{dw_{i+1}} = \frac{1}{2t}\left[\frac{\bar{p} - w_i}{t} + y_i - \left(\frac{y_{i+1} + y_i}{2} + \frac{w_{i+1} - w_i}{2t}\right)\right]$$
$$= \frac{1}{2t}\left[\frac{2\bar{p} - w_i - w_{i+1}}{2t} - \frac{y_{i+1} - y_i}{2}\right]$$

which is positive. The derivative with respect to the other price, w_{i-1}, looks just the same, except that y_{i-1} replaces y_{i+1} and w_{i-1} replaces w_{i+1}.

Moreover,

$$\frac{dD_i}{dw_i} = \frac{-1}{t}\int_{\frac{y_i + y_{i-1}}{2} + \frac{w_i - w_{i-1}}{2t}}^{\frac{y_{i+1}+y_i}{2} + \frac{w_{i+1}-w_i}{2t}} dy$$
$$+ \frac{-1}{2t}\left[\frac{\bar{p} - w_i}{t} + y_i - \left(\frac{y_{i+1} + y_i}{2} + \frac{w_{i+1} - w_i}{2t}\right)\right]$$
$$+ \frac{-1}{2t}\left[\frac{\bar{p} - w_i}{t} + \left(\frac{y_i + y_{i-1}}{2} + \frac{w_i - w_{i-1}}{2t}\right) - y_i\right]$$

Then this simplifies to

$$\frac{dD_i}{dw_i} = \frac{-1}{t}\left[\frac{y_{i+1} - y_{i-1}}{2} + \frac{w_{i+1} + w_{i-1} - 2w_i}{2t}\right]$$
$$+ \frac{-1}{2t}\left[\frac{2\bar{p} - w_i - w_{i+1}}{2t} - \frac{y_{i+1} - y_i}{2}\right]$$
$$+ \frac{-1}{2t}\left[\frac{2\bar{p} - w_i - w_{i-1}}{2t} + \frac{y_{i-1} - y_i}{2}\right]$$

or

$$\frac{dD_i}{dw_i} = \frac{-1}{t}\left[\frac{y_{i+1} - y_{i-1}}{2} + \frac{w_{i+1} + w_{i-1} - 2w_i}{2t}\right]$$
$$+ \frac{-1}{2t}\left[\frac{4\bar{p} - 2w_i - w_{i+1} - w_{i-1}}{2t} - \frac{y_{i+1} - y_{i-1}}{2}\right]$$

or

$$\frac{dD_i}{dw_i} = \frac{-1}{2t}\left[\frac{y_{i+1} - y_{i-1}}{2} + \frac{4\bar{p} + w_{i+1} + w_{i-1} - 6w_i}{2t}\right]$$

which is negative. It is also convex, which follows from its spatial roots (see Figure 9).

The cross derivatives (other second partials) are symmetric and negative. Hence, the spatial structure generates a quadratic form, which we can write as

$$D_{i\alpha} = \Sigma_{i\alpha} - \beta_i w_{i\alpha} + \gamma_i w_{i\alpha}^2 + \delta_i w_{i\alpha}(w_{i-1} + w_{i+1}) + \varepsilon_i w_{i-1} + \varepsilon_i w_{i+1},$$

where the Greek letters are positive parameters.

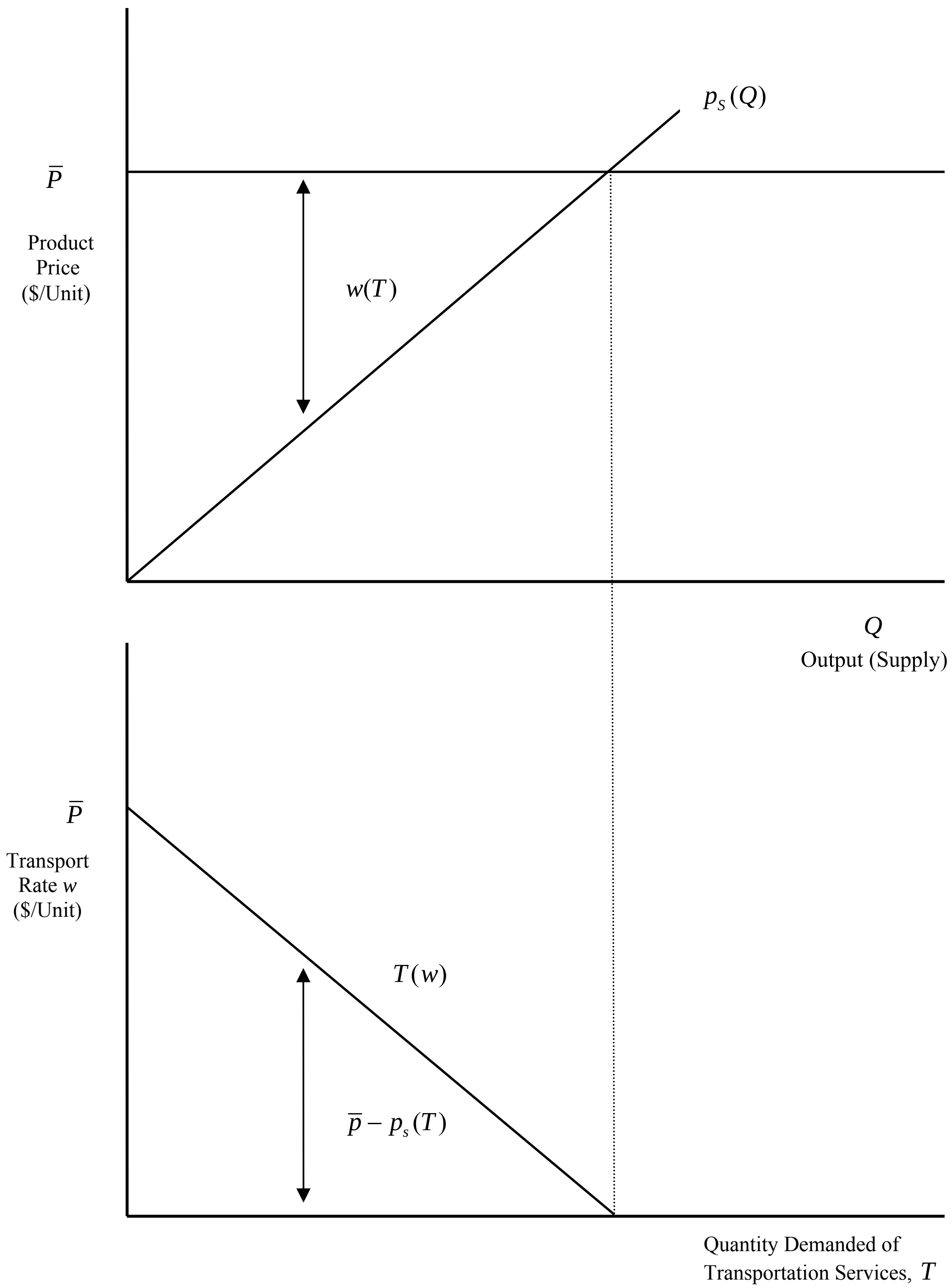

Figure 1.—Demand for Transportation Derived from the Supply of Goods and the World Market Price

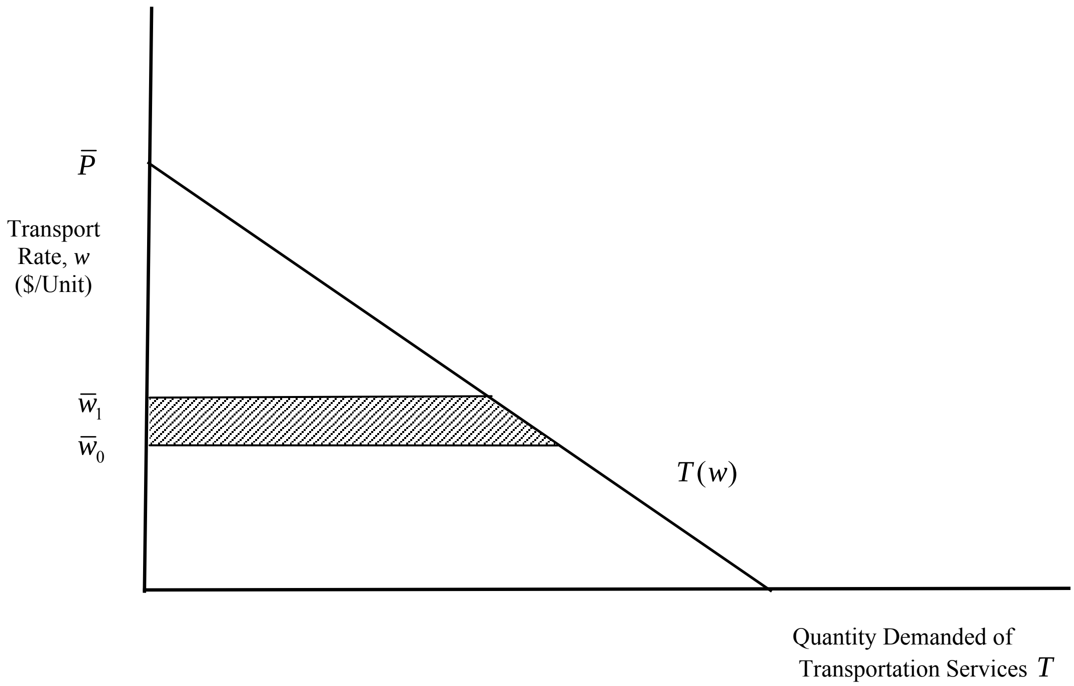

Figure 2.—Welfare Gain (accruing to producers) from a Reduction in the Cost of Transportation from $\bar{w}_1$ to $\bar{w}_0$.

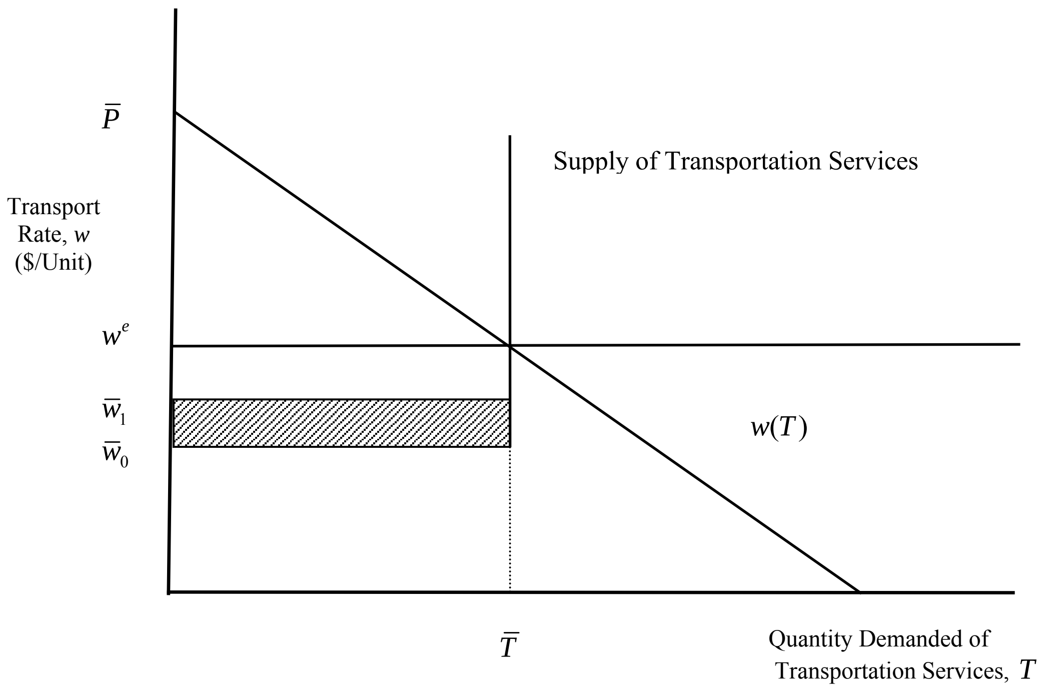

Figure 3.—Welfare gain (accruing to transporters) from a reduction in the cost of transportation from $\bar{w}_1$ to $\bar{w}_0$. Note: w^e is the equilibrium price of transportation given binding capacity, $\bar{T}$.

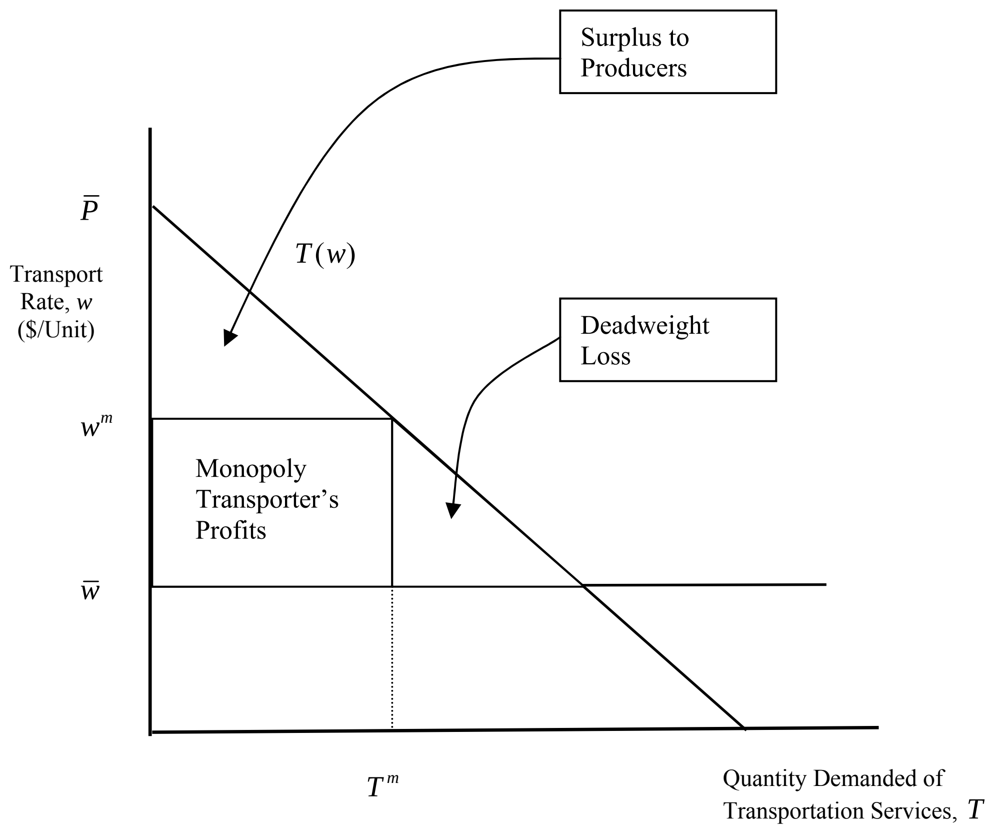

Figure 4.—Monopoly Transporter.

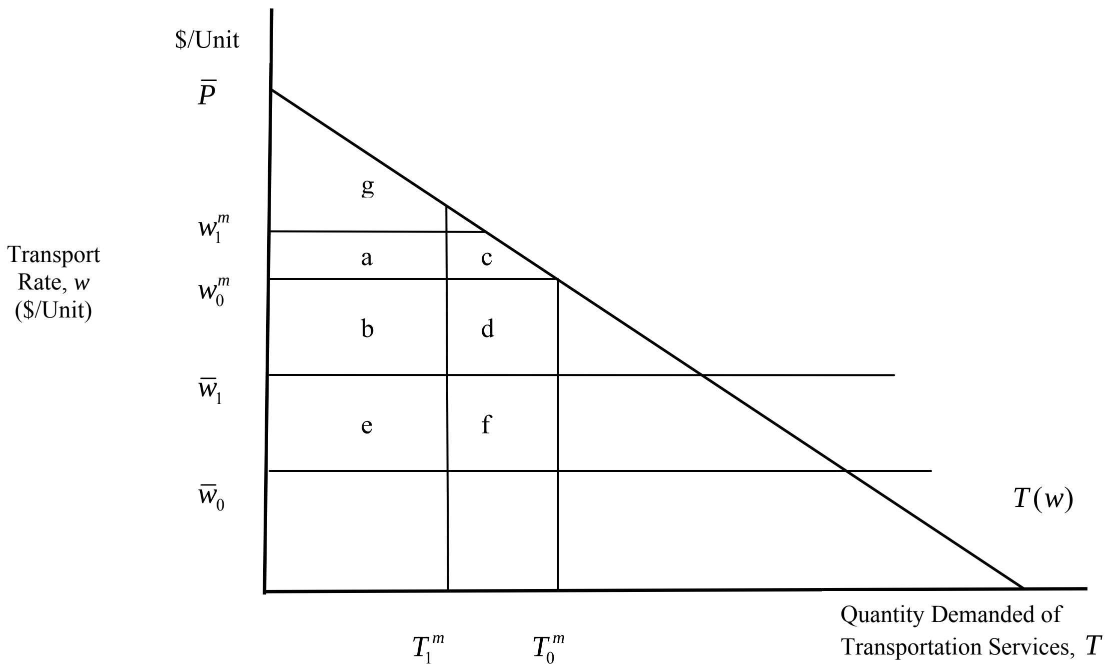

Figure 5.—Welfare Gain and Division of Surplus.

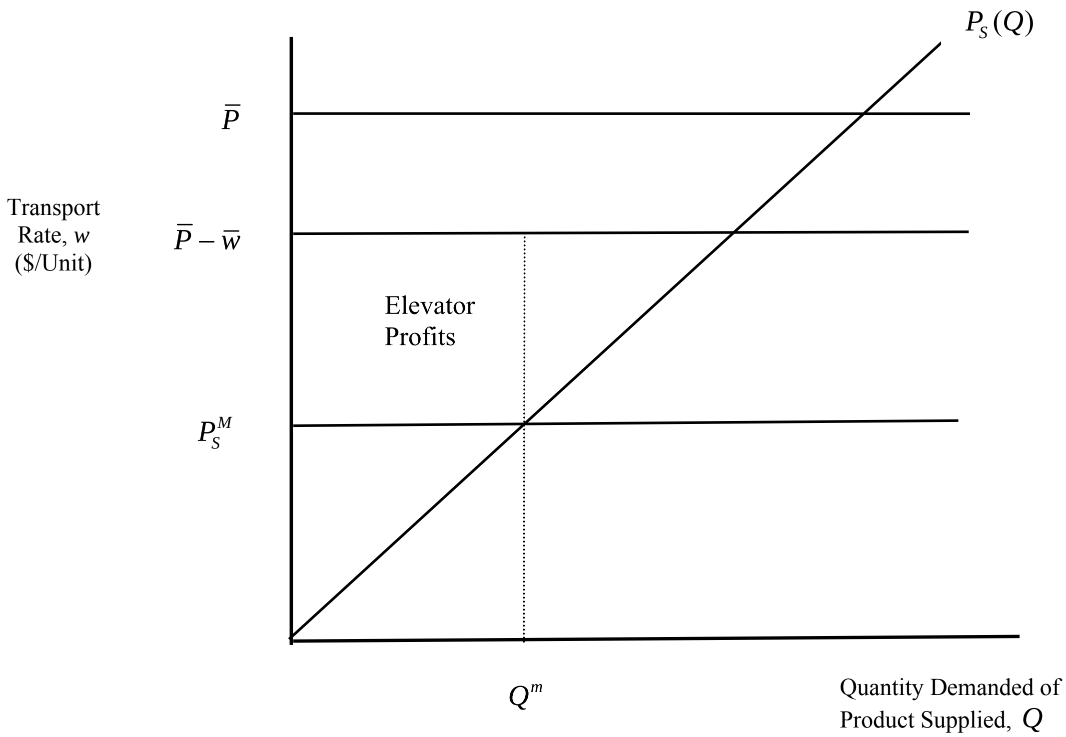

Figure 6. Monopsony Grain Elevator.

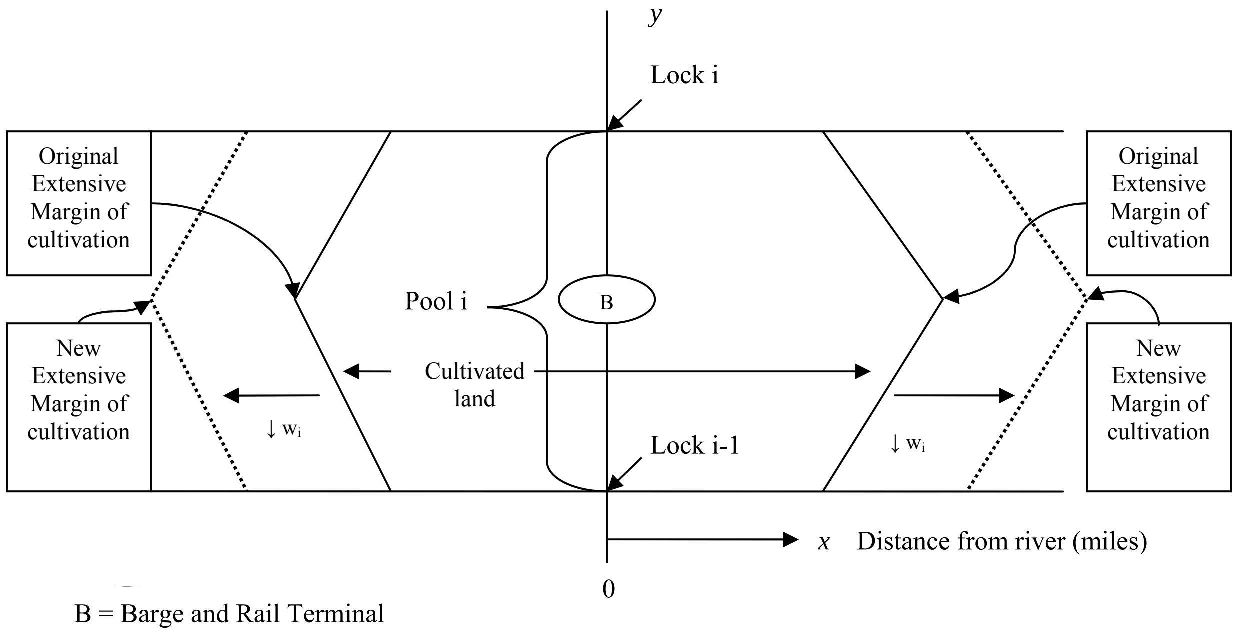

Figure 7.—Extensive Margin of Cultivation and Lower Barge Rates.

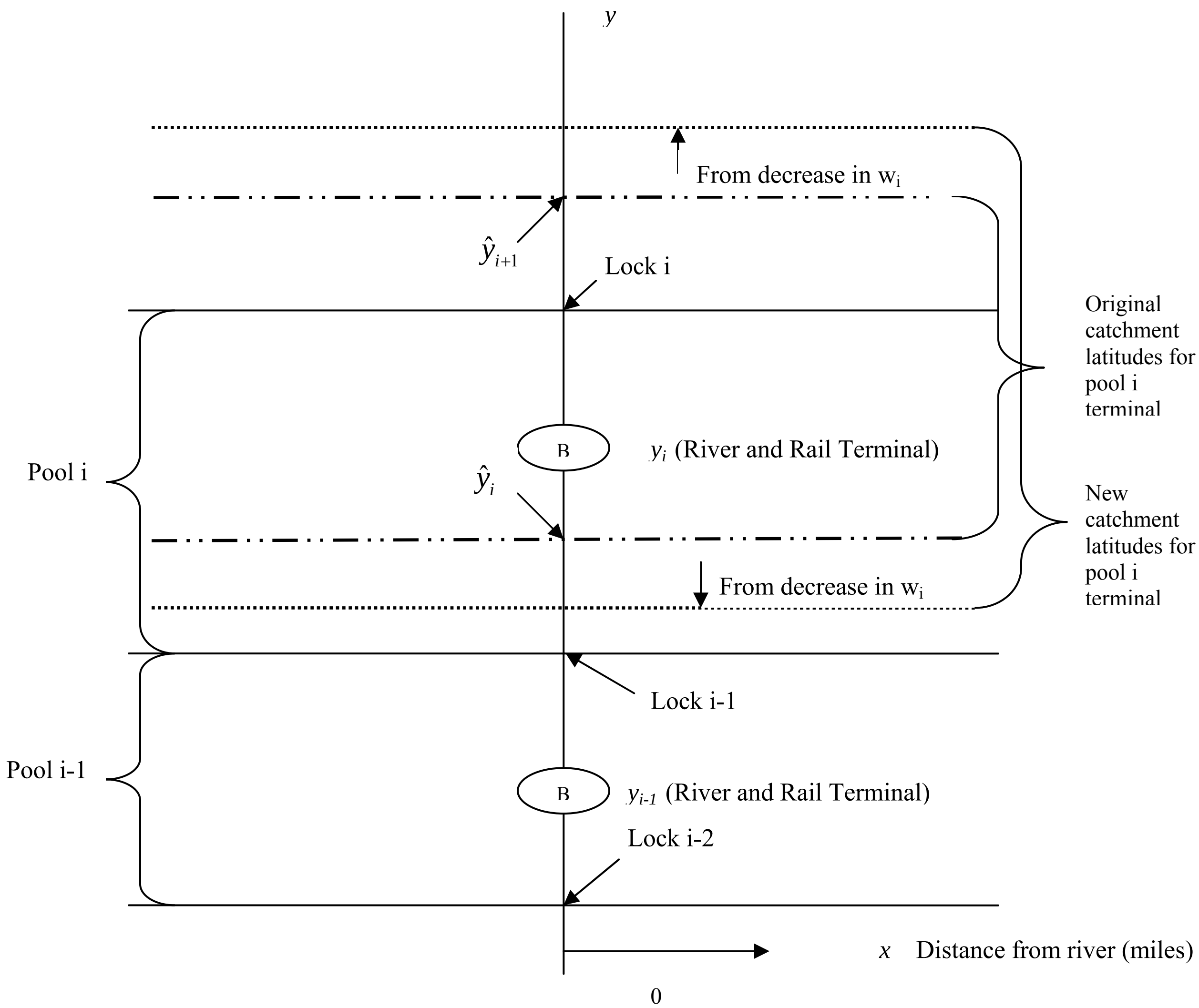

Figure 8—Endogenous Pool Markets and Barge Rates

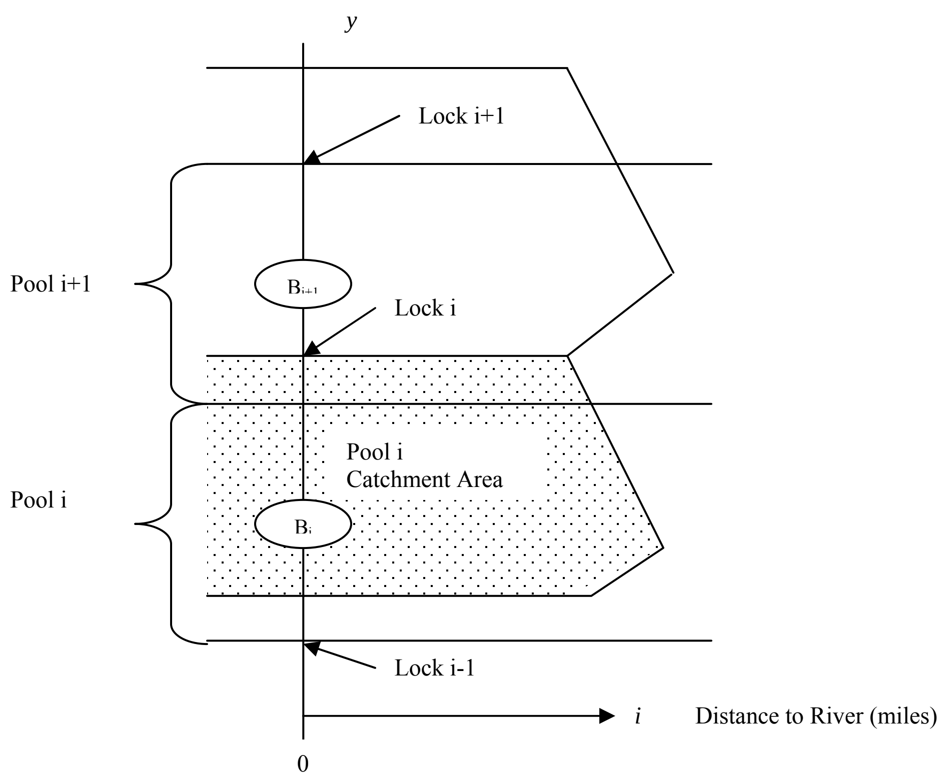

Figure 9.—Endogenous Markets

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- A regional traffic routing model that will identify the annual quantities of commodities coming from various origin points and the routes used to satisfy forecasted demand at each destination.
- A microscopic event model that will generate routes for individual shipments from commodity origin to destination in order to evaluate non-structural and reliability measures.

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