Pricing the negative externalities of freight transportation: A literature review

Summary. Pricing schemes have been proposed to address the negative externalities of freight transportation. Literature related to the following pricing strategies are reviewed: pricing programs aimed at changing shipper's mode choice, and schemes aimed at shifting freight deliveries to off-peak hours. Evidence from empirical and theoretical studies suggests that pricing strategies may have limited effect on freight agents' behavior unless they are accompanied by complementary policies, or the charges are relatively high. The idea of marketable permits systems in the context of freight transportation is discussed.

1. Introduction

For several decades the use of pricing mechanisms has been advocated as a means of controlling the negative externalities associated with transportation. Relative to the extensive study of passenger transportation pricing, little research has been conducted on the use of price signals to manage freight travel demand (Holguin-Veras, 2011). This may be rather surprising if one considers the role that freight transportation plays in traffic congestion or in the emission of harmful gases. For example, in 2010 the greenhouse gas (GHG) emissions from freight transportation represented 29 percent of the combined passenger and domestic freight emissions. Additionally, while the GHG emissions from passenger transportation increased by 13 percent from 1990 to 2009, in that same period the emissions from domestic freight transportation grew by 47 percent (EPA, 2012). The experience with freight emissions in Europe has been slightly similar (Mattila and Antikainen, 2011). According to Buhler and Jochem (2008), in the European Union transportation is the only sector with increasing CO_2 emissions (32 percent from 1990 to 2004) and the contribution of road freight transportation, which stood at 20 percent in 2007 is expected to strongly increase in the future.

In recent years pricing has been included in policy proposals aimed at creating more sustainable freight transportation systems (e.g., see CEC, 2011). However, it is not clear what effect, if any, pricing would have on the decisions of freight agents regarding, for example, mode choice, route choice, time-of-day travel, and clean technology adoption, some of the main responses expected from this type of strategy. The following sections will review literature that has examined the potential effects of pricing strategies on freight transportation. The focus will be on road and rail transportation. A distinction will be made between urban freight transportation, where trucks are the only reasonable or available transportation option, and intercity freight transportation, where mode choice can be seriously considered.

However, before the literature review it might be useful to clarify what is meant by pricing in the context of the current discussion. In passenger transportation, pricing generally refers to the levying of monetary charges (e.g., taxes, tolls) in order to internalize the negative externalities associated with travelling on a transportation facility at a particular time, or in other words, levying a charge so that the cost incurred by the road user reflects not only private costs (e.g., gasoline, time) but also the external social costs (e.g., pollution, marginal increase in congestion for all users). The charge could be applied in many different ways depending on the problem being addressed. For instance, congestion pricing refers to pricing designed to manage the external costs associated with travel demands in excess of the available roadway supply. Congestion pricing schemes can be designed to consider time (e.g., peak-hour pricing) and spatial dimensions (e.g., distance-based pricing, area-based pricing, city cordon-based pricing, freeway tolls). Carbon pricing has also being suggested as a basis for road charges. As the name suggests, carbon pricing reflects the costs associated with vehicles GHG emissions, though the term can be used more loosely to refer to any type of environmentally harmful emission. Although the design of the pricing scheme and the intended responses may be slightly different, generally speaking the rationale behind passenger and freight transportation pricing is the same. In fact, road based pricing scheme may be designed to address the impacts of passenger and freight transportation simultaneously.

However, whereas the study of potential pricing effects on personal transportation involves only one decision maker (i.e., the passenger), in the case of freight it involves multiple agents with unique, even conflicting, objectives. As a simplification, freight agents are generally classified as carriers, shippers or receivers, though any agent can assume any of these roles at different points in time, or even at the same time. The shippers are involved with the production and/or shipping goods, the carriers are involved with the physical movement of goods, and the receivers are, naturally, the agents to whom the goods are delivered. Current business practices are a challenge to this traditional classification as additional types of agents arise (e.g., third party logistic providers), but nevertheless, it is clear from this conceptual framework that the response to freight transportation pricing is the result of complex interactions between several decisions makers, a fact that, coupled with the scarcity of freight related data, makes evaluating or forecasting the response to freight pricing is a difficult task.

The next section will present a short review on the price elasticities of freight travel demand. This literature is considered since it elasticities estimate provide an indication on the level of sensitivity that freight demand has to a marginal increase in travel cost. Next, studies on mode choice are considered. In the fourth section urban freight deliveries and the off-peak hour strategy will be discussed. The idea of marketable permits for freight transportation is introduced in the fifth section. The last section presents some research opportunities based on the reviewed papers. When applicable, alternative strategies to pricing will be mentioned throughout the different sections.

2. Literature Review

2.1. Elasticity of freight travel demand - A shipper's perspective

Estimates of freight demand price elasticities by mode can serve as aggregate analysis tool to forecast the effects of a pricing strategy. Though perhaps too aggregate in nature to be used in advanced transportation forecasts, elasticity estimates provide valuable insights. Elasticities studies are generally conducted either using aggregate data (which imply an analysis that considers the behavior of a representative or average shipper in a region) or disaggregate data, that is, data from a survey of shippers. According to Graham and Glaister (2004), it is a common understanding that road freight travel demand is relatively inelastic. This would seem to imply that price signals would do little to alter the current choices of freight transportation agents. However, Graham and Glaister find that in most "studies price demand elasticity estimates are, almost without exception, negative and in many cases exceed unity" (i.e., there is evidence for elasticity). The price demand elasticities that they found in the literature ranged between -7.92 to 1.92, with a mean of -1.07. For rail, there is also evidence for elasticity (e.g., see Oum et al. 1992).

One critical insight of freight demand elasticities studies is that there are different degrees of elasticity depending on the types of commodities transported. In fact, Oum et al. (1992) note that elasticity estimates differ not only across different commodity groups, but also within the same commodity group. Since each study differs in mathematical formulations, modes considered, type of commodity aggregation, type of data used, and in many other aspects, these perhaps contradictory results are not surprising. But, the results ultimately suggest that the transport decisions associated with some goods might be more responsive to pricing strategies than for others goods. However, it is unclear if the magnitudes of these elasticities are sufficient to produce significant changes in freight travel behaviors. Holguin-Veras (2010) notes three main commodity-determined factors that affect how freight transportation might react to pricing: 1) "different commodities have different operational requirements that may require the use of specialized equipment", 2) long term business relations between shippers and carriers that leads to carrier specialization, and 3) " commodity type implicitly captures the effect of the opportunity cost of the cargo". Price elasticity studies provide evidence that supports these contentions.

2.2. Road or Rail?

Congestion or carbon pricing in passenger transportation is partly intended to modify the mode choice behavior of auto users. Ideally, the demand for road transportation would be shifted to more environmentally friendly modes, such as bikes or buses. Similarly, pricing strategies for freight transportation are meant to shift demand from truck to alternative modes that are considered to be "cleaner". This section discusses the findings of two studies that considered how pricing could affect the competitive advantage of trucks over rail.

There is evidence that suggests that, from a societal perspective, rail freight transportation is preferable to truck transportation. For example, Forkenbrock (1999) estimated that the external cost of US truckload freight transportation was around 1.11 cents per ton-mile, or 13.2 percent of total private operating costs of trucks. These estimates were based on four factors: accidents, emissions, noise, and "unrecovered costs associated with the provision, operation, and maintenance of public facilities (primarily roads and bridges)". However, the study did not reflect congestion effects since only intercity freight transportation was considered. Therefore, the 1.11 cents estimate can be understood as a lower bound of the external cost of truckload transportation. The author concludes that "user fees would need to be increased about threefold to internalize [the estimated] external costs". As a follow-up study, Forkenbrock (2001) then estimated the external cost of rail freight by considering only accidents, emissions and noise. Rail external costs were estimated to be around 0.25 cents per ton-mile. Therefore, the external cost estimate for intercity truckload transportation is more than three times the estimate for rail. In part, these results are not particularly surprising since railroads are more fuel efficient than trucks (FRA, 2009).Forkenbrock (2001) notes that pricing motivated shifts in mode share depends on several factors, including "the magnitude of change in relative prices for various types of shippers, the difference in quality of service provided by competing modes, and specific requirements on the part of shippers".

Janic (2007) modeled the full cost of an intermodal and road freight transportation network. By intermodal, the author refers to a network composed of rail links connecting shipper and receiver areas in combination with trucks that transport the goods to and from the intermodal terminals. The objective of the study was to investigate the "effects of European Union policy, which aims to internalize the external costs of transport, on the prospective competition between two networks from a social perspective". This study is not based on actual data on observed operational costs of freight and rail modes, so in a sense it is a simulation of actual costs using assumptions of network and operational parameters.

The two hypothetical networks considered where of equivalent size, that is, the networks had the same spatial coverage, number of nodes and demand (volume of goods), Nodes in the network consisted of origins and destinations of goods. These nodes represented zones with agglomerations of plants, warehouses, logistic centers, etc. Additionally, intermodal terminals were included as nodes in the system. The author then specifies tour patterns in intermodal, collection, and distribution nodes in the shipper and receiver's areas.

A critical part of the study is the definition of what constitutes internal and external costs. Internal costs are defined as the costs incurred due to vehicle ownership, insurance, maintenance, labor, energy, taxes, and the fees paid for using the network. These costs are computed for the collection, distribution, line hauling and transshipment of units in the intermodal and road networks. Internal costs are subdivided in the model into transportation costs, time costs, and handling costs. The externals costs considered in the model are air pollution, congestion, noise, and traffic accidents. Intermodal terminals were assumed to be free of congestion, noise (since it is assumed to be part of the ambient urban noise), and accidents (since these are rare events).

To apply the model data from the European Union was used to assume the parameter of the cost functions. For instance, the author assumed average gross weight of deliveries, average trip length, average operating speed, load factors for rail and trucks, and different types of operating costs. Figure 1 presents the main result of Janic (2007). The results are rather surprising and are unfoundedly a reflection of the model assumptions and network design. First, as expected, there is evidence of economies of distance, that is, as the shipping distance increases the average cost of transportation decreases in a non-linear manner. The economies of distance are greater in the intermodal network, which is expected since the time spent transferring a load from a truck to a railcar and again from a railcar to a truck makes intermodal transportation cost high in short distance trips. However, what is rather surprising is that the difference between internal costs and full costs, that is, the external costs, is relatively constant for both modes at different door-to-door shipping distances, and, more importantly, this difference is bigger for the case of intermodal transportation. In other words, the average external costs of the intermodal freight transportation are higher than truck freight transportation. This result appears to be counterintuitive considering, for instance, the difference in fuel efficiency of railroads and trucks.

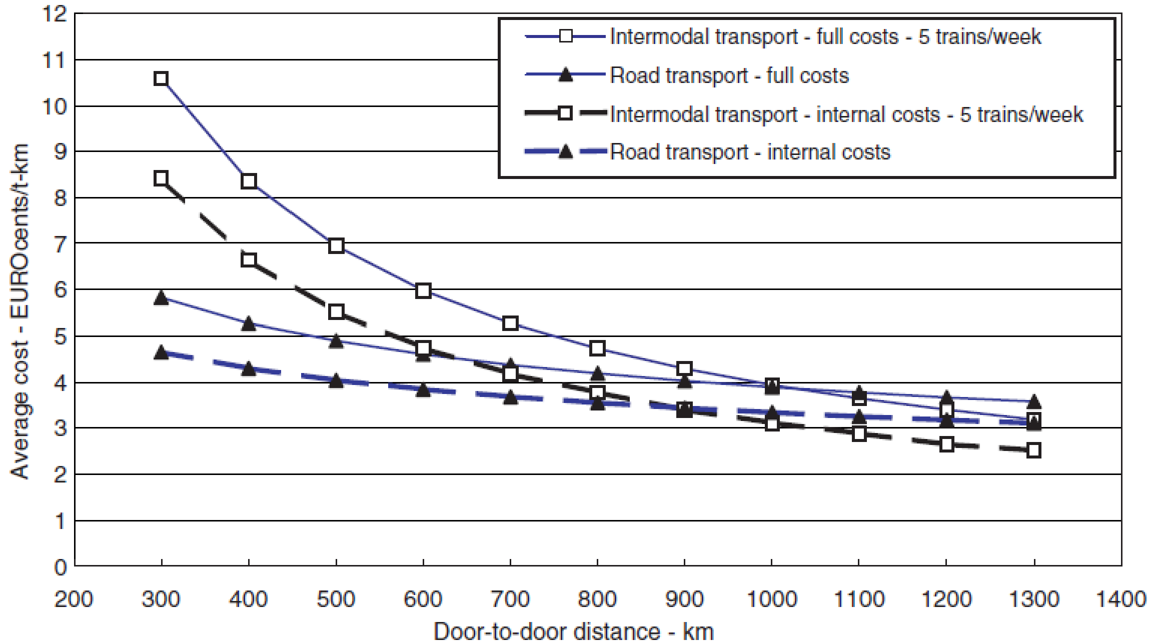

Figure 1. Simulated average costs of road and intermodal transportation (Janic, 2007)

The counterintuitive nature of the results is reflected also in the breakeven distances (i.e., the distance at which both intermodal and road have the same average cost, and from which rail becomes more competitive). Note that under average internal cost pricing the breakeven distance is around 900 km (560 miles), but if the full cost of transportation is considered the breakeven distance shifts to approximately 1,000 km (620 miles). This means that internalizing negative internalities through the use of a pricing scheme would actually result in a loss of market share for intermodal transportation since it would become competitive only at longer distances. The author concludes that “basing prices on the higher full costs may affect the already low, although still price-sensitive, demand [of transportation at distances beyond 900 km], thus making conditions under which intermodal transport can gain a higher market shares even more complex […] rais[ing] questions about the efficiency of EU policies that expects internalizing externalities to strengthen the market position of intermodal transport”.

What can be learned from Janic (2007)? Well, the answer to this question depends on the level of confidence given to the methodology and assumptions used. Undoubtedly, the results contradict the conventional perceptions regarding external costs of rail and trucks. The author presents a sensitivity analysis for the assumed frequency of train services and volume of demand, but surprisingly no sensitivity analysis is offered for the assumed parameters associated with external and internal costs. This seems to be a critical oversight since the whole point of the model was to estimate the full costs of a hypothetical intermodal and road network. So, at the very least this study should serve as a motivation for additional research since its results mean that current governmental efforts to shift demand to railroads could actually be detrimental to society.

In contrast to the analytical approach taken by Janic, Buhler and Jochem (2008) study mode choice behavior more directly by using a revealed preference survey of 500 forwarders in Germany. The objective of this study was to determine the effectiveness of service quality improvements and price signals in shifting freight transportation from trucks to intermodal (truck-rail) transportation. To do this the researchers estimated a binary logit mode choice model. The two alternatives were truck and intermodal transportation. The estimation results indicated that the main determinants of mode choice were cost per kilometer of service, trip distance, transport volume, and frequency of service, among other factors.

The binary logit mode choice model was first used to estimate elasticities of mode choice decisions for intermodal transport services. The own price elasticity of choice probability for the intermodal services was -1.20, suggesting that the demand for intermodal services is elastic. But the cross (truck) price elasticity was 0.74. This indicates that an increase in the price of truck have relatively little effect on the demand for intermodal transportation, but an increase in the price of intermodal freight transportation would result in a relatively higher shift in demand to truck.

Only rough estimates mode choice shifts could be computed with the previous elasticities since "individual cost increases vary substantially between different transport processes depending on the kilometers covered on German motorways". Therefore, the researchers use sample enumeration to simulate the impact of a distance-based road user charge implemented in Germany. To apply this method the additional road charge cost for each "transport process" (tour) in the sample was quantified. With the adjusted cost information and the estimated coefficients the model was reapplied to compute simulate mode choice probabilities. These choice probabilities were aggregated to determine a new modal share distribution, and using these results the changes in CO_2 emissions were computed. Under the simulated scenario the intermodal freight transportation share increased by only 2.1 percent resulting in a CO_2 reduction of only 1 percent. Again, using sample enumeration the authors simulated the effect of a tremendous increase in rail service speeds and found that the mode share of intermodal transport increased by 7.7 percent. The result of Buhler and Jochem suggest that pricing strategies might only have a limited impact on freight mode choice. But of course, this study is based on German data which may not be applicable in other areas.

The papers reviewed in the previous section concentrated on freight transportation decisions that included mode choice. Generally speaking, mode choice decisions are only available (or reasonable) for long-hail intercity trips. The evidence suggests that pricing schemes might only have limited persuasive power on mode choice behavior. The following section will concentrate on the behavioral response of truck carriers to pricing strategies in urban settings.

2.3. Pricing of urban freight deliveries

This section will consider pricing schemes designed to influence the travel behavior of carriers in an urban environments. The first paper that will be reviewed is an empirical study on the effects of a time-of-day scheme implemented on bridges and tunnels operated by the Port Authority of New York and New Jersey (PANYNJ). The rest of the reviewed papers are explicitly concerned with the effectiveness of pricing strategies in moving urban freight traffic to off-peak hours.

2.3.1. Case Study: The PANYNJ time-of-day pricing initiative

In March 25, 2001 the PANYNJ introduced a time-of-day pricing scheme in its six tunnels and bridges. The tolls, which are collected only in the eastbound-New York direction, varied according to time of travel (peak hours, off-peak hours and overnight), vehicle type (passenger car, trucks depending on axles), and the type of payment used (cash, electronic toll collection). With an annual eastbound traffic of 126.6 million this initiative is "is, by far, the largest application of road pricing in the United States" (Holguin-Veras et al., 2006). Of the 126.6 million trips, only 6.5 percent were trucks. Travel demand management of commercial traffic was one of the objectives of the pricing.

Holguin-Veras et al. (2006) conducted an empirical study on the travel behavior effects that the PANYNJ strategy had on freight carriers in the region. According to the authors, this is the first publication that explicitly considers the impacts of an implemented pricing strategy on commercial vehicles. The authors conducted a survey of regular and previously regular users of the PANYNJ facilities. For-hire carriers (carriers that only transport the goods) and private carriers (companies that assume both shipper and carrier roles) were included in the sample. The researcher collected data on the types of carrier operations, business profile (e.g., type of company, fleet size, number of employees), and the response to the time-of-day tolls, among other things. The survey data was collected using telephone interviews; the sample consisted of 182 current regular users of the facilities and 18 former users.

PANYNJ defined the peak hours as 6 AM – 9 AM and 4 PM – 7 PM and during this period cash paying users experienced 50 percent ($4 to $6) toll increase while carriers that used the electronic payment method (E-ZPASS) experienced a 66.7 percent increase (from $3.60 to $6). From the sample, 69.1 percent passed a toll during peak-hour periods. When inquired on the reason for their travel time decisions 73.3 percent of respondents indicated that it was determined by receiver-related constraints, 23.1 percent were interested in avoiding congestion, and only 3.1 mentioned that they choose their travel time based on cheaper tolls. Only 36 carriers (or nearly 20 percent of the sample) indicated that they changed their behavior due to the time-of-day pricing initiative (21 of which were for-hire carriers and the rest private carriers); five stopped using the facilities in part because of the tolls. The behavioral responses included reactions not usually considered when thinking about pricing strategies: 10.4 percent of the carriers that adjusted their behavior switched to or increased their E-ZPASS usage; 6.2 percent decreased their travel frequency through the PANYNJ facilities; 6.2 percent changed routes; 9 percent increased shipping charges; and only 0.5 percent switched to off-peak hour travel in response to the tolls. Other behavioral responses included increasing load factors, adjusting the fleet, and decreasing the number of stops. Figure 2 presents a summary of the combined carrier responses to the time-of-day initiative.

An interesting observation of the study is that private carriers are more able or willing to transfer costs to their customers, but for-hire carriers are more aggressive in their shipping rate increases. On average carriers increased shipping rates by 15 percent. The authors speculate that the responses to pricing depend on the "balance of power between receivers and carriers". For example, if the carrier offers a specialized service that the receiver cannot obtain from other carriers, then the carrier occupies the dominating position in the relationship. In contrast, in situations where the receiver can select among dozens of carriers invert the power paradigm.

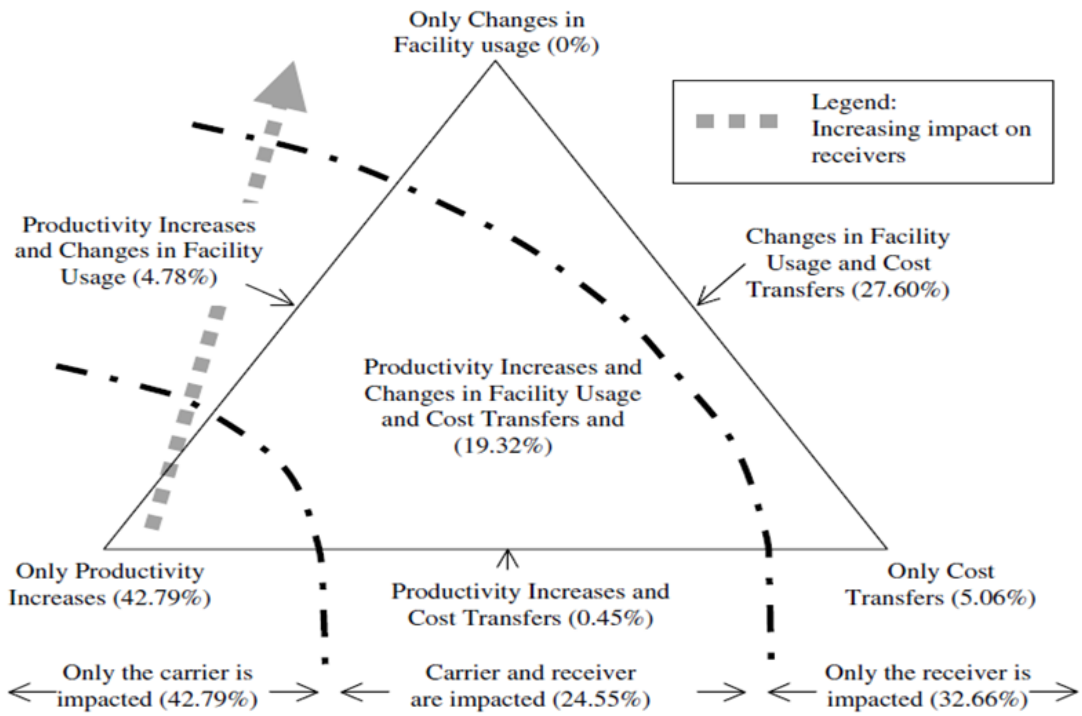

Figure 2 Carrier behavioral responses to the PANYNJ pricing strategy (Holguin-Veras et al. 2006)

The majority of the respondents (around 80 percent) did not change their behavior. The main reason for not changing operations, costs, or travel patterns was that the carrier did not have a choice (75.3 percent) given customers' requirements (68.9 percent) or that they had to use the quickest routes (6.4 percent). Other reasons included: cost increase was not significant (2 percent), carrier was not responsible for paying the toll, and the carrier already travelled in off-peak hours.

In part this study was intended to answer the following question: is road pricing effective in moving freight traffic to the off peak periods? The evidence presented in this study suggests that the answer is no; carriers are constrained (primarily by their customers) to travel on the peak hours. The authors note that tolls are of no "practical significance when compared to the marginal costs associated with paying staff to receive deliveries during the off-peak hours", so from the receivers' perspective time-of-day pricing have no effect on business practices. In fact, in the case of 91 percent of respondents the cost increase associated with the toll changes, if any, was internally absorbed (i.e., the receiver did not experience a change in tolls). In the opinion of the authors, "comprehensive policies targeting the receivers, in addition to road pricing, are needed to help achieve the objective of switching a significant portion of truck traffic to the off-peak hours".

The case study presented in the previous discussion suggests that time-of-day pricing is not an effective tool in shifting demand to off-peak hours. However, an alternative explanation is that the tolls were simply too low or the geographical region (or points) where they were applied are not conducive to a change in carrier behavior. The authors noted that higher tolls might have resulted in a higher shift in off-peak travel, though this would test the political acceptability of the toll increment.

2.3.2. Using pricing to shift urban freight transportation to off-peak periods

This section will review analytical and empirical studies that support the observation that freight pricing has limited effect on the travel time behavior of carriers. Note that pricing can have other types of effects beyond route and travel time choice. For example, a long-term effect of pricing could be the adoption of more efficient trucks (e.g., more fuel efficient, capable of using alternative fuels). However, studies that consider effects other than shifts to off-peak hour travel are beyond the scope of this paper.

Holguin-Veras (2008) studied necessary economic conditions for off-hour deliveries and possible impacts of urban freight road pricing in conjunction with complementary strategies. This study is analytical in nature, from the carriers and receivers' perspective, and it is motivated by the observations of Holguin-Veras et al. (2006). The author formulated profit conditions for three scenarios: 1) a scheme that combines freight road pricing and financial incentives for receivers that accept off-peak hour delivery, 2) a scenario where only freight road pricing is implemented, and 3) a business-as-usual scenario (i.e., no incentives or road pricing strategies). The mathematical formulations of these scenarios were developed for two industry cases: industries where receivers and carriers are not part of the same company, and industries with integrated carrier-receiver interactions.

The analysis focuses revenues and costs associated with a single tour of a carrier j that must serve a receiver i, or a series of receivers. It would be impractical to restate here the mathematical formulations presented in the paper. But, to illustrate the starting point of the analysis, consider the basic formulation that defines the necessary conditions for off-peak hour deliveries to be feasible in the case of independent carrier-receiver operations. Define the policies affecting carriers and receiver as π_C and π_R, respectively. Then off-peak hour deliveries are feasible if:

$$\begin{aligned} &\Delta G_i(\pi_R) \geq \Delta C_i(\pi_R) \quad \forall i \\ &\Delta G_j(\pi_C) \geq \Delta C_j(\pi_C) \\ &\tau_i^0 \geq \tau_{min}^0 \qquad\qquad \forall i \end{aligned}$$

The interpretations of these inequalities are straightforward. According to these inequalities, off-peak freight deliveries are possible if, for all receivers, the change in revenue $\Delta G_i(\pi_R)$ obtained from policies π_R is greater than or equal to the change in cost associated with π_R (first inequality), if the change in revenue associated with policies π_C for carrier j is greater than or equal to their associated costs (second inequality), and if the minimum amount of time required for off-hour deliveries τ_{min}^0 is less than the amount of time τ_i^0 the receiver i is opened (third inequality). For each scenario the components of the three inequalities are developed. A peculiar thing of these inequalities is that the changes in revenue and costs for both receivers and carriers are not independent of each other's policies (that is, for example, $\Delta G_i(\pi_R, \pi_C) \geq \Delta C_i(\pi_R, \pi_C)$). In any case, the analysis explicitly recognizes this fact. For example, in the case of the incentive and road pricing scenario, the change in carrier revenue is equal to the sum of the portion of the incentives that the receivers transfer to carrier j. However, as inevitably happens with models some details observed in the real world may be lost. For example, in the case of the road pricing only scenario no incremental gross revenue is specified for the carrier (i.e., $\Delta G_j(\pi_C)$=0). This is a simplification since, as noted in Holguin-Veras et al. (2006), incremental tolls could be used by carriers to justify an increase in freight rates in a way that could result in profits.

On the basis of the developed analytical framework the author concludes "that, because of the competitive nature of the urban delivery industry, rates tend to be set at marginal costs [, which] in turn prevents the industry from transferring toll surcharges to their customers because the tolls are, generally, a fixed cost that vanishes from the calculation of marginal cost". As seen in the previously reviewed paper, this implies that the price signal does not reach the receiver, who generally has the dominating role in its interaction with the carrier. Incentives (e.g., tax deductions) are, according to the authors, a way to persuade receivers to accept off-peak hour deliveries. Additionally, the author suggests using the road pricing scheme to fund the receiver tax deductions. However, it remains unclear how a government entity would monitor that indeed a receiver is coordinating with its carrier off-peak hour deliveries and what would motivate the receiver to transfer a portion of the incentives to the carrier. In a follow-up study Holguin-Veras (2011) extends the analysis framework to consider cordon time-of-day pricing and time-distance based pricing. Using parameter estimates from New York City, "the total costs to receivers are on average 85% larger than the total savings to the carriers". (According, to an estimate by Holguin-Veras (2007) the off-peak marginal cost incurred by receivers can reach \$40–\$50 per off-peak hour of operation). In this study cordon pricing was found to be ineffective, but distance-based pricing was determined to have potential since the charge would enter the marginal cost formulations. However, the potential success of time-distance based pricing depends on "extremely high" unit tolls. In addition to incentives for receivers, Holguin-Veras (2011) also proposes programs to "foster unassisted off-hour deliveries to enable businesses to safely receive deliveries in the off-hours without staff present". The author states that these voluntary measures are "clearly superior" to mandatory off-peak hour deliveries or pricing strategies that would be politically infeasible.

Holguin-Veras et al. (2007) provides evidence to support the idea that tax incentives could be useful in incentivizing off-peak deliveries. Data from a stated preference survey of 180 Manhattan receivers was used to estimate binary and mixed logit models. The respondents were presented two scenarios. In the first scenario receivers were asked if they would be more willing to accept off-peak hour deliveries in return for tax deductions. For both the binary and mixed logit models selected the coefficient associated with the tax deduction was positive and significant, indicating that the probability of accepting off-peak hour deliveries increases with the tax deduction. Interaction terms were used to identify for which commodity groups a tax deduction could influence the time of their delivery. Receivers of the following commodity groups were found to be sensitive to tax reduction incentives: wood/lumber, alcohol, paper, medical supplies, food, printed material, and metal. Reasons for not accepting off-peak hour deliveries, according to the discrete model results, included not having access to the building during non-regular business hours, the additional costs associated with off-peak deliveries, and the interference that off-peak hour deliveries would create with normal business activity. In the second scenario receivers were asked if they would accept off-peak hour deliveries if they received shipping discounts. As expected, the coefficient associated with this policy was also positive and significant. In a companion paper, Holguin Veras et al. (2008) notes that the elasticities associated with the two policies are nearly similar, but the discounts considered in the study were unreasonably high. Also, and perhaps more significant, providing shipping discounts is not the direct prerogative of the government; it is a carrier's decision. Consequently, the authors conclude that tax deduction incentives are the most appropriate policy proposal to incentivize off-peak hour deliveries.

So far we have discussed the potential effectiveness of pricing mechanisms in shifting freight traffic to off-peak periods. The evidence currently suggests that pricing strategies have limited effect, if any, on delivery time decisions. One of the main reasons for this is that, even thought it would be advantageous for carriers to operate during times of less congestion, most receivers would rather receive shipments during normal business hours. Implicit in this discussion, however, is the idea that off-peak hour deliveries are in the interest of society. For example, Holguin-Veras (2011) concludes "that the paper established the presence of a market failure that prevents the urban delivery industry to reach the most efficient outcome, i.e., off-hour deliveries". This seems intuitively correct since freight deliveries during peak hours significantly contribute to traffic congestion and pollution. However, recent research suggest that off-peak hour delivery policies could have unintended consequences.

2.3.3. Why off-peak hour deliveries?

The research reviewed in the previous section examined ways in which off-peak deliveries could be incentivized. However, why is this desirable? Interestingly, in some regions there are policies aimed at the opposite, that is, policies that prevent deliveries during off-peak hours, specifically, during night-time. The main reason for these restrictions is noise pollution, which is a concern in dense urban areas with mixed residential-commercial land uses. Perhaps, to a lesser degree, light pollution can also be a negative impact of night-time deliveries. But, whatever is the noise or light pollution cost of night-time deliveries, it would seem to be inconsequential in comparison with the main benefit of the policy: shifting trucks to the off-peak hours would reduce congestion, thus reducing in fuel consumption and therefore air pollution (Browne, 2005). Holguin-Veras et al. (2011) is an example of a study that attempted to quantify the cost and benefits of off-peak hour programs. Using planning and mesoscopic traffic models for Manhattan the authors estimated a six percent reduction in travel time (four percent if the traffic increase in the off-peak period was considered). Benefits from productivity increases, reduction in travel time, and "environmental pollution saving to road users" were estimated to be in the range of $147 to $193 million per year. This study confirmed the generally understood benefits of off-peak hour deliveries.

However, Sathaye et al. (2010) present a possible problem with night-time deliveries not previously considered: changes in concentration of diesel fuel pollutant. A fundamental concept of this study is the stability of atmospheric boundary layers. An unstable atmospheric boundary layer "allows for increased vertical dispersion and decreased concentration of pollutants". During the night the boundary layer is stable, while the solar heat during the day increases layer instability. In this study data from interstate locations in Oakland and Livermore (representing coastal and inland environment) were used to study the concentration of particulate matter from diesel exhaust under multiple scenarios. The results indicated that for most regions in California off-peak hour deliveries would increase 24-h average exhaust concentrations, “and daily human intake is likely to worsen or be unimproved at best”. Due to differences in meteorological conditions, inland regions would fare worst relative to coastal regions. However, the authors note that “environmental benefits are likely to occur if off-peak policies are directed at specific time periods, such as the morning commute period”, or when there is significant network congestion during peak hours. Extensions to the study are required since only basic traffic analysis tools were employed in the study.

The finding of Holguin-Veras et al. (2011) and Sathaye et al. (2010) are not necessarily contradictory. The point of Sathaye et al. is that there can be unintended environmental consequences of off-peak hour policies. Undoubtedly, there are traffic and environmental benefits to off-peak hour (e.g., reduction in GHG emissions). It appears that a multi-objective analysis approach is needed to design off-peak hour programs and the corresponding pricing and incentive policies.

2.4. Marketable permits in the context of freight transportation

So far only direct pricing strategies (i.e., tolls) have been discussed. Under this policy environment the price to be paid for negative externalities is set by a planning agency. Conceptually, the price can be established based on, for instance, estimated marginal social costs of freight transportation or the carbon content of transportation fuels consumed. Whatever the bases of the price, the freight agents decide to what extent they will adjust their behavior. For example, receivers could decide to reduce the frequency of shipments and increase inventory space or accept off-peak hour deliveries, while carriers could respond by incorporating cleaner technologies to their operations or switching routes. Alternatively, freight agents could simply not respond, pay the charge, and preserve the operational status quo. Unless the real objective of the pricing strategy is the generation of revenues, no change in freight transportation behavior would be an undesirable result. The studies by Holguin-Veras suggest that relatively high tolls would be needed to elicit significant responses from freight agents.

An alternative to tolls are marketable permits. Marketable permits are a type of command-and-control policy instrument. A regulatory agency sets a standard on the level of output or demand for some good (e.g., level of pollution, number of users in a transportation network), distributes a finite number of permits that allow users to consume the goods in question, and then the users trade the permits in a market as they see fit. So, in a sense it is an indirect form of pricing since the value of a permit is not determined by the agency, but by the equilibrium reached in the market. Cap-and-trade schemes are an example of a marketable permit strategy.

In transportation research the idea of marketable permits has received limited attention given the difficulty in monitoring the permit systems and the perceived political unfeasibility of the measure. However, perhaps because of new technological developments or growing environmental concerns, during the past 20 years a few papers have been published on the subject. For example, Yang and Wang (2011) proposed a system of tradable travel permits designed to manage network mobility. In this system the government sets specific credit charges for each link in the network and distributes travel credits free of charge to eligible travelers.

These users surrender their permits depending on the links used in their travel paths. A permit exchange market would allow travelers to sell or buy permits. The effects of the system on network flow patterns are examined in the cases of fixed and elastic travel demand. Both cases are analyzed using their respective Beckmann's user equilibrium formulation modified to include constraints related to the network-wide permit system. Nagurney et al. (1999) presents similar concept but from a different perspective: an emission pollution permits system for multimodal networks. It is noteworthy that most mathematical studies are focused on passenger transportation, as reflected by their use of network equilibrium conditions based on path or link disutilities. This analysis approach, however, is not suited for the study of freight transportation since, as we have seen, freight travel decisions occur as a result of complex interactions between agent with different objectives, and the determining factors behind these decisions are usually not dependent on minimum network cost paths.

Joachem (2010) may be the only paper that considers the response of freight agents to a marketable permit system, in this case, a cap-and-trade emissions program. With the forwarder data from Bühler and Joachem (2008), a multi-agent mesoeconomic model (a behavior-based model) was developed. The model accounts for the freight transportation market by treating shippers, carriers and freight forwarders as one agent class. The actions of this freight agent are simulated using a nested logit model. Oil companies are the permit holding agent in the cap-and-trade scheme (which is situated in the context of the European Union Emission Trading Scheme (ETS)). Therefore, what is proposed is an "upstream" marketable permit system since the permits are held by companies at the top of the supply chain (alternatively, it would be a downstream system if carriers, shippers, or receivers had to hold permits). With higher fuel prices from the cap-and-trade scheme, the freight agent decides whether to use road or intermodal transportation to fulfill an order. The simulation showed that high fuel prices in a closed cap-and-trade scheme (i.e., a transportation-only scheme) could reduce vehicle-miles traveled.

There are also few policy documents that explicitly consider the idea of marketable permit system for freight. Raux (2010) presents a system of "tradable fuel rights" for freight transportation in the context of the ETS. In this system freight agents have quotas on the amount of pollution they can emit based on fuel consumption. From the presented discussion, major questions in this type of systems are how to distribute the permits among the different freight agents, how effective would they be in changing behavior of for-hire carriers, and how to monitor agent emissions and ensure compliance. It appears that an unexplored idea is the design of marketable permits systems aimed specifically at receivers in an urban area. As seen from the previously reviewed literature, receivers are the agents that control when carriers travel. Holguin-Veras considers persuasive or voluntary programs to encourage receiver behavioral changes. An alternative would be a regulatory regime that establishes limit's on the external costs that a receiver can cause with its delivery decisions. For example, a freight marketable permit system could be designed similar to Yang and Wang's link-based permits proposal, with the addition of a time component to encourage deliveries during optimal time-of-day periods. The carrier would need to submit a certain number of permits to use a facility (perhaps as a function of truck type, fuel used, and time-of-day), but the permits would be obtained from the receivers being serviced. Carriers using the facilities without the required "mobility permits" would incurred significant fines. This system would be easy to monitor (using the same technologies of the electronic tolling system) and it would create an environment where receivers willing to change their behavior could receive revenue from selling their unneeded permits to other firms. Also, by reducing the number of permits that cleaner vehicles require to use the facilities, carriers could be incentivized to compete by adopting newer technologies. The advantage of marketable permit systems is that they achieve predefined environmental or traffic-related targets, assuming that freight agents do not game the system. A major disadvantage is that such a scheme may be difficult to implement from a political perspective.

3. Research opportunities and closing remarks

It appears that Holguin-Veras et al. (2006) is the only empirical study that has systematically analyzed the effects of a pricing program on freight transportation. However, there are several interesting pricing programs implemented around the world that would seem to merit an evaluation similar to the PANYNJ time-of-day pricing study. For example, British Columbia, Canada, recently introduced a carbon tax that strongly affects the cost of fuels used carriers. This is a unique carbon pricing program whose impact on freight operations should be studied. Additionally, the results of Sathaye et al. (2010) show that new evaluation methodologies are required to ascertain the impacts of off-peak hour delivery policies. It seems that a multi-objective optimization approach could be used to determine the best delivery periods according to a series of, perhaps conflicting, objectives. Further research is also required to evaluate the monitoring, compliance and economic viability issues associated with Holguin-Veras' tax deduction proposal for receiver's that accept off-peak hour deliveries. In regards to mode choice, it would appear that the main difficulty is lack of access to rail or other modes. Studies are needed on freight and logistic networks design at the national level and the role of government investment interventions.

The idea of marketable permits to control the negative externalities of freight transportation exists mainly in subsections of a few policy papers. Rigorous mathematical analysis remains. Though it would appear that this strategy is dead upon arrival due to its novelty and potential political toxicity, its possible benefits, namely, the achievement of preset environmental or mobility objectives, make it warrant further research.

The negative environmental and mobility impacts of freight transportation require the implementation of innovative policies. Pricing mechanisms are one of the instruments of choice to internalize external costs. However, the literature reviewed in this paper suggests that freight pricing might only have marginal effects on the behavior of freight agents. Among the reasons for this is the power of receivers in determining travel times and the lack of access to alternative modes of freight transportation. The price signals received by carriers appear not to be strong enough to modify receivers or shippers' business practices. However, these findings are conditional on pricing that is, perhaps, indeed too low. The literature also reveals that at relatively high tolls freight behavioral adjustments can occur. The question is if the tolls at which freight agents respond are so high that they would result in a net loss of social welfare. The integration of pricing and incentive policies requires further exploration, as does the idea of marketable permits for freight transportation. Barring drastic technological or economic changes, effectively addressing the external cost of freight transportation will require additional policy research, and, ultimately, political will.

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