

A Market for Transport

Eliminating Congestion through Scheduling, Routing, and Real-time Pricing

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16 November 2016

Abstract

Traffic congestion is a global problem with annual costs approaching \$1 trillion. In Los Angeles alone, traffic jams cost \$23 billion each year. These costs are unnecessary. Advances in mobile communications and computer technology now make it possible to efficiently schedule, route, and price the utilization of roads. Doing so can eliminate congestion, enhance safety, and increase traffic throughput—all while raising much-needed revenue to modernize decaying infrastructure and improving the allocation of investment. We describe a market design for a transport market based on efficient scheduling, routing, and pricing. Road use is priced dynamically by the marginal demand during constrained times and locations. In unconstrained times and locations, a nominal fee is paid for road use. Transport is scheduled based on forward prices and then routed in real time based on real-time prices. Efficient pricing of network capacity is not new. Wholesale electricity markets have been dynamically priced for over a decade. Communications markets are adopting dynamic pricing today. Efficient pricing of road use, however, only recently has become feasible. Advances in mobile communications now make it possible to identify and communicate the location of a vehicle within one cubic meter—allowing detailed measurement of use. User preferences can be communicated both in advance to determine scheduled transport and in real time to optimize routes in real time. Computer advances also facilitate efficient scheduling and pricing of road access. Consumer apps help road users translate detailed price information into preferred transport plans. Computers also allow the independent system operator to better model demand and adjust prices to eliminate congestion and maximize the total value of road use. An independent market monitor observes the market, identifies problems, and suggests solutions. A board governs the market subject to regulatory oversight. The goal of the market is to maximize the value of road use via scheduling, routing, and pricing. The optimization of road use eliminates congestion, making our roads safer, faster, cleaner and more enjoyable to use.

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Introduction

America's surface transportation system is composed of a network of interstate highways, state roads, local streets, bridges, overpasses, and tunnels. The 46,876 miles of Interstate highways in the United States contain 55,512 bridges and 82 tunnels. The overall road system covers over 4 million miles of state roads and millions of miles of local streets. That huge system is vitally important for the movement of both people and freight. Americans traveled almost 3 trillion miles on U.S. roads in 2011, which was nearly double the amount traveled in 1980, and spend almost 175 billion hours in transport each year, valued at some \$760 billion (in 2007 dollars).

America's extensive transportation network is dogged by an array of endemic problems that impede its performance. Traffic congestion is a mounting concern, particularly in urban areas. In 2014, congestion wasted 6.9 billion hours of motorists' travel time and almost 3.1 billion gallons of fuel (Schrank, Eisele, Lomax and Bak 2015). Congestion's overall social costs are growing rapidly over time; the congestion "invoice" in the United States for added costs in terms of fuel and time grew from \$42 billion in 1982 to about \$160 billion in 2014 (in 2014 dollars)—almost a three-fold increase—in the 471 urban areas studied by the Texas Transportation Institute (Schrank, Eisele, Lomax and Bak 2015).

Many economists and policy analysts believe that the best solution to America's ongoing infrastructure funding problem is widespread adoption of direct road-use charges. Such charges go by several names, including mileage-based user fees and road-usage charges. Each assigns a price per unit (e.g., per mile) of road use that may or may not vary depending on the scarcity of road space at that specific time. We describe a market for transport that maximizes the value of the transport network through efficient scheduling, routing and pricing of road utilization.

Wholesale electricity markets are a useful analogy.² Electricity markets have operated on this basis for over a decade. Resources are there optimally scheduled and priced one day ahead after which a real-time market allows for necessary adjustments throughout the day. In transportation, early versions of congestion pricing are seen in certain express lanes, in Uber's surge pricing, and in airlines pricing of flights. Our approach goes beyond these early versions, building on the success of electricity markets. Transport is scheduled and priced in advance with real-time routing and pricing to reflect inevitable changes.

In addition to mitigating traffic congestion, dynamic pricing creates a non-distortionary revenue source for infrastructure operation and maintenance. Further, the resulting congestion prices provide essential information to direct scarce investment resources toward projects where those dollars are most highly valued by road users and away from lower-valued uses. Dynamic pricing thus provides a crucial link between customers' value of a facility and investment flows. Stated differently, congestion pricing creates objective market signals regarding where additional investment should be directed based on users' willingness to pay. This addresses one of the most challenging problems facing transportation policy

² A second analogy is in wireless communications (Cramton and Doyle 2016), but time-and-locational markets in communications are only beginning to be implemented.

today: the perceived misdirection of scarce public funding dollars caused by widespread earmarking and high-profile, pork-barrel projects.

Although these are core benefits, congestion pricing is appealing for several additional reasons, which include: (1) generating sustainable, long-term transportation system funding; (2) divorcing charges for use of road space from fuel type used, which makes road charges independent of rapidly evolving engine technology; (3) adopting the basic horizontal-fairness principle that motorists who use roads should pay for them, which enhances social equity; (4) allowing scarce road space to be allocated to motorists who value it most highly at that particular time of day; and (5) encouraging commuters to explore travel alternatives during peak times by providing current toll prices. Although partial, this list suggests that social benefits created by dynamic pricing of road use are likely to be substantial.

Commentators have been aware of road pricing's many benefits for decades. Writing in the early 1950s, Milton Friedman and Daniel J. Boorstin noted that:

At first glance, it seems hardly possible that this apparently trivial problem of how to charge people for the highway services they use is a key to the whole problem of how to plan and pay for better highways; yet it is just that. This fact cannot be too strongly emphasized. It is a key not only for a system that would involve operation of roads by private enterprise but equally for the present system of public operation. Should a particular road be built? How should it be built? How should it be financed? Should an existing road be maintained, improved, or allowed to deteriorate? If we could charge directly for the service of the road, we could answer those questions—whether under private or public ownership—in the same way that we now decide how many automobiles should be manufactured, what kind of automobiles should be manufactured, how their production should be financed, whether a particular model should be discontinued, and so on. (Friedman and Boorstin 1996, 223)

At the time Friedman and Boorstin were writing (1951), tolls were all paid in cash. Widespread tolling implied stopping to pay tolls, thus slowing travel.

Despite broad academic agreement, use of direct road-use fees has been limited in the United States. Although Oregon recently debuted a system-wide user fee program (Morris 2015), road pricing is most often accepted on new lanes, such as high-occupancy toll (HOT) lanes, or on conversions from high-occupancy vehicle (HOV) to HOT lanes. This has left existing transportation facilities—often older roadways in need of fresh investment—out of the new funding streams generated by that pricing. Moreover, only a few small sections of the highway system, such as the I-35W MnPass Express Lanes in Minneapolis, are dynamically priced.

Analysts have attributed the limited use of road-use fees in the United States to motorists' opposition to new rates and fees. Because motorists often think that the cost of roads is already covered via gas taxes, dynamic pricing may initially be viewed as new taxes, which is why state fuel-tax rebates are crucial. Such issues are particularly important for existing transportation facilities, where user-fee revenues are usually focused on improving road quality but less often on adding additional capacity easily visible to motorists. Many commentators argue that displaying tangible improvements from road pricing greatly enhances motorists' acceptance of user fees.

Dynamic pricing and traffic congestion

Although a move toward using direct road pricing rather than fuel taxes to finance roads is an important step in improving transportation policy, its effect on traffic congestion will be limited unless the price charged varies with the costs that one motorist imposes on others by choosing to use a particular facility at a particular time of day. Similar to a pipe with water flowing through it, or a wire carrying electrical waves, a road, bridge, highway, or tunnel has a physical capacity limit: one lane can only transport a certain number of vehicles per hour.

When many motorists try to use a facility at the same time, the facility becomes congested, like a clogged water pipe. Traffic flow collapses, and the bridge, highway, or tunnel is unable to handle as many vehicles as its physical capacity allows (that is, when traffic is flowing freely). When drivers decide to use their vehicles, they incur a number of costs. These include the cost of fuel, depreciation of their vehicles, time spent driving, and wear and tear on transportation facilities, as well as the crowding out of other motorists using the facilities at the same time. The drivers will bear many of those costs directly, and will therefore take them into account in their decisions about when, how often, and how far to drive. They will, for example, bear fuel costs, vehicle depreciation, and time costs.

They will not, however, bear directly the costs associated with facility wear and tear or the crowding out of other motorists who also want to drive at that time, and thus will not take them into account in their driving choices. Their decisions will therefore not be aligned with the true overall cost of using particular facilities at particular times. Facility wear-and-tear costs can easily be addressed through a nominal fee for road use.

The second component, however, is more complex, since motorist crowding has non-linear effects on travel time. That is, as a facility gets close to its physical limits, even a small increase in the number of vehicles leads to a large drop in the speed of all vehicles. If one additional motorist tries to use the road at those peak times, he imposes a large cost on all other motorists through slower travel times. The motorist who decides to use a highway at 3:00 a.m. imposes no crowding or congestion costs on other motorists, since there is usually excess road space, while one who instead uses the highway at 8:00 AM, when many other motorists also want to use it, imposes substantial congestion costs.

Under the current approach, the individual motorist does not consider those large social crowding costs. The second key aspect of road pricing is thus a variable charge, or congestion price, to reflect the costs of social crowding. The phenomenon described above suggests the effectiveness of such charges. If even a small number of motorists can, through congestion prices, be encouraged to drive at other times, to use alternative modes of travel, to carpool, to telecommute, or to adjust in any number of other ways, then traffic flow will rise disproportionately to the number of motorists who choose *not* to use the facility at that time. Reducing the number of drivers by as little as 5 percent at peak times may enable traffic to flow smoothly, allowing the same facility to handle many more vehicles. Variable road prices therefore have the effect of allocating scarce road space at peak times to those who value it most highly. They will choose to use it at those times and pay the associated higher fee.

Under the current approach, available transportation capacity is allocated by queuing. Although queuing may be acceptable for seating at a restaurant, it is a wasteful method of apportioning something as important as scarce space on a transportation facility. Queuing ignores the cost that one motorist imposes on others in trying to use a facility at peak times, as well as the differing values motorists place on the road's use at particular times.

Because congestion prices keep traffic moving smoothly, travel times also become more predictable when road space is accurately priced. This is critical to parents, for example, who need to pick their children up (or drop them off) from school or day care at specific times. It also reduces the time wasted in planning for possible congestion, or in leaving a time cushion to allow for travel uncertainty. Furthermore, congestion prices help ensure that facilities are used more evenly throughout the day.

Current use of congestion pricing

Congestion pricing is not a novel concept. As noted, similar variable charges have been successfully utilized in other industries. For example, airfares, cell phone rates, electricity rates, room rates at hotels and resorts, and fares on Amtrak and some local transit systems use variable pricing. Congestion pricing has also been used successfully on a number of U.S. roads. It is currently used in Minneapolis on the I-394 MnPass Express Lanes, which are dynamically priced in real time. It is used on the I-15 FasTrak Lanes in San Diego, where prices are updated every six minutes, and on the I-25 express lanes in Denver. It is also used on the SR-91 Express Lanes in Orange County, California, where the price varies between \$1.15 and \$9.25 per trip and is posted prior to entry so motorists can choose between priced and non-priced lanes. Priced lanes are popular because they save substantial amounts of time. The Oregon pilot program mentioned earlier indicated that variable pricing could be incorporated into an overall pricing approach.

Many international examples of the use of congestion pricing are also available. In 1975, Singapore became the first city to implement it successfully for urban traffic. Under this approach, called the Area Licensing Scheme, cars were charged an additional fee to enter the central business district between 7:30AM and 9:30AM. This form of congestion pricing is known as cordon or central area pricing. It was strikingly successful, resulting in a 73 percent decrease in the use of private cars, a doubling of bus usage, and a 30 percent increase in carpooling. In 1995, congestion pricing was extended to three of Singapore's major freeways. On one freeway, average speed during the morning peak increased from 31 to 67 kilometers per hour. Other examples of cities using congestion pricing include Bergen, London, Oslo, Stockholm, and Trondheim.

In addition to the demand-side benefit of helping to manage traffic flow, variable pricing creates another, supply-side, benefit: it provides information on how much motorists value the use of particular facilities and thus reveals the most valuable investments. Prices reveal value, and the congestion price required to smooth traffic flows is a reflection of how much value motorists place on a facility. Relatively high prices suggest that motorists place a high value on using that facility during peak times. The social returns to expanding the road, bridge, or tunnel will thus also be high, and investment should be directed there. By providing an observable, objective indication of where expansion of the system should or should not take place, congestion prices also help depoliticize transportation investment, making it more efficient. A

consensus has emerged that tolling (and, importantly, public-private partnerships) can provide critical information on where investment should take place and thus reduce political influences in transportation spending.

If road users are prepared to pay a price for the use of roads greater than the costs of providing additional road space (including all costs, externalities etc.) then the additional road space should be built. As in any other economic activity, the charge for the use of the new facility should be sufficient to finance its cost. In short, road pricing and congestion pricing would yield important benefits on both the demand and supply sides of the transportation sector.

New technologies and dynamic road pricing

Technological developments in electronics and communications allow for much more accurate pricing of the use of road capacity. Currently available technologies allow the use of a road segment to be priced to the sub-meter level. Moreover, road use can be priced in real time based on current conditions of scarcity. Data on the current price of road capacity as established by user demands and measured externalities can be fed into the vehicle's on-board computer, giving directions to the driver in real time on what route to take. Alternatively, for autonomous vehicle's, real-time road price data can direct the vehicle's route decisions without driver intervention. In principle, real-time adjustment by vehicles in response to highly granular road pricing data has the potential to eliminate all traffic congestion.

Such approaches are being used successfully in other contexts. The most analogous is the real-time pricing of wholesale electricity. In restructured markets in the United States, electricity prices at each location reflect the efficient congestion prices. Electricity supply and demand is scheduled to maximize gains from trade subject to all physical constraints. The electricity is produced at least cost and consumed by those valuing it the most. The analogous outcome in transportation would be efficiently scheduled transportation. Road use would be utilized to the maximum extent possible, and priced high enough to ration demand at the efficient (uncongested) level.

A key principle of the electricity market is open access. The open-access market substantially enhances competition and efficiency in electricity. Those same benefits could accrue in the pricing of road capacity.

With open access, transmission capacity cannot be withheld. This has profound implications for pricing—spot-market pricing reflects congestion. The congestion price is zero at times and locations without congestion; however, during congestion the prices balance supply and demand at each location. This is called *locational marginal pricing in the real-time market*. It works extremely well. The high level of price transparency not only leads to efficient short-run decisions, but provides a wealth of market information for longer-term planning including future network investments.

Since real-time congestion prices tend to be volatile, electricity market participants have a desire to manage risks. Forward auctions, conducted in advance of real time, allow participants to make plans and lock in prices consistent with their needs. The market also allows traders to arbitrage across related products—such as yearly, monthly, and spot products in the same area—to improve price signals and resource allocation. In modern electricity markets, the vast majority of energy trades in advance of the

real-time market. The forward markets enable planning and hedging of risks, while the real-time market sends just the right price signal to efficiently manage congestion. With road access, more volume is apt to trade in real-time, since individual demands are difficult to predict. Forward markets may still play a useful role for those with more predictable demands.

Alternative market designs for road access

Congestion pricing for road access is apt to be introduced gradually as the technology evolves and opportunities are identified. In the simplest case, congestion pricing may be limited to key bottlenecks and new express lanes. Further, pricing may be limited to too narrow a range and perhaps adjust too slowly to fully relieve congestion. Nonetheless, these steps will reduce congestion and are likely to build support for more significant management of congestion.

Additional steps would expand the number of roads with congestion management and relax the constraints on pricing. The result would be further improvements in congestion pricing and reduced congestion. However, the system would remain one where a system operator is adjusting real-time prices to limit congestion, rather than a full optimization and scheduling of transport.

The final leap forward involves both full optimization and scheduling of transport. The system operator would receive preferences from all vehicles for road access at alternative times, such as \$10 at the most preferred time to travel from A to B and then lower prices at inferior times. The system operator then optimizes the expressed demands with the available supply to identify the assignment of road access that maximizes the value of road use. The optimization would also identify congestion prices that support the efficient assignment. Although this is a complex optimization, the problem is made easier by the limited number of bottlenecks and the large number of vehicles. The latter reduces the lumpiness of the problem making it more likely that efficient congestion prices exist. Another helpful factor is that aggregate traffic patterns tend to follow a predictable cycle.

One important detail is the timing of the optimization. The state of the system and preferences are constantly changing. The initial optimization needs to be done when preferences are fairly complete, not too far from real time, and then re-optimized as circumstances change, say in response to a lane loss.

The evolution of the road access market from primitive to advanced is both desirable and inevitable. We have seen this evolution in other industries. Again the electricity market may be the best example. Early markets of about twenty years ago did a good job of facilitating trade across locations, but initially ignored important factors such as congestion pricing. This shortcoming was resolved with the introduction of locational marginal cost pricing. Many other shortcomings have been addressed both in response to better market rules and improved technology. The result has been a steady and significant improvement in electricity markets over the last twenty years.

A key insight from experience with electricity markets is that it is important to adopt as good a market design as possible initially, but to also ensure that issues of governance and management are such that there are strong incentives for constant improvement of the market over time.

In electricity markets, scheduling of generating resources plays an important role. This is because many resources are large and limited in how quickly they can respond—both time to start/stop and ability to ramp up/down. As a result, in electricity, the optimal scheduling of resources was introduced early to the market.

Efficient scheduling may be much less important in road access because of the large number of vehicles and the speed with which marginal vehicles can respond to price information. This suggests that a useful market simplification, at least initially, may be to focus entirely on efficient congestion prices and to initially ignore scheduling of transport. We do that in the initial market design discussed below. In the subsequent section we extend the market design to include forward purchase and scheduling.

Congestion pricing of road access

We now present a market model for road access based entirely on efficient congestion pricing. Operation of the transport system is centralized, although users' decisions on road use are decentralized. Transport is not scheduled. Vehicles and drivers simply respond to congestion prices that are set to efficiently manage congestion.

The market is conducted by an independent system operator (ISO). The ISO's mission is to maximize the value of the road resource. The key instrument available to the ISO is the ability to set efficient congestion prices. The ISO models demand for road access and establishes prices at each congested segment and at each time to minimize congestion. Usage is monitored and charged to each user based on the marginal system cost of segment use (including congestion externalities).

The modeling of demand is critical to establishing efficient prices. Users do not directly express how they substitute across alternative travel times, but simply select their most preferred option given the current prices and expectations of future prices. This complicates the ISO's modeling, but the ISO will have an abundance of data on transport choices with which to adjust prices. When prices are set too low, congestion appears; when prices are set too high, the segment is underutilized. Uncertainties in the system mean that the ISO cannot operate the road at 100% capacity. Some capacity is reserved to handle momentary surges in demand or drops in supply.

The modeling and management of the system is a complex engineering problem. Nonetheless there is good reason to think that the ISO can address this challenge well. The problem is well-studied in the economics and engineering literature and there have been large computational and algorithmic advances in recent years. Most importantly, it is now possible to monitor a vehicle's road use precisely, even down to the lane of travel, with existing mobile communications.

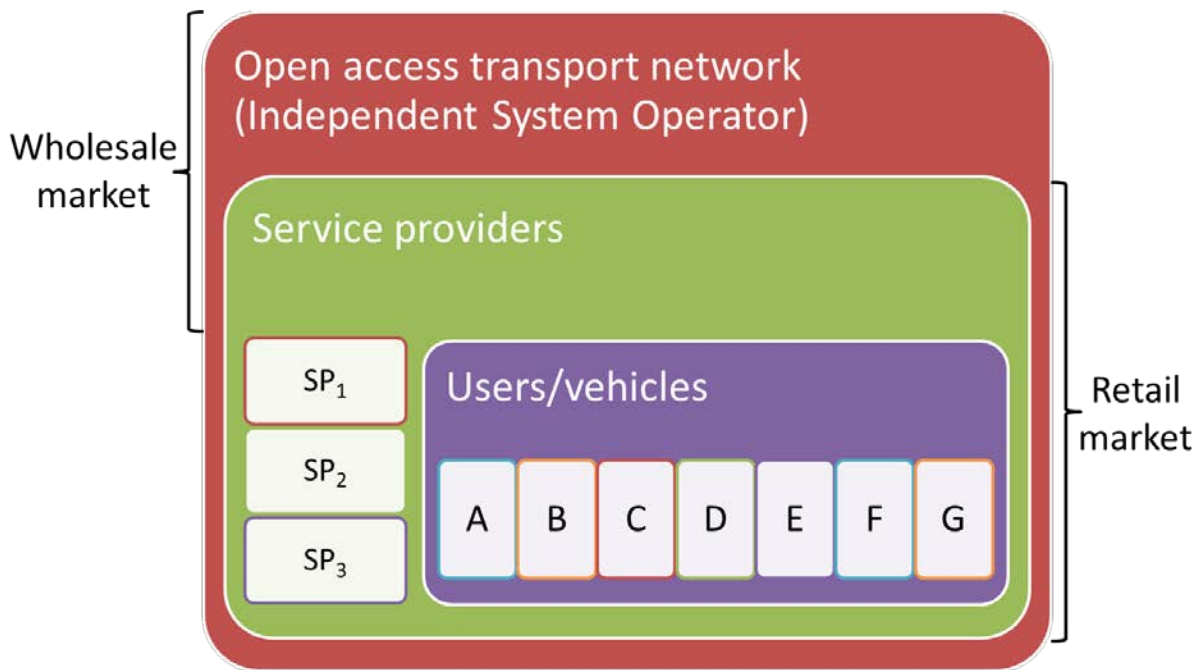
A second challenge is consumer acceptance. Consumers must be able to easily use and understand the system and see large benefits. Given that the status quo involves much frustration and delay, the reduction or elimination of delay and frustration is the source of consumer gain that will breed acceptance. But ease of use is also necessary. Sophisticated apps are needed to translate a consumer's preferences and the price information into a recommended transport strategy or menu of choices. All of this is possible with existing technology.

This market design focusing solely on congestion pricing seems to be a good starting point. Eventually, the market may shift to a more complex system that both prices *and schedules* transport system-wide. However, congestion pricing alone is much simpler and likely to go a long way toward maximizing the value of road use.

A wholesale market for transport

We now discuss an alternative market design that is built on the wholesale/retail market model. This is the market model successfully used in electricity markets for more than a decade (O'Connor, et al. 2015). The independent system operator has the same mission—to maximize the value of road use—but does so by operating a wholesale market in which service providers (e.g., Uber) compete for road access in forward markets as well as in real time, aggregating the demands of individual users. Wholesale pricing is determined in frequent auctions. The market model is shown in Figure 1.

Figure 1: Wholesale/retail market model



Users provide the fundamental demand for road use. Service providers compete for users in the retail market. Providers that offer more attractive plans are apt to be more successful. Some large companies, such as UPS, would participate directly in the wholesale market.

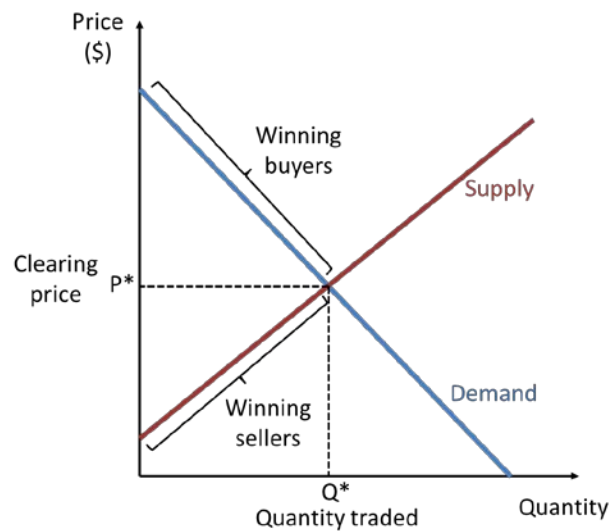
An advantage of the wholesale market model is that entry at the service provider level is relatively easy. This fosters competition and innovation, which is desirable given the important role played by service providers. In the wholesale market, service providers aggregate user demand. To do this well, the service provider must develop a user app that enables users to easily and effectively express demand. The service provider also guides the user, both in scheduling future demand as well as routing during real time. Finally, the service provider establishes user plans and settles payment. We expect a great deal of innovation to occur in service provision.

The wholesale market allows a relatively simple product design. The product is a slot on a congested road segment at a particular time. Time is broken into discrete intervals, such as 10 minutes, to keep the number of products manageable.

There are three promising features of the market. First, the number of congested road segments is limited. The most obvious congested segments are bridges, tunnels, and other bottlenecks. Second, the congested segments are highly predictable. Rush hours are a good example. Third, demand does respond to price, even close to real time. The demand response takes one of four forms: (1) time shifters, who shift transport to a less congested time; (2) route shifters, who shift to a less congested route; (3) mode shifters, who decide to take a train, bus, or bike, rather than drive; and (4) curtailers, who decide to work at home or otherwise eliminate the transport. In one sense, responding to price in transport is nothing new. Today the “price” is delay cost. Users do respond to this price, but today the price is waste and is set incorrectly—the delay cost does not reflect the negative externality one user imposes on others. In the market model, congestion is eliminated—the real-time price is set at the marginal value of demand at the point of supply and demand balance.

The foundation of the transport market is the real-time market, pricing road use in real time, say every ten minutes. The real-time market is a physical market, based on actual (physical) road use. One challenge of the real-time market is that prices can be volatile as it becomes more difficult for demand to respond to events, such as a lane loss, in a short period of time. User apps can redirect traffic given preferences and prices, but the response is limited.

Figure 2: Single-price auction model



Each product is traded in a single-price auction, as shown in Figure 2. Bidders express demand schedules, which indicate the quantity demanded at each price. The ISO forms the aggregate demand curve and crosses it with supply to find the clearing price (P^*) and quantity (Q^*) where supply and demand balance. All trade takes place at the clearing price. Demand schedules are expressed with a series of price-quantity pairs to form a weakly decreasing demand curve.

To mitigate risk and promote efficient scheduling, it is important for the market to provide multiple opportunities to trade. We envision three forward markets: yearly, monthly, and daily. The ISO determines the supply offered in each forward market consistent with service providers' interest in taking forward positions. The ISO offers more supply at higher prices.

Service providers bid in the forward and real-time markets to maximize net value to users and manage risk. Typically, this involves purchasing some fraction of user demand in each of the markets and to make adjustments to positions as uncertainty about demand is resolved.

The forward markets are financial, not physical. Service providers take positions in the forward markets, while subsequent markets allow adjustment of positions as uncertainty is resolved. Speculators also participate in the forward markets, arbitraging across forward markets. Profitable speculators improve price efficiency in forward markets before covering positions in the real-time market.

In the yearly auction, service providers estimate demand for the coming year and bid in the auction based on this demand and expectation of future prices. In the monthly auction, service providers now have better information about demand and can make adjustments to their current positions. In the daily auction, further uncertainty about demand has been resolved. Service providers can further adjust positions. The real-time auction occurs shortly before physical consumption.

Having multiple opportunities to trade reduces risk to the service provider and facilitates planning. Forward markets also facilitate price discovery through price transparency. Finally, the forward trading mitigates market power in the real-time market by putting service providers in a more balanced position entering the real-time market.

The further forward markets (yearly and monthly) offer more aggregated products to promote liquidity. For example, it would be natural to have a weekday product and a weekend-holiday product for each congested road segment and 10-minute interval. Thus, with the 8AM weekday product, the bidder is purchasing some number of slots on each weekday of the month or year in the 8AM to 8:10AM interval for the specified road segment.

Governance

The independent system operator conducts the market for road access. "Independent" means that the ISO has no ownership interest in the road network and no interest in the congestion revenues collected. The ISO is charged by its board to operate the market to maximize the value of road access. The ISO's chief instrument to achieve that efficiency goal is congestion pricing, setting prices for road use that mitigate congestion.

An independent market monitor observes the market, identifies problems, and suggests solutions. "Independent" in this case means that the market monitor, in addition to being independent of the market participants is also independent of the ISO. The market monitor brings expert market knowledge. Importantly, the market monitor is not a judge; the market monitor cannot enforce market rules and inflict penalties. Rather the market monitor is an observer who writes reports and makes

recommendations. In electricity markets, this has allowed the market monitor to quickly identify and address problems. The same would be true here. The market monitor reports to the ISO board.

The board oversees the ISO. To ensure that the board includes the knowledge and views of a diversity of market participants, the board has affiliated directors who are affiliated with a particular stakeholder group. The board also has a number of unaffiliated directors who are independent of the stakeholder groups, but bring essential subject matter expertise. Unaffiliated directors are approved by the regulator.

Conclusion

Congestion severely reduces the value users get from our road infrastructure. Worldwide congestion costs are estimated at about \$1 trillion per year. Fortunately, as a result of technologic advance, we are at a point where we can largely eliminate congestion through efficient congestion pricing. In the simplest approach, an independent system operator models demand and computes real-time prices for road use to maximize the value of road access. User-friendly computer apps armed with this price information then guide consumers in making transport choices consistent with their preferences.

A more sophisticated market design is based on a wholesale market model, as we see in electricity markets. The advantage of a wholesale market is it allows relatively easy entry as a service provider. The ensuing competition among service providers then promotes innovation. This innovation helps service providers to better understand user demands, translate user demands into bids in the wholesale market, and develop forward trading strategies to mitigate risk.

A complete system of scheduling, routing, and congestion pricing may seem like a radical idea. It, however, has been successfully applied in electricity markets for over a decade. Modern mobile communications allow road use to be monitored and charged based on real-time scarcity. Doing so gets the most out of our existing transport infrastructure and simultaneously provides essential funding of the roads and valuable price information to evaluate road enhancements.

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