A dominant firm model of pricing transportation over space[*]

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Abstract

Transport firms compete over space. We develop a dominant firm model of transport services wherein one firm (the railroad) has market power, but competes in space with a competitive alternative (truck-barge). When constrained, the dominant firm prices to "beat the competition", which impedes efficiency when demand has some elasticity. We extend the basic model in a number of directions that include the relationship between monopoly prices and the generalized concavity of the shipper demand functions, the effects of multiple terminal markets, the role of joint production (fronthaul-backhaul markets), and the effects of capacity constraints.

KEYWORDS: Dominant firm and competitive fringe, spatial equilibrium, market power, transportation networks, mode/destination choice, equilibrium mode price, backhaul, capacity constraints, truck-barge competition, railroad economics.

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1 Introduction

Much has been written in the Economics literature about spatial competition between firms.[1] The actual transportation of commodities is usually assumed competitive, however, and is typically not further discussed.[2] Market power in transportation industries is important for many reasons. First, transport costs are an important component of final price in many products, especially for low value, bulky, and heavy commodities. Second, the cost of transportation is a key determinant of economic geography, especially for agriculture. Third, over the last few decades, some modes of transportation, and, the railroad mode in particular, have experienced tremendous growth in concentration.[3]

While some transport sectors are reasonably construed as competitive, there remain several important elements of market power. Railroads with few nearby competitors[4], airlines owning many landing slots at airports, and shipping lines with exclusive port facilities are all examples. In these examples, there are other options, so there is not a complete monopoly: there are imperfect substitutes to the monopolized service. Farmers are not obliged to use the rails, they can use truck or barge (or both) to move the product; airfreight can take off from alternative airports, passengers can take less direct routes through other hubs; ocean shipping can be embarked through alternative ports. Thus, the nature of transport is that alternative markets can be accessed, and this access can limit the exercise of market power at each point. While modes require tracks, roads, and waterways, all shippers have access to truck and through truck can access the other modes of transportation. Thus, while, for example, a railroad has a cost advantage at a point in space, its market power is limited by a movement by truck to other alternatives. This market structure can be modeled as a dominant firm/competitive fringe framework, following Forchheimer (1908).

This point motivates our framework below where we use a simple spatial set-up. The demanders of transportation are (spatially separated) suppliers of the product shipped. The product is sold in a final market at a given price (so individual suppliers have no market power), which is the same for all suppliers

[1] See, for example, Anderson, de Palma, and Thisse (1992), Ch.8 for an overview, and Ch. 9 for some extensions.

[2] An exception is the empirical literature on the pricing of transportation services; in particular, the literature on the effects of deregulation on railroad rates and market power. Typically, though, papers in this vein do not explicitly model the spatial context of the pricing. See, for example, Wilson (1996), MacDonald (1987, 1989), and Burton (1993).

[3] Railroads were partially deregulated in 1980. At that time, there were 40 Class I railroads. Since then the number of Class I railroads has fallen to seven, largely through consolidation. See Bitzan and Wilson (2008) and Wilson (1997) for further discussion.

[4] This is true for railroads that own the tracks, as in the US, though this is no longer true in Europe.

since the product is assumed homogenous (think of corn, say).[5] The product's suppliers pay the cost of transporting the product to the final market.[6] The set-up simply models two competing modes: these are truck-barge and rail. The truck-barge combination mode has a cost advantage close to the river, and rail further away from it. (A somewhat similar spatial set-up was used by Gersovitz (1989), building on the work of Ellet (1839) and Walters (1968), to address government policy in third world development and to model an agricultural hinterland serving the outside world via a single road accessing a port.[7])

Market power in the transport sector affects transport rates, and these rates determine the location of economic activity. If transport rates are high, economic development will be curtailed. However, the ability to exercise market power and charge high rates is limited by the efficiency of the substitute transport modes available.[8] This paper focuses on the extent to which such substitutes limit monopoly rate setting by the dominant firm.[9]

Our first task is, therefore, to model competition between transport sectors.[10] To do this, we apply insights from the theory of oligopolistic pricing under product differentiation to the case of transport services. There are two reference points in the oligopoly pricing literature that underpin our analysis. The first (chronologically) is the spatial discrimination monopoly pricing framework of Hoover (1937). The second is the oligopoly analysis of Lederer and Hurter (1986), which uses perfectly inelastic demands. Combining the two, the monopoly analysis is pertinent when the monopoly price (for transport services) is lower than the rival's cost, and the upshot is the spatial extension of the dominant firm model of Forchheimer (1908). When the competitive constraint is binding, the price of transport services may not be monotone in the cost of providing them (for example, distance from a terminal market).[11] This property follows from the "beat the

[5] The price in the final market can therefore be thought of as a c.i.f. price.

[6] We ignore till later the possibility of backhauling from the final destination to supplier points. On similar lines, we assume away the realities of railroad hauling across the rail net to coordinate the pick up and delivery of cargoes.

[7] The road in Gersovitz (1989) is analogous to our river, but he does not have the two modes we analyze.

[8] A number of empirical studies demonstrate that railroad prices react to competition. Wilson, Wilson and Koo (1988) examine railroad pricing in the context of truck competition; MacDonald (1987, 1989) and Burton (1993) provide strong evidence that railroad prices increase as the distance from the waterway increases.

[9] An important extension is to analyze the patterns of economic development that may arise with market power in transportation, and the role of substitutes in forming the economic geography. Investment in infrastructure in such a context is also a topic for further research.

[10] Yu and Fuller (2005) and Yu, Zhang, and Fuller (2006) use a two region spatial equilibrium model to infer a transportation demand function, in the tradition of Samuelson (1952) and Takayama and Judge (1964).

[11] When constrained, the price may fall even as the distance shipped by the dominant firm rises. Think, for example, of a case when truck-barge ships one direction, and a monopoly railroad ships in the opposite direction.

competition" property of equilibrium pricing, which is reminiscent of contestable equilibrium.[12] This implies that there may be hidden welfare gains from transport improvements in other sectors: the sector with market power may be more effectively "policed" by the competitive one, even if the latter does not actively serve the market. The paper contributes to the dominant firm literature by adding an explicit spatial dimension, along with the other extensions (such as the backhaul problem) noted below.

The analysis starts with the simplest model and then builds upon it. Throughout, we assume a fixed price at the destination for the good that is being transported and derive the demand for transportation for the service of delivering the good from producer location to destination on that basis.[13] At first, we suppose that producer demand for transportation is totally inelastic and the producer chooses the cheaper mode. This benchmark case shows that the dominant firm's pricing policy is to just beat the competitive sector's cost (or else choosing the producer's reservation price, if that is lower). In this set-up, the consequences of an improvement in the transport technology in the competitive sector (reducing the cost of barge traffic, say) will be purely distributional in those areas that remain served by the dominant firm. Namely, prices will have to go down (and producers will benefit) even if they still ship with the dominant firm. This is because the dominant firm now has to beat tougher competition, and the (Bertrand) best-reply price falls. Producers gain, and the dominant firm loses out.

There are additional welfare gains once we allow for a downward sloping producer demand function for transportation. Once again, the dominant firm's actions are constrained by the existence of the competing transportation option. When unconstrained, the price charged for transport services rises with distance. The price, though, may rise faster or slower than the cost of providing them, depending on the demand shape. This is analogous to Freight Absorption and charging Phantom Freight in the spatial delivered pricing literature.[14] Freight Absorption arises here when demand for transportation services is not "too" convex. With linear demand, for example, the monopoly price rises at half the rate that costs rise.[15] For

[12] See Baumol, Panzar, and Willig (1982). Wilson (1996) develops such a model of pricing to evaluate the market dominance regulatory criteria of the Interstate Commerce Commission. The railroad prices to "beat the competition" defined as the shipper's next best alternative, but does not consider the role of spatial competition and spatial equilibrium.

[13] This technique can be used to determine the supply curve for the good at the destination point: coupling with the demand relation at the destination gives the equilibrium final price at the destination. See Train and Wilson (2006).

[14] See Stigler (1949), and see Phlips (1983) for further discussion.

[15] Put another way, the incidence on the producer is the same as on the consumer for the linear case. The cost increase due to higher distance is shared equally between them.

sufficiently convex demand curves, the pass-on rate of costs exceeds 100%. In such cases, the welfare cost of market power can be quite large (see Anderson and Renault, 2003).

When the dominant firm's pricing is locally constrained by the competitive option, there may be a hidden benefit to a reduction in costs in the competitive mode, a benefit that is not identified by just looking at the producers who actually use the competitive sector. This benefit accrues because the constraint on the dominant firm's pricing tightens, and it reduces its price in response. With a downward sloping producer demand, this causes more than a simple redistribution to producers; it also yields a greater volume of production and an increased social surplus. That is, there is an efficiency gain to producers who do not even use the competitive system, and it is larger than the reduction in profits to the dominant firm.

Commodity transportation from production areas to final markets or ports is sometimes partially balanced with some transportation in the reverse direction. The strength of this demand can affect the equilibrium pricing of the outbound trip, which is known as the backhaul problem. Our analysis contributes to this literature by addressing the backhaul problem in the context of transporter market power. As throughout the paper, the dominant firm may find itself constrained by the competitive fringe in its overall pricing, but has some leeway in determining the composition of prices for each direction.

We then introduce capacity constraints on the dominant firm. We model these by assuming that the railroad has a fixed number of train-hours available. This implies that the dominant firm chooses to serve locations yielding the highest mark-ups per mile (i.e., the total trip mark-up divided by the distance traversed). The producer locations that generate the highest mark-up per mile tend to be those furthest from the restraining force of the competing rival shipping industry.

The next section sets out the basic model and determines the equilibrium pricing behavior. Section 3 allows for different possible terminal markets for the railroad industry's shipping destination. Section 4 goes through the analysis for downward-sloping demand, and indicates sources of deadweight loss. It also indicates where welfare gains are possible due to improvements in barge efficiency, even on account of shippers who do not use truck-barge to ship. Section 5 allows for backhaul, and Section 6 then introduces the possibility of capacity constraints in the railroad industry and finds the locations served by rail and the corresponding prices. Section 7 concludes and indicates the wider applicability of the results and some directions for future research.

2 The Model

There is a competitive transport sector (the competitive fringe) and one with market power (the dominant firm). We illustrate with competition between the joint truck-barge sector and the railroad sector, and we indicate at appropriate points in the analysis how to modify the results for multiple sectors with combinations of competition and market power.[16] In keeping with our previous work in the river-canal context (Anderson and Wilson, 2004), we suppose that shipments by river-canal must first be transported by truck to a river terminal, and then loaded onto barges. The river-canal system runs from North to South, and terminates at the final transshipment port. Let the EW distance to the river-canal be in the x direction, and let the NS direction up and down the river-canal be denoted $y \geq 0$. Shipping by truck and by barge is perfectly competitive, and constant per unit per unit distance shipped, at rates t and b respectively. Hence, the cost of transportation from coordinate (y, x) to the terminal market location at $(0, 0)$ is $tx + by$.

The alternative transport method is by rail. The railroad incurs costs of r per unit per mile shipped. The railroad controls the rails – it has market power over its transport mode, though it is constrained in its exercise of its market power by the existence of the truck-barge option. Rail transport is assumed to follow the "Manhattan metric," meaning that distances must be traversed EW and NS only. We assume that $t > r > b$, so that, if transport modes are priced at cost, the combination of truck and barge is the cheaper option for locations close to the river since the high per mile cost of trucking is offset by the low per unit cost of barge.

However, since the railroad has market power, it will typically exercise that power by pricing above cost. Denote the railroad's price per unit (since it is a price setter) by $p(y, x)$: this is the price for shipping the commodity to the terminal port $(0, 0)$ from coordinate (y, x). We next characterize this price.

First assume that each shipment point (i.e., coordinate (y, x)) is associated to a shipment of unit size up to a reservation value that is "high enough" that it plays no role in what immediately follows.[17] In the

[16] Carriquiry and Babcock (2005) frame a somewhat similar spatial model directly around the decisions of sellers of agricultural products. They locate four grain buyers on a Hotelling line representing the Mississippi River and then find a Nash equilibrium in bid prices offered to sellers of grain. Sellers of grain have a high enough reservation price that all grain is sold. The model is then applied to determining the effects of closing down one buyer.

[17] Think here of farmers (say) who directly ship their produce down to the terminal market. Equivalently, they could sell to an intermediary that would then ship the product down to the final market. If the intermediary makes no profit (for example, if there were competing intermediaries offering their services to farmers) then farmers would make exactly the same revenues whether or not they shipped the product themselves or via intermediaries. In that case, none of the results of the model would

sequel, we address the case of a binding cap and introduce a downward sloping demand at each point in space. Let the space of shipment points be denoted Ω. This space may be simply thought of as the land cultivated for corn in the mid-West, for example.

We define the "natural market area" for barge shipping as that area for which barge shipping is cheaper than rail shipping. This means that the natural market area is the set

$$\mathcal{B} = \{(y,x) \in \Omega : t\,|x| + by \leq r\,|x| + ry\}$$

The set $\mathcal{B}$ is a cone with vertex at $(0,0)$, and is illustrated in Figure 1. This shape reflects the increasing advantage for points further North of the cheaper river mode in overcoming the higher truck rate with which it is bundled.

INSERT FIGURE 1

Clearly, the railroad will not entertain the prospect of pricing below marginal cost, so that the full area of $\mathcal{B}$ is served by river-canal (i.e., truck-barge). Note that it is optimal to serve all of $\mathcal{B}$ by truck-barge from a cost-minimizing social optimum perspective: the cheaper shipment mode ought to be used. What is perhaps more surprising is that the railroad serves everything outside $\mathcal{B}$, i.e., it serves its own natural market, $\mathcal{R}$, defined by

$$\mathcal{R} = \{(y,x) \in \Omega : t\,|x| + by > r\,|x| + ry\}$$

The objective of the railroad is to maximize profits by choosing a transportation price for each location it wishes to serve. The analysis is greatly simplified by the property that its price choice at any point is independent of its choice at any other point. This property follows from the assumption that its costs of

be altered.

In practice, intermediaries (grain elevators) in the agricultural market *do* have some market power. Grain elevators buy up produce locally from farmers and then take care of shipping. They have some local monopsony power due to spatial proximity insofar as rival elevators are further from nearby farmers. Since farmers have the option of taking care of shipping themselves, the grain elevators might be seen as having countervailing market power with railroads. They also might act to smooth shipping patterns across the season. A fuller description of their behavior remains an objective for further research, but for now they are left out of the model.

transportation are constant per unit it delivers, so that the costs of serving any point are independent of which other points are served.[18]

Given the assumption of inelastic demand, and the pricing independence property, the railroad's problem is simply to "beat the competition" over all its natural market, $\mathcal{R}$ (it clearly does not need to serve any point in $\mathcal{B}$ and does not want to either). That is, the railroad will serve all demanders over the area for which it has a cost advantage. At any point outside its natural market area, it would have to price below its serving cost without any corresponding benefit.

For technical reasons (having to do with maximization over an open set), we assume that the railroad can price to meet the competition and still retain the shipping contract. Formally, we invoke the efficient serving rule introduced by Lederer and Hurter (1987). This means that the commodity is shipped by the more efficient mode (in terms of actual transport cost) in the case of a quoted price tie. The rationale is that the more efficient mode could always profitably undercut the less efficient one.[19] The transportation price charged by the railroad is, therefore, equal to the cost of transportation via the rival mode, so that

$$p(y,x) = t\,|x| + by \text{ for } (y,x) \in \mathcal{R}. \tag{1}$$

This is understood as meeting the competition and still making the sale.[20] This price schedule has the property that the railroad's profit per unit shipped is greatest the further the location is distant from the river-canal, *ceteris paribus*, because there it is least constrained. To see this property formally, note that the railroad's profit per unit shipped is given by $p(y,x) - r\,|x| - ry$ for $(y,x) \in \mathcal{R}$, which is simply its price minus its shipping cost. Rewriting and using (1), this means that its profit per unit is $t\,|x| + by - r\,|x| - ry$ for $(y,x) \in \mathcal{R}$. For any given y, each extra mile further from the river (i.e., a rise in $|x|$) raises profit by $t - r > 0$.

[18] When we analyze capacity constraints, decisions at one point *do* affect profits elsewhere. Understanding the current case renders the later one manageable.

[19] There is a further technical issue in the case of rival oligopolistic railroads. We then also need that equilibrium play is in strictly non-dominated strategies – otherwise there may be multiple equilibria. Dealing carefully with the technical difficulties associated to the standard Bertrand homogenous goods pricing model with asymmetric goods allows us to pick the "natural" equilibrium: the market at any point is served by the lowest cost shipper, at a price equal to the serving cost of the second lowest cost shipper. This is "meeting the competition."

[20] The condition $t > r$ ensures the railroad has an advantage for locations far enough from the river. Arbitrage (by shipping by truck to iron out anomalies in spatial pricing by the railroad) will not be a concern for the railroad since shipping costs are constant per unit distance shipped for truck too.

The discussion above is summarized in the following Proposition, and the equilibrium prices and costs are illustrated in Figure 2 for a given ordinate, $\bar{y}$.

Proposition 1 *The equilibrium shipping mode is truck-barge for all* $(y, x) \in \mathcal{B}$*, which is the natural market for truck-barge, with corresponding price* $t\,|x| + by$*. The equilibrium shipping mode is by rail for all* $(y, x) \in \mathcal{R}$*, which is the natural market for rail, with price* $p(y, x) = t\,|x| + by$ *per unit shipped. The railroad's profit per unit rises linearly with distance from the river.*

The reference point in the literature on oligopolistic pricing with product differentiation is the analysis of Lederer and Hurter (1986). They consider two duopolists delivering their goods over space. These firms have the same transport technology. In equilibrium, the firm with the lower delivery cost at any point prices to just beat the delivery cost of its rival. This set-up effectively carries over to the current context of the pricing of transportation services for the dominant firm's equilibrium pricing behavior. With two different modes, it is natural that rail has a transport cost advantage for locations far from the river.

INSERT FIGURE 2

Corollary *The equilibrium allocation is efficient.*

This property follows because each mode serves its natural market and demand is totally inelastic at each point. In other words, there is no deadweight loss because all transportation is done by the cheapest mode. The price level *per se* is not a source of deadweight loss but rather has distributional consequences only.

This result is not confined to the case of only two modes, and is independent of whether there is market power or competition in a mode. The general property, whatever the mix of monopoly and competitive sectors,[21] is that each point will be served by the mode with the lower cost. Clearly this is the case already with competition, but it is also true for every monopolized mode. (The latter point is already recognized in the literature on spatial price discrimination: see MacLeod, Norman, and Thisse, 1987.) Thus the outcome is efficient regardless of market structure.

The equilibrium pricing does differ according to the structure of market power in the various transport industries. Any competitive industry will price at marginal cost: this cost will be the market price if it is the

[21] In this context, as with the classic Bertrand model, two firms suffices for a sector to be competitive. This result is sometimes termed the "Bertrand Paradox" (e.g., Tirole, 1988).

lowest at a particular point. If the lowest cost server at any point has market power, it will serve the market, and its price will be the "beat the competition" price of the next lowest cost supplier, be it a competitive industry or a monopoly one. Thus, in terms of Figure 2, if both industries were competitive, the equilibrium pricing schedule would be the (standard) lower envelope of the cost functions. If both exercise market power, the equilibrium pricing schedule would be the *upper* envelope of the cost functions. For our current application, the equilibrium pricing schedule follows the competitive (truck-barge) schedule throughout.

The strong welfare property is relaxed in some of the following extensions. In this model, a reduction in the barge rate causes a reduction in the equilibrium rail price too because the competition is stronger for the alternative option to rail.[22] Hence, a reduction yields a larger natural market for truck-barge, $\mathcal{B}$. The lower barge rate induces a transfer from the railroad to farmers.

We can now see what are the effects of a reservation price "cap" that limits the price that can be charged.[23] Such a price will simply act as a cap on the price charged in the market. Referring to Figure 2, think of a horizontal line at reservation price $\bar{p}$, across the top of the Figure. This represents the price cap, and is drawn in Figure 3.

INSERT FIGURE 3

Introducing such a cap then means that the mark-up on rail starts diminishing as soon as the truck-barge rate hits the cap. Thereafter, the binding constraint is the reservation price rather than the competing truck-barge industry rate. The mark-up for the rail shipper then decreases with distance away from the river[24] all the way to the point where it hits zero. At this point, the costs of railroad shipping reach the reservation price for using that mode. Thereafter, no shipments are profitable. If the reservation price represents a long-run value (as opposed to a transitory one, say waiting for an alternative shipping date with higher expected prices at the terminal market), then the land will not be farmed beyond this point.

[22] In a recent survey by one of the authors, *rail* shippers routinely commented on the need for an efficient waterway to temper and restrain railroad pricing. The survey is reported in Train and Wilson (2004): the results are consistent with other empirical work by MacDonald (1987, 1989) and Burton (1993).

[23] One (rather loose) interpretation is that this reservation price reflects the possibility that shippers may store the commodity if the price is currently too low.

[24] Indeed, if the reservation price is $\bar{p}$, the profit per unit is $\bar{p} - t\,|x| - by$, which decreases with $|x|$.

Proposition 2 *Let the reservation price be* $\bar{p}$*. The equilibrium shipping mode is truck-barge for all* $(y, x) \in \mathcal{B}$*, with corresponding price* $t|x| + by$*. The equilibrium shipping mode is by rail for all* $(y, x) \in \mathcal{R}$ *such that* $r|x| + ry \leq \bar{p}$ *with price* $p(y, x) = \min\{t|x| + by, \bar{p}\}$ *per unit shipped. The railroad's profit per unit rises linearly with distance from the river up to the point where* $t|x| + by = \bar{p}$ *and thereafter diminishes linearly.*

The strong efficiency property of the preceding set-up is retained here. The equilibrium allocation is efficient since demand still has no elasticity and it is, furthermore, efficient to serve up to the point where serving cost reaches the reservation price. The rail shipper does this because such shipments still generate profits. Following our earlier arguments, these efficiency results hold over to the case of multiple industries regardless of the competitive/monopoly mix. The qualification that has been introduced is that the equilibrium price when a monopolist is the lowest cost server is the minimum of the cost of the next lowest cost server and the reservation price. This property holds over to elastic demands, though there the monopoly pricing is distortionary. We develop this point below, but first we allow for different possible destinations for shipments.

3 Alternative markets

We assumed above that rail shipments have the same final destination as truck-barge shipments, namely the terminal market at the South end of the river. In practice though, railroads are not as constrained by geography as is river transport. The river can only deliver to locations along its banks and at its mouth (if we except costly trucking and in the absence of a canal system). The railroad tracks are typically part of a large network and so railroads can deliver output to any node on a large and expansive grid. This gives the railroad another advantage not enjoyed by the river users: the railroad has the choice of different possible terminal markets.

Suppose an alternative terminal market is available for the railroad (for example, a different port, such as the Pacific Northwest, or Baltimore). Assume for simplicity that the price received by the farmer is the same at either final market, so that the objective of the farmer at any (y, x) coordinate is still to choose the least cost transport mode.[25]

[25] Different prices at different terminal modes are readily added.

The same principles apply as above, namely that the railroad will meet the competition in its pricing. However, its natural market will be extended (and the other will contract) with the availability of the second option. Consider the situation illustrated in Figure 4, with a second terminal market, M, at $(\tilde{y}, \tilde{x})$ in the North-East quadrant.

INSERT FIGURE 4

The railroad will find it less costly to ship to M from points (y, x) such that[26]

$$rx + ry > r\,|x - \tilde{x}| + r\,|y - \tilde{y}|\,.$$

Assume, as in the Figure, that $x < \tilde{x}$ for all $(y, x) \in \Omega$. Then, for $y \geq \tilde{y}$, the port M is preferred for $x > [\tilde{x} - \tilde{y}]\,/2$. For $y < \tilde{y}$, the port M is preferred for $y > \frac{[\tilde{x}+\tilde{y}]}{2} - x$.

Suppose that the boundary between $\mathcal{B}$ and $\mathcal{R}$ (using the original definitions, i.e., before we allow for the existence of M) intersects the locus of indifference between M and O for rail shipping at a level below $\tilde{y}$, as illustrated in the Figure. The intersection is the intersection of the two lines $r\,(x + y) = tx + by$ with $y = \frac{[\tilde{x}+\tilde{y}]}{2} - x$, and so the relevant y value is given by $y = \frac{[\tilde{x}+\tilde{y}]}{2} - \frac{(r-b)}{(t-r)}y$, which simplifies to $y = \frac{(t-r)}{(t-b)}\frac{[\tilde{x}+\tilde{y}]}{2}$. The condition that this is below $\tilde{y}$ is then $[\tilde{x} + \tilde{y}] < \tilde{y}\frac{2(t-b)}{(t-r)}$ or $\tilde{x} < \tilde{y}\frac{t-2b+r}{(t-r)}$, so we assume this parameter condition holds.

Hence for $y \leq \frac{(t-r)}{(t-b)}\frac{[\tilde{x}+\tilde{y}]}{2}$, the equilibrium entails truck-barge shipping for $x \leq \frac{(r-b)}{(t-r)}y$, rail shipping to O for $x > \frac{(r-b)}{(t-r)}y$ and $x < \frac{[\tilde{x}+\tilde{y}]}{2} - y$, and rail shipping to M for $x > \frac{[\tilde{x}+\tilde{y}]}{2} - y$.

For $y \in \left(\frac{(t-r)}{(t-b)}\frac{[\tilde{x}+\tilde{y}]}{2}, \tilde{y}\right)$, the boundary between truck-barge and rail shipping to M is determined from the condition $tx + by = r\,[\tilde{x} - x + \tilde{y} - y]$, or $y = \frac{r[\tilde{x}+\tilde{y}]}{(b+r)} - x\frac{(t+r)}{(b+r)}$, so that truck-barge is preferred for lesser y values in this range. Note this critical locus is downward-sloping because shipping by rail to M becomes relatively more attractive for higher $y < \tilde{y}$.

Finally, for $y \geq \tilde{y}$, the boundary between truck-barge and rail shipping to M is determined from the condition $tx + by = r\,[\tilde{x} - x + y - \tilde{y}]$, or $y = \frac{r[\tilde{x}-\tilde{y}]}{(b+r)} + x\frac{(t+r)}{(r-b)}$, so that truck-barge is preferred for lesser y values in this range. This critical locus is upward sloping because the relative benefit of barge rises further North than $\tilde{y}$. Note that the equilibrium transport mode choice is the one with least social cost even

[26] With different prices at different terminal modes, the price advantage of M may be simply added to the RHS.

when there are multiple terminal markets. This property also extends to multiple modes and any mix of competition and monopoly modal industrial organization.

In the model so far, there are no total social surplus consequences to there being market power in the railroad sector. The effects are instead purely distributional. Comparing a monopoly railroad to a benchmark case of a railroad that prices at cost, market power shifts farmer surplus to railroad profit. Another facet of this property is illustrated by considering the effects of an improvement in the barge rate (a reduction in b). Such an improvement will broaden the area served by truck-barge (the truck-barge catchment area, $\mathcal{B}$), and welfare improvements may be measured by the reduced costs of shippers in $\mathcal{B}$. However, shippers outside also benefit from the improved barge rate, because it reduces the railroad price. Since this is purely a transfer from railroads to shippers, there are no implications for social surplus, other than the redistribution.

These results stem from the assumption that demand at each point in space is perfectly inelastic. Introducing demand elasticity in the amount shipped as a function of the price paid for shipping introduces direct welfare losses from supra-competitive pricing. We now turn to this complication.

4 Downward-sloping demand

We return now to the case of a single terminal market, so the railroad delivers to O only. Instead of a rectangular demand, as above, suppose now that each point generates a downward-sloping demand for transportation services.[27] It is worth spending a little time on the provenance of this demand. In particular, the shippers themselves (those who produce or farm the commodity that is being shipped) are assumed price takers in the transportation market and in the final downstream market. They do, though, decide how much to produce and ship. Accordingly, suppose that production of Q units of output is associated with a production cost of $C(Q)$ (assumed twice continuously differentiable, increasing, and convex) and, for simplicity, assume that this cost is independent of location. If the price paid per unit for the commodity at the terminal market is p_T and the price paid to transport one unit there is p, then the producer's profit is

$$\pi = [p_T - p]\, Q - C(Q)\,.$$

[27] These points could form a continuum (for example, if there are many farms over the landscape), or they could be isolated spots (like coal mines). Under some caveats, the isolated points could be grain elevators. Ideally though, one would like to model more finely the behavior of grain elevators, and to derive their behavior in shipping from a full-fledged model of their competition for farmers' produce in local markets.

The producer will then optimally choose Q to maximize this profit. The producer's problem is concave in Q. The solution is to product nothing if $C'(0) \geq [p_T - p]$. If this does not hold, the producer produces at the unique solution, Q^*, to $C'(Q^*) = [p_T - p]$. Equivalently,

$$Q^* = C'^{-1}(p_T - p).$$

This is then the demand for transportation services. Note that it is declining in p because a higher transportation price reduces revenue per unit and so elicits a lower supply response. The marginal cost curve, $C'(.)$, and the derivation of the transportation demand curve from it, are illustrated in Figure 5. By construction, the demand curve mirrors the properties of the marginal cost curve. As p changes, then the supply of the produced good changes according to the marginal cost schedule, and this supply is simultaneously the demand for transportation services. In the sequel, we refer to the demand for transportation services as $D(p)$ and we suppress the terminal price p_T, so that (for constant p_T) we can write $D(p) = C'^{-1}(p_T - p)$.

INSERT FIGURE 5

We impose some regularity properties on the demand curve, $D(p)$, where p is the price paid per unit for delivering the commodity to O (e.g., $p = tx + by$).[28] In particular, let $D(.)$ be strictly (-1)-concave, meaning that $1/D(p)$ is a strictly convex function, and let $D(.)$ be twice continuously differentiable. The differentiability property implies that the strict convexity of $1/D(p)$ is equivalent to $D"D - 2(D')^2 < 0$ almost everywhere. Recalling that $D'(.) < 0$ (demand slopes down), then this property is clearly satisfied by any concave demand. It also allows for demand to be convex, as long as it is not "too" convex. The class of log-concave functions is necessarily (-1)-concave: the property means that $\ln D(.)$ is concave, so that D'/D is decreasing.[29] This in turn implies that $D"D - (D')^2 \leq 0$, which implies that $D"D - 2(D')^2 < 0$. The concept of log-convexity is also employed below, and is defined analogously. That is, $\ln D(.)$ is convex, so that D'/D is increasing and so $D"D - (D')^2 \geq 0$.

[28] In the case of different prices at different terminal markets, we might subtract the terminal price (received by the producer) from these costs, in order to get a net cost.

[29] A log-concave function is concave, but the converse is not necessarily true. Intuitively, since ln is an increasing and concave operator, then applying it to a concave function also yields a concave function. As long as it is applied to a function no more convex than an exponential function, taking the logarithm also gives a concave function.

Further insight into these functions is given by noting that the function $D(p) = \exp(a - bp)$, with $b > 0$ is log-linear, and so forms a boundary case. Anything "more concave" than a negative exponential function is therefore log-concave. Any function "more convex" is log-convex. Likewise, the function $D(p) = b/p$, with $b > 0$ is (-1)-linear, so that any function "more concave" than this is (-1)-concave.

For what follows, we need some properties of the railroad's (unconstrained) profit function at each point in space, as well as its monopoly price. These properties are determined by considering the behavior of the railroad's price derivative. The profit earned from any point is $\pi = (p - c) D(p)$, where we let c denote the railroad's marginal cost from that point (and we temporarily drop the dependence of this marginal cost on the location under consideration). The desired profit derivative is then

$$\frac{d\pi}{dp} = (p - c) D'(p) + D(p),$$

which we can rewrite as

$$\frac{d\pi}{dp} = -D'(p)\left[-(p - c) - \frac{D(p)}{D'(p)}\right].$$

The profit derivative, therefore, has the sign of the term in square brackets. This may be graphed as a function of p as the difference between the two positive functions $(p - c)$ and $-\frac{D(p)}{D'(p)}$ as in Figure 6. The former has slope 1, so as long as the latter has slope less than 1, then there is a single intersection, and profit is rising left of the intersection (because the profit derivative is positive) and falling right of the intersection (because the profit derivative is negative). That is, the profit function is quasi-concave. The desired condition is therefore that the derivative of $\frac{D(p)}{D'(p)}$ be greater than -1: writing this out shows it to be satisfied if $D(p)$ is strictly (-1)-concave, which we have assumed.

INSERT FIGURE 6

We are also interested in how the monopoly price changes as a function of the serving cost, c. In the present spatial context, following Stigler (1949), we shall say there is *freight absorption* if the price rises by less than does the serving cost. Conversely, if the price rises faster, there is *phantom freight.*[30]

[30] These properties apply too to transportation improvements in the railroad sector. That is, in the case of freight absorption, a change that reduces the cost by a dollar (to the railroad) of serving a location is passed on by less than 100% to the shipper. The benefits are shared in that sense. In Public Finance, these are essentially incidence questions, and the analysis is applied to

The monopoly price is given implicitly by the solution, p^m, to the first-order condition,

$$(p-c)\,D'(p)+D(p)=0,$$

as described above. Applying the implicit function theorem gives the rate at which cost increases are passed on as

$$\frac{dp^m}{dc}=\frac{D'(p)}{(p-c)\,D"(p)+2D'(p)}.$$

The denominator is negative by the second order condition for a maximum, and the numerator is negative, so that (clearly) the monopoly price rises with cost. Further insight is provided by substituting the first-order condition into this expression, to give

$$\frac{dp^m}{dc}=\frac{[D'(p)]^2}{-D(p)\,D"(p)+2\,[D'(p)]^2}. \tag{2}$$

The denominator is positive by the condition that $D(.)$ be strictly (-1)-concave.

We are interested in whether the monopoly price rises more or less quickly than costs. That is, whether $\frac{dp^m}{dc}$ is greater or less than one. Since the denominator of (2) is positive, it is a simple matter to cross-multiply and check this condition: i.e., $\frac{dp^m}{dc}\lesseqgtr 1$ as $[D'(p)]^2\lesseqgtr -D(p)\,D"(p)+2\,[D'(p)]^2$. This readily simplifies to $0\lesseqgtr -D(p)\,D"(p)+[D'(p)]^2$. It is worth breaking out the possibilities one at a time.

Proposition 3 *If $D(.)$ is strictly log-concave, then $\frac{dp^m}{dc}<1$ and there is freight absorption.*

This means that the monopoly price rises more slowly than the cost rises. All concave demands thus exhibit freight absorption. In the special case of linear demand, it is readily verified that costs are passed on 50 cents on the dollar. The freight absorption property holds for even some convex demands (but not "too convex").

Proposition 4 *The monopoly price satisfies $\frac{dp^m}{dc}=1$ if and only if demand, $D(.)$, is log-linear.*

A log-linear demand is, therefore, the demand function for which costs are passed on dollar for dollar.[31] The intuition is that the marginal revenue curve is parallel to the demand curve for this demand function.

who "bears" a tax (see Anderson, de Palma, and Kreider, 2001). A tax is analogous to a cost increase, and a subsidy to a cost decrease. Notice that in the case of phantom freight, a reduction in the cost to the railroad of $1 in serving a given location will lead to the price charged to shippers going down by more than $1. In that sense, the shippers could be said to benefit directly by even more than the magnitude of any transport reduction. Even stronger, insofar as shippers are induced to ship more when prices go down, their benefits would be even greater still due to additional shipper surplus.

[31] See also Anderson (1986).

Proposition 5 *If $D(.)$ is strictly log-convex, then $\frac{dp^m}{dc} > 1$, and there is phantom freight.*

For this class of demand functions, the marginal revenue function is actually flatter than the demand curve. This property implies that a cost increase raises marginal revenue by the amount of the increase, but the consequent price increase is smaller.

The three Propositions above underscore the key properties in describing the behavior of the railroad's price when unconstrained by the truck-barge rate. Otherwise, the same principles apply as above, but with now the monopoly rail price forming a cap. Therefore, consider the behavior of the equilibrium shipping price at a given y, as a function of x. The truck-barge cost curve at any given y rises with x at rate t from a (low) base level of by at $x = 0$. The rail rate starts out higher but rises more slowly. The intersection is the boundary between the natural areas, as in Figure 2 above. Furthermore, the "conditional monopoly price" (i.e., if the railroad was an unconstrained monopolist) is $p^m(y, x) = \arg\max[p - (rx + ry)]D(p)$, where the term $(rx + ry)$ is the marginal cost, denoted c previously.

Proposition 6 *For a downward sloping and (-1)-concave point demand function, $D(p)$, the railroad serves all points in its natural market area and the equilibrium rail price per unit is given by $p(y, x) = \min\{(tx + by), p^m(y, x)\}$ for $(y, x) \in \mathcal{R}$.*

Recall that (-1)-concavity covers most demand functions typically used in economics. It just rules out those that are "very" convex – including those that kink outward.[32] The typical situation is illustrated in Figure 7.

INSERT FIGURE 7

For linear demand, as illustrated, the monopoly price increases at half the rate that costs increase. Close by the river, truck-barge is the equilibrium modal choice. Further out, the choice is rail, but the rail price is constrained by the truck-barge cost. Thereafter, the unconstrained monopoly price is charged, given that this is below the truck-barge rate (that is, for locations such that $p^m(y, x) \leq (tx + by)$). The

[32] Outward demand kinks can imply that the point profit function is not quasi-concave. This can mean that the optimal price choice (if another mode is cheaper than the monopoly price) may be in turn *below* the cost of the cheaper alternative mode. (Loosely, there may be multiple local monopoly prices.)

market is no longer served beyond the point at which the rail cost exceeds the demand curve intercept, that is, where $D(rx + ry) = 0$.[33] The basic point of the Proposition carries over to multiple modes with mixed (competitive/monopoly) market structure. The market delineation (which mode serves which market) remains efficient, but market power in a controlling mode (defined as a mode with lowest serving cost) will entail the equilibrium price being the lower of that mode's monopoly price or the serving cost of the next cheapest serving mode. As expanded upon below, such market power will also lead to deadweight loss.

The case illustrated in Figure 7 is important for hidden welfare gains from barge cost reductions. In particular, there is the direct benefit from the cost reduction in the natural truck-barge market. Then, however, there is the induced reduction in the rail rate over the next interval. Part of the latter benefit accrues as a transfer from railroads, but with downward sloping demand, there is also a reduction in deadweight loss. The same observation applies to the other cases considered in this section.

Proposition 7 *For a downward sloping point demand function, $D(p)$, the equilibrium rail price per unit causes deadweight loss for $(y, x) \in \mathcal{R}$. A reduction in the barge cost generates additional surplus in the natural market for truck-barge exceeding the cost reduction applied to the existing volume of shipping: it generates additional surplus in expanding the natural market, and it generates additional surplus in reducing the rail price in the natural rail market.*

Figure 8 illustrates the analogous case for costs and prices when truck-barge and rail shipping go to different terminal transshipment points. In this case, the railroad's price actually rises further away from the river even though its cost of serving the market are falling. This is the case of the cost of meeting the competition and the cost of serving the market going in different directions.

INSERT FIGURE 8

The case when the railroad can choose whether to ship to O or to M is illustrated in Figure 9. In this case, the railroad's cost first rises with x while shipping to O is cheaper, and then falls with x.

[33] This treatment abstracts from non-price features that may affect choices, such as time of transit and reliability. In accord with a long history in transportation research, and as noted by Train and Wilson (2004), these factors may be extremely important in demand decisions. In the present case, such complications may be allowed for by redefining rates to include non-price factors along with the monetary price.

INSERT FIGURE 9

The next section addresses the possibility that there is also a demand for using the transport capacity in the reverse direction.

5 Backhauling

It has been assumed so far that there is no profit to hauling freight on the trip back on the way to picking up another cargo to go to the final market. In this section, we extend the analysis to consider demand for trips in the reverse direction too. We frame the model in the classic fronthaul and backhaul context (e.g., Mohring, 1976), and so we make the heroic assumption that the backhaul terminates at the same point in space as the origin of the fronthaul.[34] This is well known in economic theory as a joint production problem, much as the textbook mutton and wool joint production in raising a sheep. Analogously, once an outbound trip to the final market is created (fronthaul), then a return trip is also created (backhaul). We shall retain the truck-barge vs. rail nomenclature, but the analysis might also be framed in terms of (competitive) car or bus trips vs. a monopoly passenger railway service: see Rietveld and Roson (2002) for a recent application in this vein. Many commuters might wish to make the trip to the Central Business District in the morning rush-hour commute, but few people want to go in the reverse direction soon afterwards.[35]

The economic theory of pricing for competitive markets with backhaul is well understood. Suppose, as above, that the round trip from (y, x) by truck-barge costs $p = t\,|x| + by$, and that the demand for such trips is given by a well-behaved downward-sloping demand, $D\,(p)$. Suppose too that the demand for trips from the final market back to (y, x) is $D_b\,(p)$. Denote the inverses of these demand curves as $P\,(Q)$ and $P_b\,(Q)$ respectively. For simplicity we assume that the incremental cost when carrying cargo for the trip back is zero. The relevant demand price for round trips is, therefore, the sum of the demand prices for the outbound and

[34] More reasonably, demands at one point could be served by backhauls originating somewhere else, so that dependencies over space may occur. In such cases, we are ill justified in treating each point in space as independent of each other one. When demand points in space are isolated and distant from each other, then the assumption can be tenable. Likewise, when backhaul demands are weak, the competitive solution has a zero price for backhauls, and the monopoly one has the revenue maximizing price, so spatial interdependence is side-stepped. A full treatment remains a subject for future research.

[35] Of course, in the evening, the “backhaul” is stronger than the “fronthaul” in the sense that relatively empty trains com into the city and full ones go back out. For the present purposes we shall identify the stronger demand as the "fronthaul" even if it happens after the weaker demand (backhaul).

inbound trips, censored to be non-negative (because the transporter can always come back empty). That is, if Q is quantity, the demand price for the round trip is $P(Q) + P_b(Q)$ (where it is understood the demand prices are non-negative) and this sum is equal to p in equilibrium. Denote the solution as $\hat{Q}$: transport prices for each leg are then $P\left(\hat{Q}\right)$ and $P_b\left(\hat{Q}\right)$. Clearly, if the backhaul demand is weak then $P_b\left(\hat{Q}\right)$ can very well be zero. Some cargo can be carried, but backhaul demand is not contributing anything to reducing the price on the fronthaul, and effectively $\hat{Q}_b < \hat{Q}$ where $\hat{Q}_b$ is the amount transported on the backhaul.

It is now simple enough to see how to introduce incremental costs for backhaul: they can be netted off the demand price for the backhaul. The same principle applies in what follows: it suffices to net the incremental costs off the demand price.[36]

For a monopolist, say the railroad where it has a large cost advantage and is unconstrained, the appropriate principle for determining the quantity to carry (and the corresponding prices) is that the sum of the marginal revenues equal the marginal cost. Here again, the monopolist is not obligated to carry as much back as it carries out, and so we truncate the marginal revenues at zero. Then the solution for the fronthaul quantity, Q^*, is given as the solution to $\max\{MR(Q), 0\} + \max\{MR_b(Q), 0\} = r|x| + ry$, where $MR(.)$ denotes the marginal revenue to the outbound demand curve (and $MR_b(Q)$ for the backhaul demand). In this case, with a weak backhaul demand the price charged will not be zero but rather the revenue maximizing point on the (net) backhaul demand curve. This "zero-cost monopoly price" (which is equivalently the revenue maximizing price) will prevail when some backhauls carry no cargo. Equivalently, any solution with $Q_b^* < Q^*$ involves $Q_b^* = MR_b^{-1}(0)$. For any solution to the monopoly problem, the prices on the two legs are given from the inverse demand curves as $P(Q^*)$ and $P_b(Q_b^*)$. This will be the relevant solution when the sum $P(Q^*) + P_b(Q_b^*)$ is no higher than the competitive truck-barge price, $t|x| + by$.

Now consider the economics of the constrained monopolist's (i.e., dominant firm's) pricing solution. The issue here is how to determine the railroad's price when its costs are lower than the truck-barge sector, but the latter's costs are below the unconstrained monopoly price (i.e., $P(Q^*) + P_b(Q_b^*) > t|x| + by$). The equilibrium pricing structure is found by recognizing that the relevant constraint is the price of the *round-trip* by the competitive sector, i.e., $t|x| + by$. Although the dominant firm's price components can differ

[36] Wilson (1987) and (1994) uses a similar set-up for analyzing fronthaul and backhaul decisions. In his model, there is a round trip capacity cost and then firms decide whether to provide service on the basis of prices and access costs. This framework is used to model the distortions of entry regulation by the Interstate Commerce Commission.

individually from those set by the competitive sector ($P\left(\hat{Q}\right)$ and $P_b\left(\hat{Q}\right)$ above), the sum cannot be greater or else a competitive supplier can offer a joint deal that would undercut it. Conversely, though, the dominant firm can charge a higher price on one leg if its price on the other is lower, so that a competitive transporter undercutting the price on one leg will not be able to recoup its full costs because the price it has to beat on the other leg is too low. In this case the competitive supplier would refuse to ship on one leg knowing its loss on the other would exceed any profit. Thus the dominant firm's problem is:

$$\max_{\{Q,Q_b\}} P(Q)\,Q + P_b(Q_b)\,Q_b - [r|x| + ry]\max\{Q, Q_b\} \quad \text{subject to } t|x| + by \geq P(Q) + P_b(Q_b).$$

When the dominant firm is unconstrained (so the qualification is not binding and it acts as a monopolist), the solution is as given above. With a binding constraint from the competitive sector, and assuming that fronthaul is dominant, the constrained monopoly solution involves either $\tilde{Q} = \tilde{Q}_b$ or $\tilde{Q} > \tilde{Q}_b$. We now compare this solution to the competitive one. For transparency, the analysis will be framed in terms of marginal deviations (i.e., local profitability), and the requisite concavity will be assumed.

Suppose first that under competition we have $\hat{Q} = \hat{Q}_b$, so the backhaul does contribute a positive price. Then we cannot have an outcome with the dominant firm choosing $\tilde{Q} = \tilde{Q}_b$ different from $\hat{Q}$. First, $\tilde{Q}$ cannot be lower because the constraint would be violated (both prices would have to be higher). Second, $\tilde{Q}$ cannot be higher because then the constraint would not be binding (i.e., $P\left(\tilde{Q}\right) + P_b\left(\tilde{Q}_b\right)$ would be strictly less than $t|x| + by$) and the unconstrained monopoly solution would hold. Hence, in this case, since the sum of the prices is equal to the competitive price and since the quantity is the same, both prices are the same as in the competitive case.

If $\tilde{Q} > \tilde{Q}_b$, then these quantities must bracket the competitive quantity or else the constraint will be violated, so $\tilde{Q} > \hat{Q} = \hat{Q}_b > \tilde{Q}_b$. This means the fronthaul price must be lower and the backhaul price higher. The condition for this to happen is that profits rise by moving quantities apart from a situation of setting $\hat{Q} = \hat{Q}_b$. First, the competitive pricing constraint implies that quantity changes must satisfy $P'(Q)\,dQ + P_b'(Q_b)\,dQ_b = 0$. Second, in order to wish to move further apart, it must be that $[MR(Q) - [r|x| + ry]]\,dQ +$

$MR_b\left(Q_b\right)dQ_b > 0$. Putting these together yields the condition

$$\frac{\left[MR\left(\hat{Q}\right) - [r\left|x\right| + ry]\right]}{\left[-P'\left(\hat{Q}\right)\right]} - \frac{MR_b\left(\hat{Q}\right)}{\left[-P_b'\left(\hat{Q}\right)\right]} > 0$$

in order for the splitting case $\tilde{Q} > \hat{Q} = \hat{Q}_b > \tilde{Q}_b$ to arise. If both $MR\left(\hat{Q}\right) - [r\left|x\right| + ry]$ and $MR_b\left(\hat{Q}\right)$ were positive, the dominant firm would wish to go ahead and increase both quantities anyway, so that the competitive pricing constraint would not bind. Second, if $MR\left(\hat{Q}\right) - [r\left|x\right| + ry]$ were negative, and $MR_b\left(\hat{Q}\right)$ were positive, the condition cannot hold (since the denominators are positive). Therefore, for this situation to arise, we must have $MR_b\left(\hat{Q}\right) < 0$ (as is consistent with the fronthaul being dominant). For interpretation of the condition, note that if the demand slopes were locally the same, the dominant firm would want to move the quantities apart from the competitive solution if the marginal revenue difference exceeds marginal cost. This difference is germane because the fronthaul quantity is to rise while the backhaul one is to fall.

The solution in the case above is given by

$$\frac{\left[MR\left(\tilde{Q}\right) - [r\left|x\right| + ry]\right]}{\left[-P'\left(\tilde{Q}\right)\right]} = \frac{MR_b\left(\tilde{Q}_b\right)}{\left[-P_b'\left(\tilde{Q}_b\right)\right]}.$$

This means the weighted net marginal revenues are equalized, where it is recognized that the expansion of $\hat{Q}$ entails a fronthaul trip cost, and where the weights reflect the contribution to relaxing the competitive pricing constraints.[37]

To illustrate, suppose that (inverse) demands for fronthaul and backhaul are linear, with the same slope, and the fronthaul one dominates in the sense of a higher price intercept. Then both demands and marginal revenues for the two are vertically parallel, with the fronthaul one larger. Let the (inverse) demands be $P = \alpha_f - \beta Q$ and $P = \alpha_b - \beta Q$ for the backhaul. Call c_c the competitive cost per round trip, and c_m the dominant firm one. The competitive output with both prices positive is such that $\alpha_f + \alpha_b - 2\beta\hat{Q} = c_c$ or $\hat{Q} = \frac{\alpha_f + \alpha_b - c_c}{2\beta}$, which is below the quantity intercept on the backhaul demand, α_b/β, as long as $\alpha_f - \alpha_b - c_c < 0$, which we therefore assume for this example.

We now determine when the constrained monopolist would choose the same output. Using the logic in the text above, such a dominant firm would neither like to increase both outputs, nor increase one and drop

[37] When the demand slopes are locally the same, the net marginal revenues are equalized.

the other. Increasing both would return a net marginal profit of $MR_f\left(\hat{Q}\right) + MR_b\left(\hat{Q}\right) - c_m$, which we therefore assume to be negative, i.e., $\alpha_f + \alpha_b - 4\beta\hat{Q} - c_m < 0$: inserting the value of $\hat{Q} = \frac{\alpha_f+\alpha_b-c_c}{2\beta}$ gives the condition as $2c_c - c_m < \alpha_f + \alpha_b$. Increasing the fronthaul and decreasing the backhaul quantities would return $MR_f\left(\hat{Q}\right) - MR_b\left(\hat{Q}\right) - c_m$ (since the demand slopes are the same, this would keep the total trip price the same). For this strategy to be undesirable, then $\alpha_f - \alpha_b - c_m < 0$. This condition implies the first one above (given that $c_m < c_c$), so that this case arises if $\alpha_f - \alpha_b < c_m$ and $2c_c - c_m < \alpha_f + \alpha_b$.

Now suppose that $\hat{Q} > \hat{Q}_b$ under competition so the backhaul price is zero. If the constrained monopolist does not want to finance reductions in the backhaul quantity with increases in the fronthaul quantity (in terms of relaxing the pricing constraint), the dominant firm will choose the same pair $\hat{Q}$ and $\hat{Q}_b$ (recall that we implicitly assume that $\left[MR\left(\tilde{Q}\right) - [r|x| + ry]\right] < 0$ or else the dominant firm would not be locally constrained). The condition for retaining a zero price on the backhaul is thus

$$\frac{\left[MR\left(\hat{Q}\right) - [r|x| + ry]\right]}{\left[-P'\left(\hat{Q}\right)\right]} - \frac{MR_b\left(\hat{Q}_b\right)}{\left[-P_b'\left(\hat{Q}_b\right)\right]} < 0,$$

where $MR_b\left(\hat{Q}_b\right)$ and $P_b'\left(\hat{Q}_b\right)$ are understood to be the left derivatives of total revenue and demand (the right derivatives being zero since $P_b\left(\hat{Q}_b\right) = 0$).

In terms of the linear example above, this last condition is

$$\alpha_f - 2\beta\hat{Q} - c_m - \alpha_b + 2\beta\hat{Q}_b < 0,$$

but since $\beta\hat{Q}_b = \alpha_b$ and $\hat{Q} = [\alpha_f - c_c]/\beta$, this reduces to:[38]

$$2c_c - c_m < \alpha_f - \alpha_b.$$

If this condition holds (of relatively weak backhaul demand), the dominant firm retains a zero price on backhauls. Otherwise, it drops the fronthaul price and raises the backhaul one. This means dominant firm

[38] This must hold along with the other conditions for being in this case, namely that $\alpha_f - \alpha_b - c_c > 0$, which is needed for a zero competitive backhaul, but the condition given (along with $c_m < c_c$) implies this. (Note that the condition that the monopolist does not want to raise output in the fronthaul market alone is $MR\left(\hat{Q}\right) < c_m$, or $\alpha_f - 2\beta\hat{Q} < c_m$: the latter condition is then $\alpha_f - 2\left[\alpha_f - c_c\right] < c_m$, which is implied by the condition of not wanting to shift, as anticipated.)

is likely to have more even pricing across legs than competition. It is likely to have a greater spread in quantities though.

We summarize as follows:

Proposition 8 *With the possibility of backhaul to the fronthaul origination points, competition prevails as the equilibrium wherever truck-barge has the cost advantage, and the market outputs and prices are determined from the sum of demands for fronthauls and backhauls. Otherwise, as long as demand prices cover costs, the dominant firm is the equilibrium market provider. In an unconstrained monopoly, the outputs and prices are determined from the sum of (negative-censored) marginal revenues for fronthauls and backhauls. For locations where the monopoly hauls back less than it hauls out, it charges the revenue-maximizing price on the backhauls. A constrained monopoly dominant firm will choose the same total trip price as the competitive alternative, but may choose a lower outbound price to get more revenue from the backhaul: if it sets the same quantity, it sets the same prices.*

The next section reverts to absence of backhaul demand and addresses the possibility that there is a limited capacity in the mode with market power.

6 Capacity constraints for the dominant firm

The analysis above has supposed that the capacity of the railroad is unlimited. However, the rolling stock is limited, and it takes time to make deliveries. Not all profitable contracts may be taken in view of these limitations. We now address this issue, and with it some more general pointers for a full (long-run) analysis including the costs of increasing railroad capacity. We suppose throughout that there is no capacity constraint for barges or barge pricing.[39]

Consider the original case where points in space generate unit demand. For simplicity, and to fix ideas, we start by considering a given y ordinate. Suppose too that rail shipping at that y level is constrained, and less than the natural market for rail would prescribe. The railroad would then choose to serve all the locations farthest away, up to capacity, since these give the highest profit. Then a reduction in the truck-barge cost

[39] Capacity constraints in the barge market are analyzed in Anderson and Wilson (2004).

would give the same type of transfers that we saw above, as well as directly reducing the barge shipping costs.

The sketch in the preceding paragraph takes the number of trips *per se* as a constraint. The more relevant concept would be to take the number of miles that can be traveled as representing the capacity constraint. This constraint makes sense when the railroad capacity is construed as a fixed total amount of time available (for example, train-hours per month). We now analyze such a constraint, namely that the number train hours is fixed exogenously by the capacity of the rail sector.

The economic principle involves considering the opportunity cost of a trip at various distances from the river. Clearly, with a tight capacity constraint the railroad does not want the trips right near the "competitive boundary" but those are also the ones that can be "turned around" quicker (i.e., the rolling stock can get back faster to pick up more cargo). A trip taking half the time as another needs to take in less than half the markup in order to not supplant the other one. The proper criterion for the current context is to choose the trips with the highest mark-up per mile. The main question then boils down to whether those further out deliver better mark-ups per mile. The mark-up earned at any point is $(tx + by) - (rx + ry)$, and hence, dividing by the distance traversed, $(x + y)$, gives the mark-up per mile as

$$m(y, x) = \frac{(tx + by) - (rx + ry)}{(x + y)}.$$

Differentiating shows how this mark-up changes with distance from the river, x:

$$\begin{aligned} \frac{dm}{dx} &\overset{s}{=} (t - r)(x + y) - [(tx + by) - (rx + ry)] \\ &= (t - b)y > 0, \end{aligned}$$

where the notation $\overset{s}{=}$ denotes the sign of the expression. Thus, the mark-up per mile is higher further out, so that these are the locations that are served by the railroad, up to its capacity. This allocation also forms the optimal pattern from a social perspective. The intuition is that the hinterlands are further from the river and so less constrained by potential competition. They then generate higher mark-ups per ton-mile shipped.

We now consider the full two-dimensional picture. We have first to specify the nature of the capacity constraints more carefully. In particular, suppose that there is a fixed number of ton-miles that can be shipped in a given period, and that the demand from each location is still fixed. The criterion for a location to be served is that it yield higher mark-up per mile than any location left unserved by the railroad, given that the railroad must meet the going truck-barge rate at any location. As above, the mark-up per mile is $[(tx + by) - (rx + ry)]/(x + y)$. We have shown that this rises with x. It varies with y according to:

$$\frac{dm}{dy} \stackrel{s}{=} (b - r)(x + y) - [(tx + by) - (rx + ry)]$$
$$= \quad (b - t)x < 0.$$

This indicates that the mark-up per mile is higher lower down. Pulling this together, there is a big "fixed" cost disadvantage to rail up-river; and more advantage further out (the "fixed" cost disadvantage from is then offset by the advantage over trucking). This means that the set of locations served will look like the natural market space for rail illustrated in Figure 1, except further out.

Another way to see this is to determine a locus of constant mark-up per unit. For a level of mark-up, k, this means that

$$\frac{(tx + by) - (rx + ry)}{(x + y)} = k$$

or $[(tx + by) - (rx + ry)] = k(x + y)$. Rearranging, $x(t - r - k) = y(-b + r + k)$, or

$$y = \frac{t - r - k}{-b + r + k}x$$

These are rays emanating from the origin. The higher is k, the lower the y value for given x. This observation suggests an algorithm that may be useful in the more complex cases. Since the relation is monotonic, take a value for k and find the ray of constant mark-up per unit. Then see if capacity is met. If not, reduce k, so that the y value rises at each x. This implies that the catchment area rises and capacity is closer to being met. Continue until capacity is met: clearly the process is stable and unique.[40]

Proposition 9 *Let demand at each point in space be totally inelastic, and suppose that the railroad is capacity constrained. Then, for each location (y, x), the equilibrium shipping mode is rail if $y \geq \frac{t-r-k}{-b+r+k}x$, where k is determined from the capacity constraint that all points served by rail completely exhaust the*

[40] In the current case, the problem can be solved directly algebraically given any specification for Ω.

railroad's capacity. The equilibrium rail price at such points is $p(y,x) = tx + by$, and the allocation of the given capacity is socially efficient.

The principles above are readily extended to other variants of the problem, involving relaxing some of the assumptions made. First of all, consider endogenous capacity choice by the railroad. What this does, in effect, do is to determine the appropriate level of k in the above analysis. Indeed, suppose that a unit of extra capacity has an amortized purchase cost of $\$Z$ per year and enables W unit-miles to be shipped in the year. This translates into a cost of $\$Z/W$ per unit per mile: when capacity is optimally chosen, this is therefore the equilibrium value of k. It is interesting that it is also the optimal value. It is also noteworthy that equating Z/W to the marginal benefit is the marginal condition for a maximum in profits and that infra-marginal locations generate positive profits. That is, the railroad earns positive profits.

If demand is no longer fixed, and is downward-sloping, as in Section 4, the appropriate principle that determines the allocation of a fixed capacity is that marginal profit be equalized at all locations served, where marginal profit is the marginal revenue minus the per unit variable transport cost. This principle applies for all locations that are unconstrained by the truck-barge rate. Locations where the railroad is constrained by the truck-barge rate (thus implying a constant marginal profit) will be served as long as the marginal profit is at least as large as that earned elsewhere. Hence shipping costs across locations vary according to whether or not the railroad is constrained or not, as well as by the distance shipped. When capacity is endogenous, the price of capacity determines the relevant level of marginal profit that is to be equalized across locations served.

7 Conclusions

Transportation is fundamental to the development of the economic landscape, from the arrangement of hierarchies of cities to the structure of individual cities to agricultural land usage. The pricing of transportation services will affect the full economic geography of the country. In practice, some transport sectors have considerable market clout, but are nonetheless restrained by competitive pressure from other modes – and this competitive pressure varies over space too by proximity. Distortions in pricing impede developments at some places and erroneously encourage them at others, and so distort geographical economic development. These considerations point to the need for clean and simple models of market power in transportation wherein market power varies over space.

We elaborate upon such a theory of pricing of transport services by drawing on the economics of spatial price discrimination and introducing a dominant firm facing a competitive fringe. The degree to which market power can be exercised depends on distance from competing modes, and so varies over space in a natural manner. One important benchmark case of the model is when demand for transportation services is perfectly inelastic over space. Market power in transportation has then no allocative inefficiency but only the distributive effect of transferring resources away from shippers and to the dominant firm. The fact that the dominant firm can appropriate all the surplus it creates means that it will then make socially efficient decisions in the choice of such matters as capacity choice. In this context the regulatory role for Governments is then quite simply redistributive, to tax away benefits from monopolists. When we allow for elasticity in the demand for transportation, the market power leads to deadweight loss, and typically more so the more distant is the competitive disciplining force. Regulation or intervention has a substantially larger role to play in such contexts, as we elaborate below.

The analysis points to benefits from transport improvements that might be hidden at first inspection. For example, the U.S. Army Corps of Engineers (ACE) has recently been interested in evaluating the benefits from improving the locks on the rivers in the US. One might typically first think of adding up the cost reductions for those customers who use the river system. Yet this procedure might seriously underestimate the total benefits. Some benefits might accrue to railroad users as prices fall to beat tougher competition. With perfectly inelastic demand, these consumer benefits would be purely a transfer from the monopoly sector (railroad) to shippers. However, when there is elasticity in the demand for transportation, the gains from tougher competition include extra efficiency gains as deadweight loss is reduced. These efficiency gains might be manifested in extra output in the original economic activity, but they might also engender changes in the economic use of land, especially over the longer term, even outside the sphere of existing barge transportation.

Our analysis is also pertinent to passenger transportation under the appropriate caveats and restrictions. The competitive sector might represent car, and the dominant firm could be the railway (assumed throughout to be acting to maximize profits: other objectives, such as socially optimal pricing remain for extensions).

Although the catchment areas for the different modes would look different from those in the Figures, the economic principles of the dominant firm analysis remain. The analysis of backhaul pricing is also relevant to the problem insofar as passenger transit involves sending back trains at off-peak hours in the reverse direction.

In the larger context of regional development and the New Economic Geography of agglomeration externalities in the formation of centers of activity, lower transport costs (from reducing market power or from competition from more efficient alternatives) might significantly effect the structure of centers in terms of both size and nature of activities. If indeed there are substantial economies in agglomeration, formation of centers might be fostered by low transport costs that start the ball rolling. It is an open question to what extent a transport sector with market power can internalize the externalities through its transportation pricing (and so encourage the formation of centers). Insofar as a monopolist is constrained in its ability to write long-term contracts guaranteeing low prices - perhaps with agents who have not yet appeared on the economic scene! - this would appear to be a formidable problem: an industrial firm that sets up might be subject to a hold-up problem after incurring set up costs. This remains an issue for future research.

The model indicates that the economic landscape will be most affected by the exercise of market power in remote sectors. This in turn could reinforce an underdevelopment spiral: regions that are not well served by transportation services will not develop adequately, which means they will not attract sufficient transport services because their demand for transportation is too weak. The externalities involved here can be readily sketched in terms of the market power model developed in the paper. Fleshing out the details of this approach would indicate the appropriate regulatory or direct intervention for regional development.

References

[1] Anderson, Simon P. [1989] Socially Optimal Spatial Pricing. *Regional Science and Urban Economics*, 19, 60-86.

[2] Anderson, Simon P., Andre de Palma and Brent Kreider [2001] Tax Incidence In Differentiated Products Oligopoly, *Journal of Public Economics*, (2001), 81(2), 173-192.

[3] Anderson, Simon P., Andre de Palma and Jacques-François Thisse [1992] *Discrete Choice Theory of Product Differentiation*. MIT Press..

[4] Anderson, Simon P. and Régis Renault [2003] Efficiency and Surplus Bounds in Cournot Competition, *Journal of Economic Theory*, 113(2), 253-264.

[5] Anderson, Simon P. and Wesley W. Wilson [2004] Spatial Modeling in Transportation: Congestion and Modal Choice. Mimeo, University of Oregon.

[6] Baumol, William, John C. Panzar, and Robert D. Willig [1982] *Contestable Markets and the Theory of Industry Structure.* New York: Harcourt Brace.

[7] Bitzan, John, and Wesley W. Wilson [2008], Industry Costs and Consolidation: Efficiency Gains and Mergers in the Railroad Industry. Mimeo, University of Oregon.

[8] Burton, Mark L. [1993] Railroad Deregulation, Carrier Behavior, and Shipper Response: A Disaggregated Analysis. *Journal of Regulatory Economics,* 5, 417-34.

[9] Carriquiry, Miguel A. and Bruce A. Babcock [2005] The Impact of Transportation Costs on Spatial Competition of Buyers: An Iowa Case Study. *Journal of the Transportation Research Forum*, 44(2),

[10] Ellet, Charles [1839] An Essay on the Laws of Trade in Reference to the Works of Internal Improvement in the United States. Richmond, VA: P. D. Bernard. Augustus Kelley, reprint, 1966.

[11] Forchheimer, Karl [1908] Theoretisches zum unvollstandigen Monopol. *Schmollers Jahrbuch*, 1-12.

[12] Gersovitz, Mark [1989] Transportation, State Marketing, and the Taxation of the Agricultural Hinterland. *Journal of Political Economy*, 97(5), 1113-1137.

[13] Hoover, E. M., [1937] Spatial Price Discrimination. *Review of Economic Studies*, 4, 182-191.

[14] Lederer, Phillip J. and A. P. Hurter [1986] Competition of Firms: Discriminatory Pricing and Location. *Econometrica*, 54, 623-640. Reprinted in *The Economics of Location*, M. Greenhut and G. Norman, eds., Edward Elgar Publishing Company, 1993.

[15] Lederer, Phillip and A. P. Hurter [1985] Spatial Duopoly with Discriminatory Pricing. *Regional Science and Urban Economics*, 15, 541-553.

[16] MacLeod, W. Bentley, George Norman, and Jacques-François Thisse [1987] Price discrimination and equilibrium in monopolistic competition. *International Journal of Industrial Organization*, 6(4), 429-446.

[17] McDonald, James M. [1987].Competition and Rail Rates for the Shipment of Corn, Soybeans, and Wheat. *RAND Journal of Economics,* 18, 151-163.

[18] McDonald, James M. [1989] Railroad Deregulation, Innovation, and Competition: Effects of the Staggers Act on Grain Transportation. *Journal of Law and Economics,* 32, 63-96.

[19] Mohring, Herbert [1976] *Transportation Economics*. Cambridge, MA, Ballinger.

[20] Phlips, Louis [1983] *The Economics of Price Discrimination.* Cambridge University Press.

[21] Rietveld, Piet, and Roberto Roson [2002] Direction dependent prices in public transport: A good idea? The back haul pricing problem for a monopolistic transport firm. *Transportation*, 29, 397-417.

[22] Samuelson, Paul A. [1952] Spatial Price Equilibrium and Linear Programming. *American Economic Review*, 42(3), 283-303.

[23] Smithies, Arthur [1941] Optimum Location in Spatial Competition. *Journal of Political Economy*, 49(3), 423-439.

[24] Stigler, George J. [1949] A Theory of Delivered Price Systems. *American Economic Review*, 39(6) 1143-1159.

[25] Takayama, T. and G. G. Judge [1964]. Equilibrium among Spatially Separated Markets: A Reformulation. *Econometrica*, 32(4), 510-524.

[26] Tirole, Jean [1988] *The Theory of Industrial Organization*. MIT Press, Cambridge, Mass.

[27] Train, Kenneth, and Wesley W. Wilson [2004] Shipper Responses to Changes in Transportation Rates and Times: The Mid-American Grain Study. Institute for Water Resources, Army Corps of Engineers. Available at www.CORPSNETS.US

[28] Train, Kenneth, and Wesley W. Wilson [2006] Spatially generated transportation demands. Forthcoming in *Research in Transport Economics: Railroad Economics*, ed. Wayne K. Talley and Scott Dennis, Elsevier, North Holland.

[29] Walters, Alan A. [1968] *The Economics of Road User Charges*. Washington, International Bank of Reconstruction and Development.

[30] Wilson, William W., Wesley W. Wilson, and Won W. Koo [1988] Model Competition in Grain Transport. *Journal of Transport Economics and Policy,* 12, 319-37.

[31] Wilson, Wesley W. [1987] Transport Markets and Firm Behavior: The Backhaul Problem. *Journal of the Transportation Research Forum*, 28(1), 325-333.

[32] Wilson, Wesley W. [1996] Legislated Market Dominance. *Research in Transportation Economics*, 4(1), 33-48.

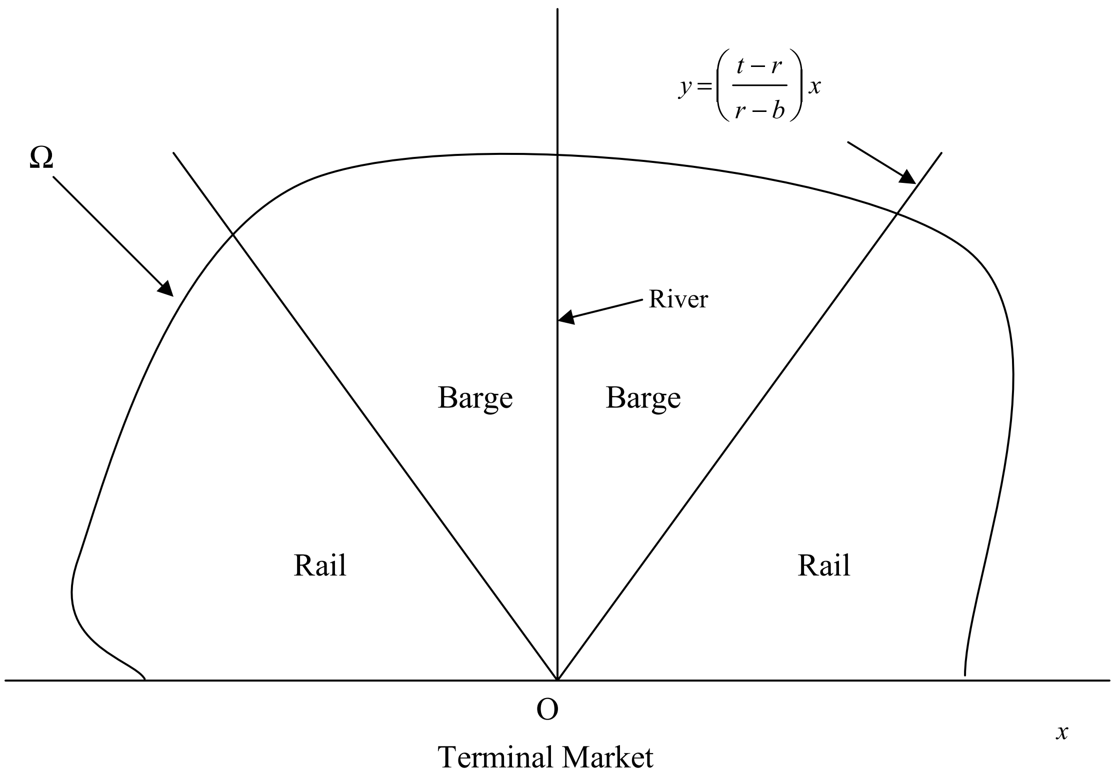
[33] Wilson, Wesley W. [1994] Market Choice, Entry Regulation, and Joint Production. *Review of Industrial Organization*, 9(6), 791-812.

[34] Wilson, Wesley W. [1997] Cost Savings and Productivity Gains in the Railroad Industry. *Journal of Regulatory Economics,* 11, 21-40.

[35] Yu, Tun-Hsiang (Edward), and Stephen Fuller [2005] The Measurement of Grain Barge Demand on Inland Waterways: A Study of the Mississippi River. *Journal of the Transportation Research Forum*, 44(1),

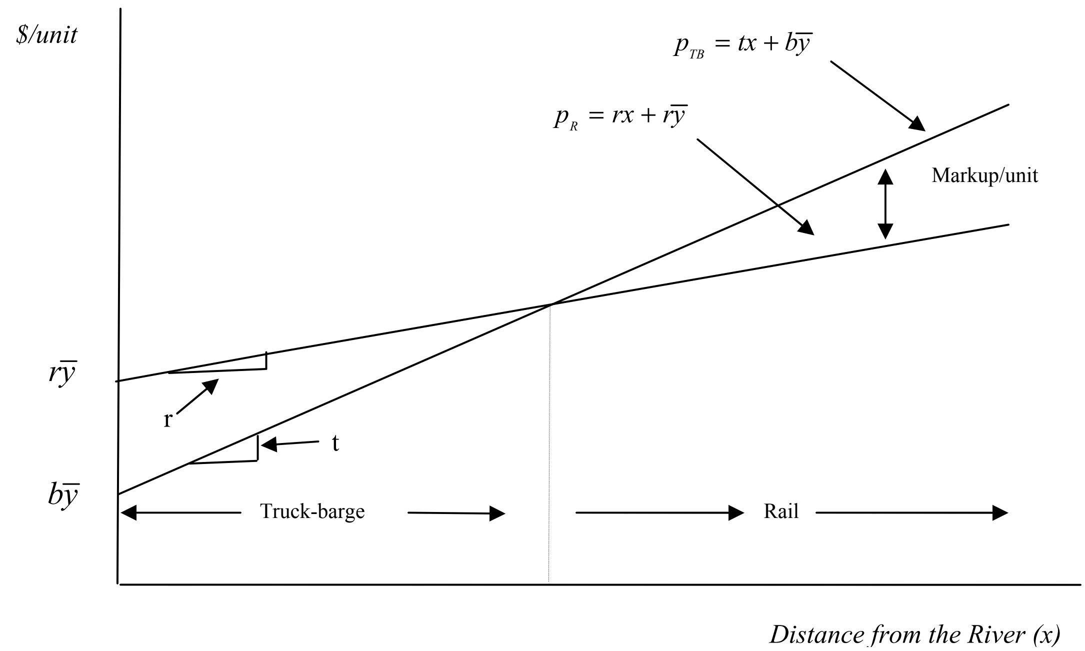
[36] Yu, Tun-Hsiang (Edward), Jin Zhang,and Stephen Fuller [2006] Freight Transportation Demands on the Upper Mississippi and Illinois Rivers. *Journal of the Transportation Research Forum*, 45(2),

Figure 1



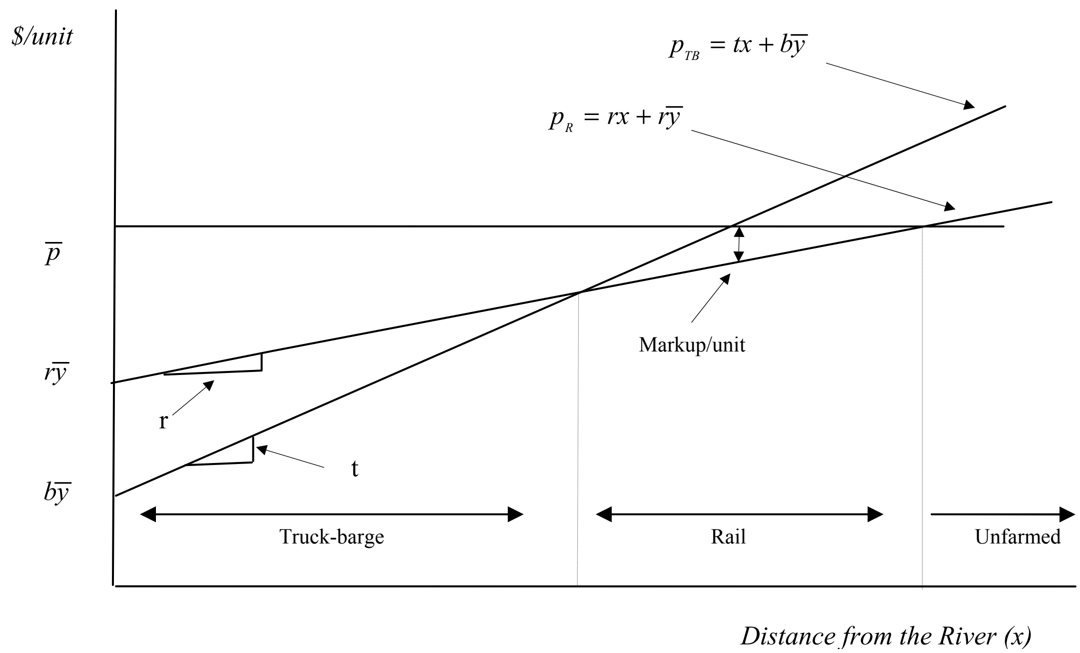
$y=\left(\frac{t-r}{r-b}\right)x$
Ω
River
Barge
Barge
Rail
Rail
O
x
Terminal Market

Figure 2.



$/unit
$p_{TB} = tx + b\overline{y}$
$p_R = rx + r\overline{y}$
Markup/unit
$r\overline{y}$
r
t
$b\overline{y}$
Truck-barge
Rail
Distance from the River (x)

Figure 3.



$/unit
$p_{TB} = tx + b\overline{y}$
$p_R = rx + r\overline{y}$
$\overline{p}$
$r\overline{y}$
$b\overline{y}$
r
t
Markup/unit
Truck-barge
Rail
Unfarmed
Distance from the River (x)

Figure 4. Alternative Port

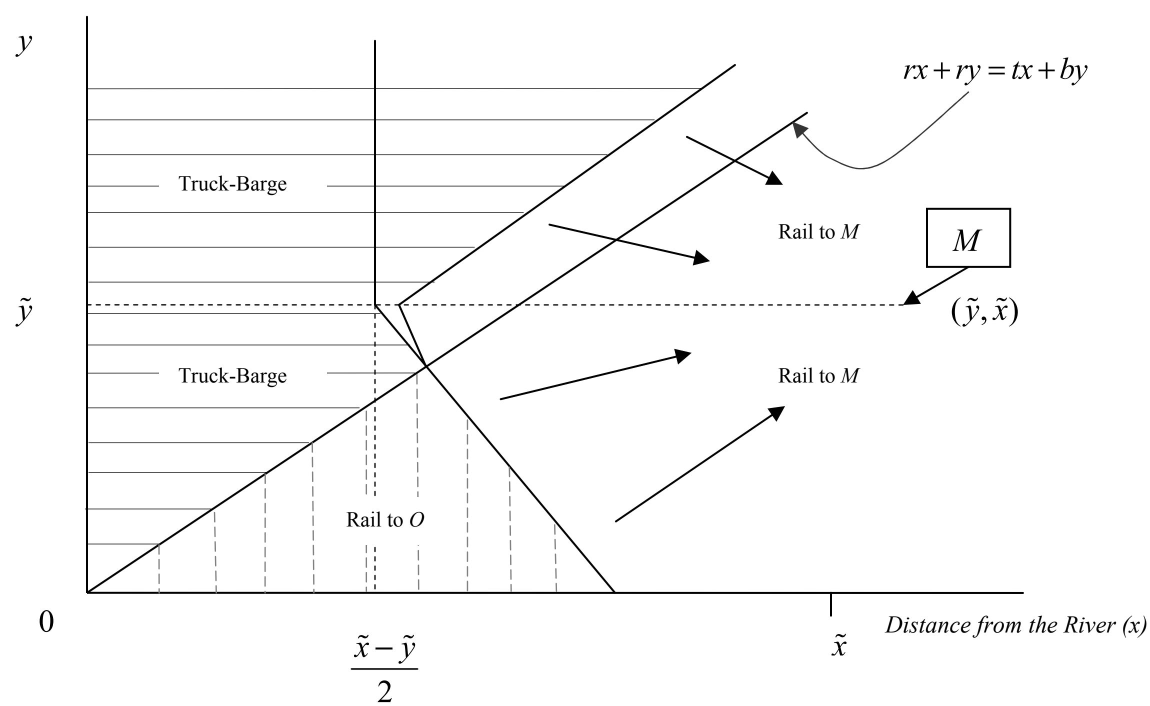
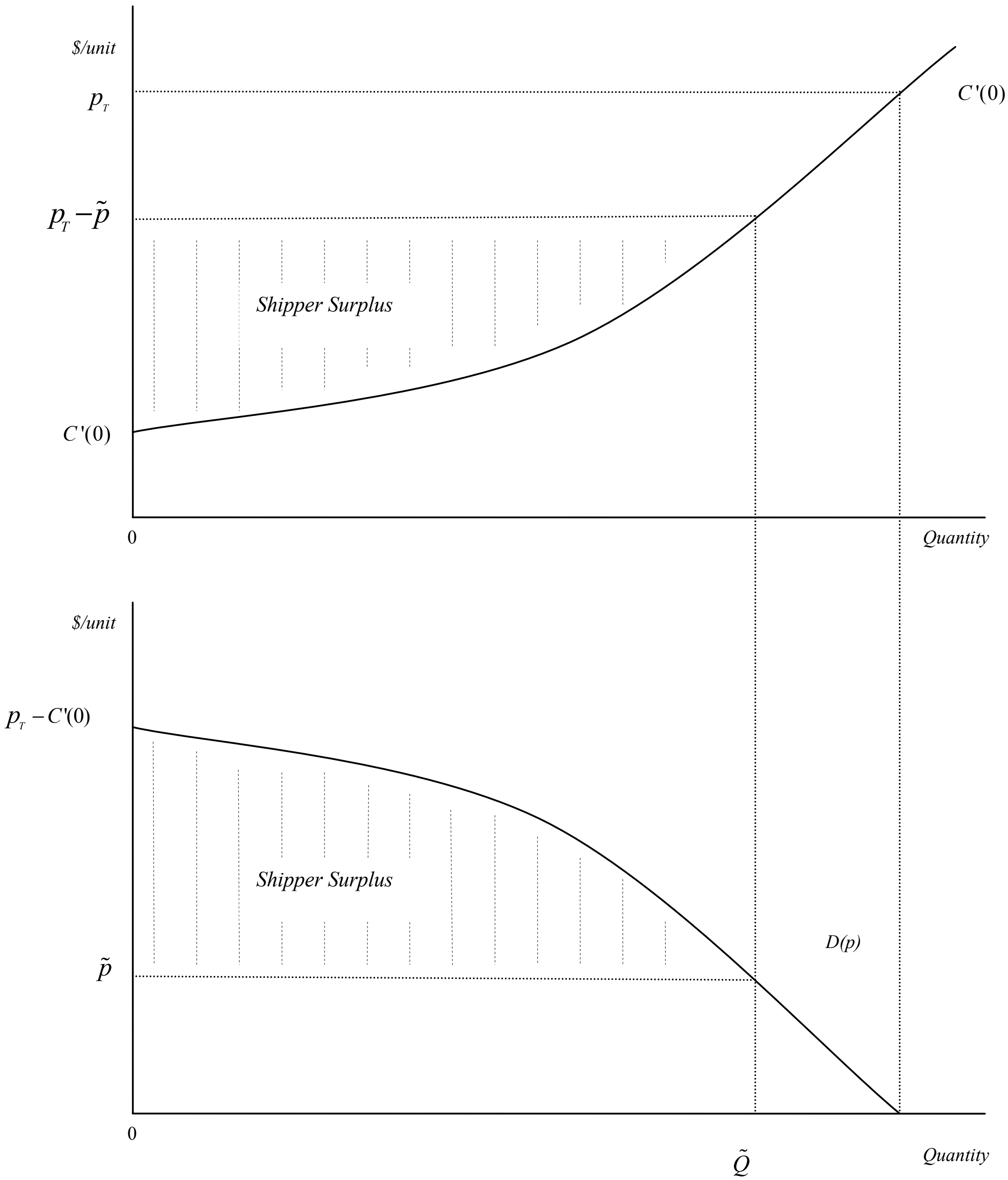


Figure 5.



$/unit
p_T
$C'(0)$
$p_T - \tilde{p}$
Shipper Surplus
$C'(0)$
0
Quantity
$/unit
$p_T - C'(0)$
Shipper Surplus
D(p)
$\tilde{p}$
0
$\tilde{Q}$
Quantity

Figure 6.

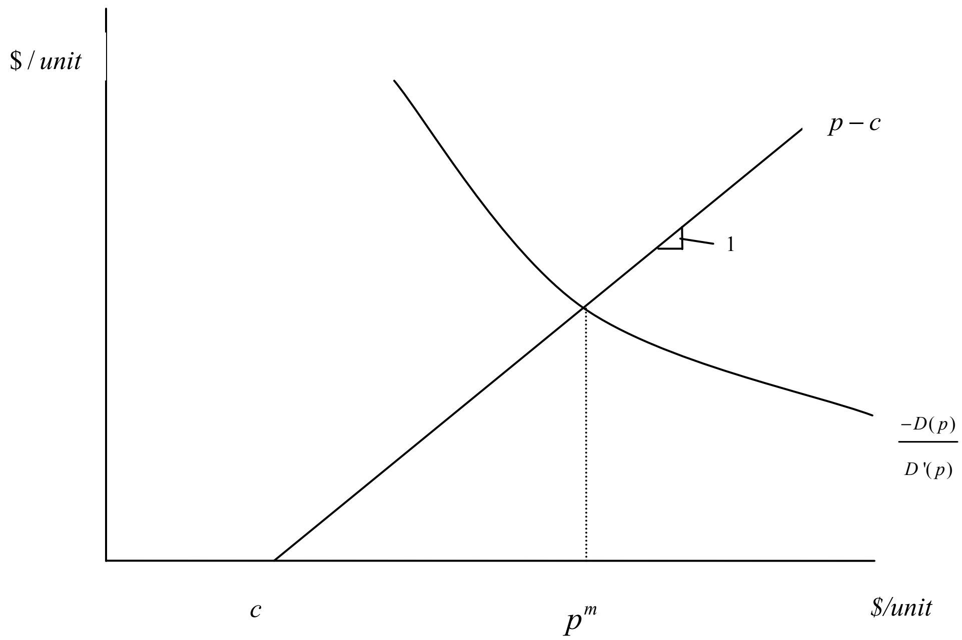


Figure 7.

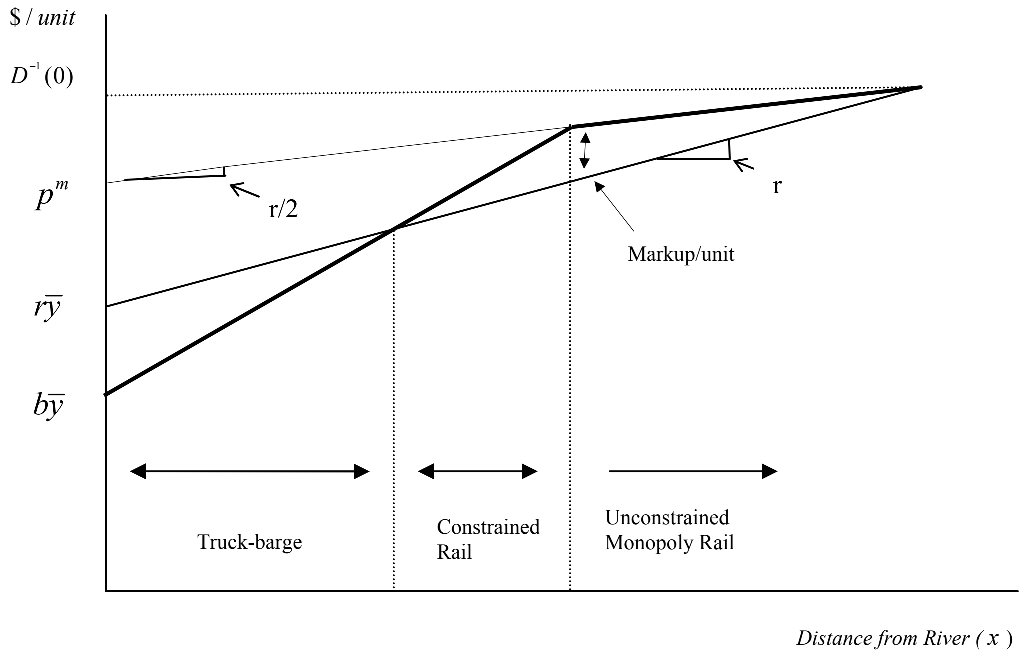
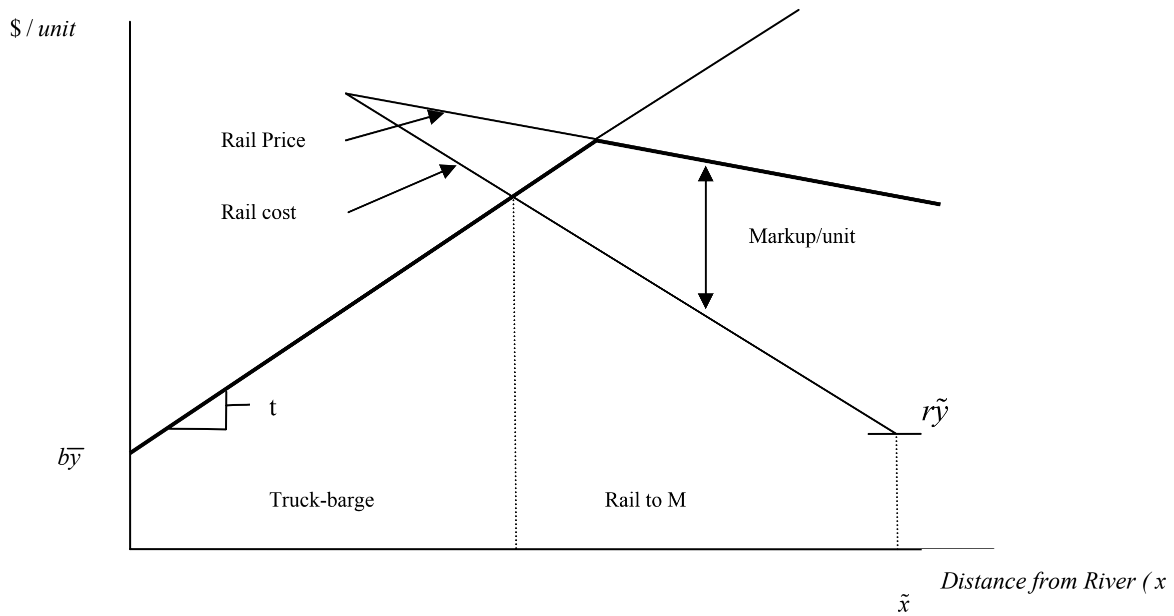
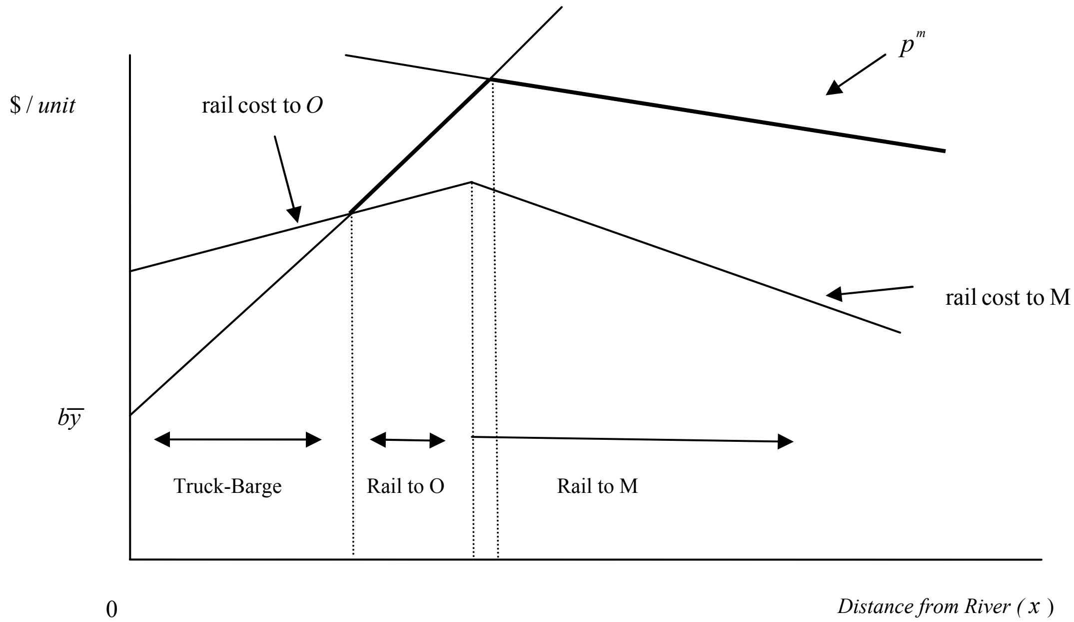

$ / unit
$D^{-1}(0)$
p^m
r/2
r
Markup/unit
$r\bar{y}$
$b\bar{y}$
Truck-barge
Constrained
Rail
Unconstrained
Monopoly Rail
Distance from River (x)

Figure 8



$ / *unit*
Rail Price
Rail cost
Markup/unit
t
$r\tilde{y}$
$b\overline{y}$
Truck-barge
Rail to M
Distance from River (x)
$\tilde{x}$

Figure 9


p^m
$ / *unit*
rail cost to *O*
rail cost to M
$b\overline{y}$
Truck-Barge
Rail to O
Rail to M
0
Distance from River (x)