TRANSPORTATION WHITE PAPER

Fair and Efficient Congestion Pricing for Downtown Seattle

July, 2019

Prepared for:

Uber Technologies, Inc.

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ECONorthwest is solely responsible for the contents of this report.

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Any errors or omissions are entirely our own.

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Summary

Congestion Pricing Gets a Close Look

Uber supports congestion pricing as a solution to urban traffic and so sponsored this white paper to explore the potential impacts of one approach to introducing tolls in Seattle. This analysis uses the best available information on regional travel patterns and the Seattle road network from local planning agencies and Uber's own operations. While the results offer considerable insight into how congestion pricing could work in Seattle, additional analysis would help validate and extend these findings.

The City of Seattle released a Phase 1 congestion pricing summary report in May 2019 that reviews lessons learned from other cities. The City's report also identifies potential pricing policies for additional study including an area pricing policy. We analyze one version of area pricing in this white paper that we label Fair and Efficient tolling. The City's Phase 1 report maps out a multi-stage public process that includes a public vote. Uber intends that this study support the City of Seattle's efforts to shape a congestion pricing policy that is equitable, beneficial to residents, and capable of gaining public support.

Fair and Efficient Pricing Would Reduce Traffic Significantly

Tolls to enter downtown Seattle that take into account the hourly demand for travel are estimated to reduce congestion:

- Auto travel times in downtown decline by 30 percent during the morning and afternoon commutes.
- The average time savings from tolling for auto travelers is estimated to be 6 minutes per peak period trip with an economic value of over $90 million per year.
- Bus transit speeds increase and so does ridership. Transit trips into downtown are estimated to increase by 4 percent, even without investments in new transit service. The percentage increase in transit usage would be largest for trips originating in neighborhoods closest to downtown Seattle.

Tolls Could Generate Annual Gross Revenues of $130 Million

Tolls to minimize the costs of congestion on downtown roads would need to vary hour to hour to reflect peak and off-peak demand. Tolls would range from $1.50 at midday, to a peak of $3.80 in the afternoon, to $0 between 11pm and 5am. The particular version of area pricing we evaluated only charges one toll per day for the most expensive hour the vehicle travels within the downtown tolling area. The maximum charge any one vehicle would pay in a single day is therefore $3.80.

This toll structure is estimated to generate gross revenues of at least $130 million per year. By way of comparison, the Puget Sound Regional Council maintains records of public sector transportation revenues and expenditures for the 4-county region[1]. In the year 2014, regional transportation related revenues (relating to city streets, county roads, local transit, Sound Transit[2], and state highway and ferry programs) totaled around $7.8 billion[3]. Gross revenues from the proposed congestion charge is thus equivalent to less than 2 percent of the regional public tax revenues currently dedicated to transportation purposes.

Based on experience in other toll settings, the annualized capital costs and operating costs of the tolling system, as a share of gross revenue, could range broadly depending on the technologies selected for collection and enforcement[4]. Many program design decisions would determine the actual implementation costs for tolling downtown Seattle. As a result we do not specifically estimate the net revenues available for other public purposes such as transit investments and road maintenance. Additional work on toll system design could yield those estimates.

High-Income Households Pay Most of the Tolls

Even before considering potential uses of toll revenue, the burden of tolls is estimated to fall most heavily on those best able to pay. Households in the lower 50 percent of income earners would pay less than 25 percent of the total tolls while the top 10 percent of income earning households would pay nearly 25 percent of the tolls.

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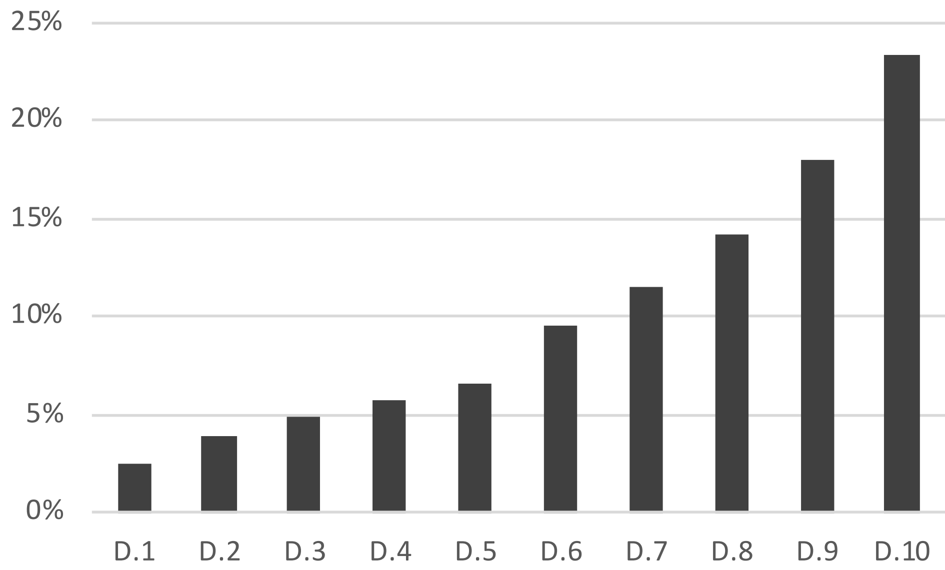
1 https://www.psrc.org/sites/default/files/rtp-appendixp-financialstrategy.pdf

2 This period did not yet include revenues associated with the latest ST3 voter approved program.

3 Adjusted to 2018 dollars.

4 Very preliminary estimates could place toll system operating costs somewhere between 10 and 20 percent of gross revenues.

Share of Toll Revenue Paid by Regional Household Income Decile



Source: ECONorthwest

Toll Rebates for Low-Income Households

Though households below the regional median income are estimated to pay just 25 percent of the total toll collections, people in that income group who must pay tolls would find them burdensome since the charges represent a larger share of their income than is true for higher income households. Rebating a portion of the net toll revenues to modest income households could eliminate this potential burden.

Using $50 million per year of the net toll revenues, the City could implement a mobility fairness program. Such a program could target rebates for moderate income downtown employees, low income households' trips into downtown for critical purposes, and support the general mobility needs of low income Seattle households.

Using toll revenues, Seattle based employers could provide employees whose incomes are near or below the regional median a monthly e-purse starting at about $85, or about $1,000 per year. Eligible service expenses might include transit fares, bike-share expenses, shared-ride expenses, parking charges and tolls. For the eligible employees that daily pay the toll to enter downtown Seattle this could entirely offset daily expenses. For employees that pay the downtown toll less frequently, or avoid the toll entirely by taking transit or other means the e-purse disbursements could represent a net fiscal gain.

Rather than harming moderate-income workers downtown and low-income Seattle households, congestion pricing with toll rebates could put money in people's pockets. As a group, those households eligible for the e-purse and other rebates would receive $50 million while paying $31 million in tolls.

Commuters from Outside the City Would Pay Fair Share

Commuters who live outside Seattle contribute to the city's congestion and wear and tear on its roads. Trips originating outside the City of Seattle are estimated to pay 44% of the total toll revenue in this analysis. Those travelers would all benefit from improved travel times in and out of downtown Seattle and may also benefit from any street or transit improvements funded from net toll revenues. Moderate income downtown employees living outside of Seattle could receive the benefits of the e-purse mobility program, and low-income households from outside Seattle could also receive a voucher for tolls paid for critical trips purposes into downtown.

Next Steps

This white paper offers a promising glimpse of a fair and efficient approach to congestion pricing that could generate significant benefits for the city and potentially win broad support. It also identifies additional analytic work that could be done by the City of Seattle, others working in the public interest, and the professional planning and engineering community to advance public understanding of how best to implement congestion pricing.

Background

Current State of Urban Mobility

Cities are busy, dynamic, complex environments that create social and economic value at a large scale.

Public rights-of-way enable people, goods and services to move through urban places in the service of creating that social and economic value. These rights-of-way are limited resources that face many competing demands. And they are congestible.

As a result, most successful cities are also plagued by chronic traffic problems on urban streets during peak periods of travel, which represents a sizable drain on the productivity of urban economies. The time spent in traffic is largely unproductive and lost forever.

Urban roads are also often undermaintained, largely due to a lack of available funding for investment in their upkeep. Deteriorating road surfaces lead to vehicle damage, and eventually undermine the foundations upon which the roads are built. These are costs that compound with time.

Urban transit often cannot keep pace with the demand for services. Effectively competing with auto modes involves providing fast, frequent and direct services from trip origins to destinations. Yet transit vehicles often operate in the same failing traffic conditions as automobiles. And providing urban rail corridors everywhere there is strong demand for transit is prohibitively expensive.

Increasingly, urban residents are looking for transportation options. Walking and biking are important means of urban mobility, but retrofitting urban places to make these options safer and more effective takes time and resources.

In the meantime, peak period traffic is one of the most visible and dominant characteristics of urban life. And urban congestion is a fundamentally limiting force on the economic productivity of cities and their residents, as traffic congestion grows its negative consequences increase as well.

New Information, New Services

As long as there have been cities there has been urban congestion. And while urban congestion will likely never be eliminated, it can be managed, and its detrimental consequences minimized.

Recently there has been a proliferation of information available to individuals as they make travel decisions. Information technology has resulted in a connected world that makes real time information on the performance of urban transportation systems ubiquitous. Cellular connected devices offer bus arrival times, auto routing guidance, road closure and delay alerts.

New services are being designed and offered that change how we move and connect in urban places. Ride hail services allow us to respond to immediate needs and unplanned changes in our daily activities. Car, bike and other sharing services may change how we think about auto ownership. And same-day delivery for consumer goods, food deliveries and household services will alter historical patterns and practices around freight movement.

These forces seem irresistible and are potentially disruptive. And while they may alter the details around where and when urban traffic congestion occurs, they will not eliminate the underlying problems. Urban roads become congested during high-demand periods of travel.

How Congestion Pricing Can Help

The Persistence of Traffic

Peak period congestion on urban roads is a daily occurrence and is stubbornly resistant to attempts to reduce its influence on the lives of urban residents. Even large investments in road capacity, new transit services, dedicated transit rights-of-way, and non-motorized infrastructure have proven unable to significantly alleviate the pain caused by urban traffic. Anthony Downs introduced what is known as the *fundamental law of traffic congestion* as follows. "On urban commuter expressways, peak-hour traffic congestion rises to meet maximum capacity."[5]

The concept extends beyond expressways to urban roads more broadly. The *Fundamental Law* describes a process by which travel activities that are currently not able to occur during peak periods on the most desirable routes (due to congestion) converge onto any routes that are improved through investments. This convergence of travel (from other routes, times of day and modes) ultimately leads the improved facility to become re-congested.

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[5] Anthony Downs, 'The Law of Peak-Hour Expressway Congestion,' *Traffic Quarterly*, vol. 16 (July 1962), p. 393. The Fundamental Law is often misunderstood to imply that no investments yield improvements. Instead, it describes the general tendency of motorists to take advantage of the mobility improvements that are produced. And while the peak hour becomes congested there are gains to the new users and likely are speed improvement during shoulder periods and improved travel reliability generally.

The *Fundamental Law* helps explain why investments in roads, or transit services, on their own cannot obviate the peak-period congestion problem. This does not mean that those investments have no value, but rather that we can expect to have to live with congestion during high-demand travel times even after costly infrastructure projects have been completed.

And in our most urbanized settings, the rights-of-ways that are dedicated to transportation must compete with alternative urban uses. The total urban land dedicated to transportation rights-of-way is likely to decline over time, rather than increase. This means that any remedies to peak-period congestion will need to focus on the more efficient management of those rights-of-way.

How Peak-Period Pricing Works

Congestion-pricing attempts to make more efficient use of roads by directly charging a fee to the people who use them, when they use them. Flat rate tolls are one form of charging for the use of roads. But the major transportation problem in urban areas is congestion, which occurs when too many people want to use the same routes at the same time. Thus, congestion pricing is a variable toll that is higher on congested routes at congested times, offering a lower cost option when demand is less.

Ideally, variable tolling would apply to all roads in a region, and efficient tolling would be based on costs that vary by volumes on the roadways, vehicle type, facility, and distance. In practice, applying a congestion charge to all roads represents a major shift in policy and involves coordination across multiple public and private institutions.

Within urban areas with relatively mature transportation systems, peak-period demand also drives the need for new investments in road and transit infrastructure. Urban transportation systems are sized and built primarily in response to peak-period use. And since consumers (travelers) do not perceive the full costs their travel imposes on the system, their behavior leads to excess congestion and inadequately financed transportation systems.

Congestion pricing changes all this. Charges are levied selectively on certain vehicle-miles of travel (at certain times and locations). Traffic responds to these prices, which controls excessive congestion during peak periods. Congestion pricing generates revenue, from those who burden capacity, to invest in new transportation services where and when they are really needed.

Optimal Pricing

The theory of efficient pricing leads us to the notion of what is called variable pricing, i.e., pricing that varies with the vehicle class, and specific roadway conditions–especially the ambient level of congestion. There are many variations on this theme that have been devised to approximate variable pricing. The key ones, from a practical standpoint, are the following.

Ubiquitous Network Tolling

This is the most comprehensive version of tolling and the one that conforms most closely to what theory predicts will be the most efficient, and thus beneficial, tolling strategy. In this form, variable tolls are applied throughout a region's network on both freeways and arterials, and perhaps even local streets and roads. The tolls are variable by roadway segment, where a segment is large enough to make the pricing that is in place understandable by the motorist, but small enough to capture significant differences in level of congestion from one segment to the next. Implementation of network tolling is only practical with vehicle on-board tolling technology.

Freeway-Only Tolling

Freeway-only tolling is a compromise that focuses on the backbone facilities of the regional network. The technical implementation options are enlarged to include gantry-and-transponder type tolling technologies. In addition, communication to motorists of the toll policy is simplified because of the far smaller number of toll segments. The disadvantage of this approach occurs when the arterial road system is a viable alternative to freeway travel. With freeway-only tolling, diversion of traffic to arterials and local streets and roads will occur. If these latter facilities are convenient but more easily congested than freeways, the efficiency goals of congestion pricing will be compromised or thwarted.

Area Pricing

Area pricing involves levying tolls when one enters certain congestion-vulnerable areas. This involves defining a geographic zone and charging a toll as vehicles cross the boundary to enter or leave the charging area. Charges may be applied to vehicles crossing the boundary, or on any vehicles driving within the zone, or on a per mile basis while driving within the zone. The cities of London and Stockholm have adopted variations on the area pricing method of tolling their congested downtown. Levying area charges in a manner that reflects, even coarsely, the same charge that would be levied on the congested paths is very difficult. Thus, the area pricing tolls tend to be an approximation of efficient and ubiquitous tolling and can be expected, therefore, to not perform as well from an economic benefit standpoint. Nonetheless, they are relatively easy to administer, and have appeal on that basis.

Partial Pricing

Partial pricing involves tolling only portions of the network on some basis other than the roadway functional class. There are two, primary types of partial pricing in practice:

The High Occupancy Toll (HOT) lane version of this policy has evolved from the High Occupancy Vehicle (HOV) lane strategy. In this latter strategy, vehicles with high-occupancies have exclusive access to a special lane. The HOT lane is an HOV lane that also allows single-occupant vehicles (SOVs) to buy-in to the lane. The ability to levy, and the efficiency of, HOT lane tolls depends on the nature of the corridor (the number of general-purpose vs. HOT lanes, corridor volumes, etc.) and on the HOV-free policy. There are a large number of operating and planned HOT lane facilities. They have the attraction of requiring only a few gantries and transponder adoption by motorists to implement the policy.

Another manifestation of partial pricing involves selecting particular facilities for toll implementation. This is a fairly traditional application of tolling, with bridges or new facilities permitted to levy tolls–primarily as a means of financing the facility. The toll structure tends not to be particularly variable but, rather, with a constant charge for facility use charged to vehicles of various size or axle classes. Even if levied in a variable way, such selected implementations are not expected to yield significant efficiency advantages since their application is to a small fraction of total regional capacity. In addition, the distortion introduced by tolling only a portion of the network may be significant if alternative travel or development paths result from efforts to avoid the toll.

VMT Charges

A final class of pricing strategy is the Vehicle-Mile Traveled (VMT) Charge. Although many pricing strategies levy on the basis of vehicle miles, the term VMT Charge used here refers to the application of a flat, per mile charge at all times and on all facilities. VMT charges are usually advocated either as replacements for their near-equivalent, motor-fuel and weight-mile charges, or as arbitrarily-high levies intended to discourage driving, rather than improve efficiency per se.

Seattle Context

The City of Seattle is currently contemplating a congestion charge levied on vehicles entering the downtown. This is a version of the area pricing approach described above, and therefor is unlikely to yield the same benefits associated with a broader application of pricing. In particular, such a charge will typically over-charge shorter trips into downtown while under-charging trips with origins further away from the core.

Nonetheless, such a program can be designed to reduce congestion and capture some of the traffic relief benefits of a more optimal policy. Key features of a successful policy would include charges that vary by time of day and ensuring that all vehicles entering the congested area are subject to the toll. Failure to meet these requirements would result in poor performance and no real improvement to traffic congestion.

What This Paper Accomplishes

This white paper explores how new data can aid in the evaluation of an old problem (urban congestion) and program design of a potential remedy (area pricing). The paper aims to demonstrate the magnitude of the urban peak-period congestion problem and examines an approach to addressing that problem by doing the following:

- Help define the geographic scale and temporal nature of urban congestion
- Develop order of magnitude estimates of optimal toll rates based on existing congestion conditions.
- Imagine how congestion pricing could be implemented in a downtown Seattle setting.
- Describe the gross revenue opportunity and its potential uses.
- Propose one possible use of a portion of tolling revenues to improve the policy's fairness.

This paper summarizes a preliminary analysis of zone-based congestion pricing. There is nothing simple about congestion pricing, or the ways in which such a policy might influence human behavior and the urban transportation system. The analysis described here is a balance between simplicity and complexity, appropriate to this stage in the evaluation process.

Our approach, a demand elasticity model we refer to here as Method X[6], does not employ a network model, or traffic assignment process (see Figure 1 below). Instead it makes use of very detailed information on urban arterial speeds by time of day[7], disaggregate records of trips coming into downtown Seattle, optimal price theory to establish toll rates, and revealed responses to tolls[8] as a basis of estimating behavioral and revenue findings.

This approach has advantages and limitations. It makes use of detailed information about speeds and travel times on Seattle's roads and allows for a representation of behavior and results at a household level, but does not forecast a future condition and is not a full equilibrium result.

Preliminary analysis offers insights into policy suitability and allows high-level design questions to be considered. It is not a substitute for more detailed evaluation, but the analysis has been designed in a manner that allows for additional detail and/or feasibility analysis to be incorporated at a later date.

A preliminary analysis of congestion pricing can significantly advance our understanding of policy options (e.g. toll rates, tolling zone geography, design of supporting programs) at a relatively low analysis cost. This permits additional methods to be employed efficiently at a later stage of evaluation. Any final program design will require additional analysis as well as a testing

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6 Method X represents a low cost, flexible approach to analysis that does not require any specialized software licenses.

7 Uber Speeds data are described more later in the paper.

8 Traffic Choices Study, PSRC 2006

of a full range of assumptions that can appropriately reflect any uncertainties regarding the robustness of methods, policy design, and human behaviors.

Figure 1: Comparison of Method X and Typical Planning Models

	Method X	4-Step Planning Models
Analysis Dimension		
Time of Day Detail	Hourly	Peak/Off-Peak Periods
Values of Time	Continuous	Averages by HH/Trip Type
Household Incomes	Continuous	Averages by HH Type
Trip/Tour Purpose	Work/Various Non-Work	Work/Various Non-Work
Demand Geography	TAZ	TAZ
Mode Choice	Elasticity	Discrete Choice
Destination Choice	Elasticity	Gravity or Discrete Choice
Trip Generation	Elasticity	NA
Time of Day Shift	Based on Tolls and Time Costs	NA
Auto Assignment	NA	Various Methods
Free-Flow Speeds	Uber Speeds Data	Posted Speeds
Congested Speeds	Uber Speeds Data	Volume Delay Functions (VDF)
Traffic Volumes	Speeds Data and VDF	Traffic Assignment
Transit Assignment	NA	Various Methods
Toll Optimization	Speeds Data and Modified VDF	Modified VDF
Trip/Tour Origins	Region	Region
Trip/Tour Destinations	Congestion Zone	Region
Results		
Toll Revenues	Non-equilibrium	Equilibrium
Speeds	Non-equilibrium	Equilibrium
Incidence of Tolls Paid	Individual Household	TAZ & HH/Trip Type
Consumer Surplus (time savings)	Individual Household	TAZ & HH/Trip Type
Time period	Current	Current & Future Forecast

Approach and Methods

Overview

Urban street networks are more complex than sparse highway networks. However, the pricing principles that apply to urban streets are the same as for conventional highway settings. The work of Ken Small, Chu[9], Arnott[10] and others, has demonstrated that urban networks, in aggregate, may behave in a similar manner as individual congested links.

Conventional wisdom regarding congestion pricing has led to the design of cordon or area tolls (Stockholm, London) that are relatively unresponsive to the variability in traffic conditions. The result is both undercharging (resulting in excess congestion) and overcharging (resulting in significant losses of welfare to the public) for access to downtown areas. Avoiding these problems requires an understanding of optimal pricing theory and the dynamic nature of the local traffic conditions.

For this white paper, ECONorthwest first made use of Uber Movement 'Travel Time' and 'Speeds' data to help characterize the nature of Seattle downtown congestion, and to identify the design parameters of efficient congestion pricing policies. These design parameters include the geographic extent and duration of congested conditions, and the potential congestion pricing remedy. Subsequent tasks more fully specified those congestion pricing policy parameters by combining the initial assessment of congested conditions with other traffic data and empirical estimates of behavioral responses to downtown access charges. The approach is presented in Figure 2 below.

This white paper provides a generalized description of how the City of Seattle might implement congestion pricing in downtown, including the geography of the toll zone, example toll rates that approach the theoretical optimal tolls, a characterization of the aggregate behavioral response to tolls, and high-level estimates of gross toll revenues. Our approach abstracts from some of the complex dimensions of the behavioral responses to tolls. In lieu of using advanced, behaviorally detailed transport models that solve for network equilibrium, our approach makes use of a detailed representation of the road conditions, demand geography, toll rates and individual trip records, but adopts a more aggregate representation of transportation system user behaviors. We capture these behaviors using demand elasticities originally estimated from

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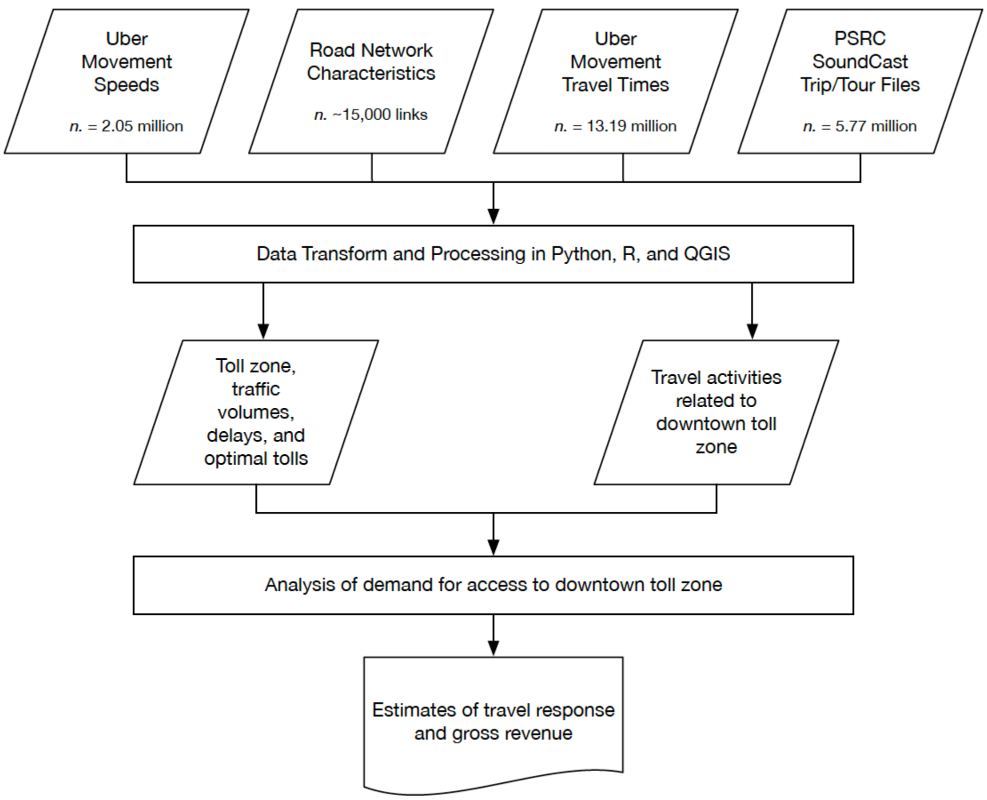
[9] Kenneth A. Small & Xuehao Chu, 2003. "Hypercongestion," Journal of Transport Economics and Policy, University of Bath, vol. 37(3), pages 319-352, September.

[10] Richard Arnott. 2013. "A Bathtub Model of Downtown Traffic Congestion," Journal of Urban Economics, 76: 110–121.

a road pricing experiment[11]. Together these analytic components constitute a framework suitable to test congestion pricing program designs for this type of early-stage evaluation.

The methods employed in this paper can advance the evaluation of congestion pricing and even support screening of alternative approaches. Later stages of analysis might eventually require the use of, and modification to, existing travel demand models used by the city and/or traffic consultants. Policy designs identified through this effort that gain support among key constituencies can later be studied in greater depth by the City of Seattle as part of their efforts to develop a congestion pricing pilot program.

Figure 2: Overview of Analytic Approach



Using Uber Data to Characterize the Network

Our initial task involved making use of existing data to establish a baseline understanding of the traffic conditions in Seattle that may argue for an application of congestion pricing. To aid in this analysis, Uber provided access to Travel Time data on its Movement© platform as well as a beta version of its Speeds data product. These datasets are derived from anonymized and aggregated Uber trip-level records. Travel time summaries are available for select cities,

[11] The *Traffic Choices Study* https://www.psrc.org/sites/default/files/traffic-choices.pdf was a revealed preference study implemented in the Seattle area that yielded disaggregate elasticities of travel demand under simulated toll conditions.

including Seattle. Travel times are estimated for each hour of each day between origins and destinations (Census Tracts or Transportation Analysis Zones). Data includes mean values and measures of variance and can be downloaded as .csv files for individual date ranges, or for entire quarters. In addition to travel times between origins and destinations Uber provided access to a beta version of its Speeds data. The Speeds data product calculates speeds for individual road segments from trips records. Like travel times, the speeds summaries are available by day and hour of day and include mean values and measures of variance.

For this white paper ECONorthwest made use of both Travel Time and Speeds summary (.csv) files for the first quarter of 2018. The first quarter was selected to avoid the influence of summer and holiday travel on the summary statistics. The data processing steps, however, can be replicated and applied to any temporal period. As a test we made use of data for the second quarter of 2018 that yielded analogous results.

Data provided by Uber yielded important insights into the dynamic of traffic (where, when, and for how long hyper-congested conditions persist) in downtown Seattle. Such congested conditions occur on specific links in a network but are also associated with behavioral choices tied to specific origins and destinations. The Uber datasets provide a unique opportunity to combine information about origins-destinations[12] and information about network operational conditions. Speeds data was initially employed to gain an understanding of the level of congestion on Seattle streets and to establish whether an identifiable area of downtown might be a suitable candidate for an application of congestion pricing.

Clustering of Roads Segments

Identifying a network of streets that are candidates for an application of congestion pricing begins with understanding the performance of those streets. If tolls will vary by road segment (ideal from an efficiency standpoint), then pre-defining the tolled network is less problematic. In the case of area charges, or zone-based tolling, a suitable geography must be identified in advance.

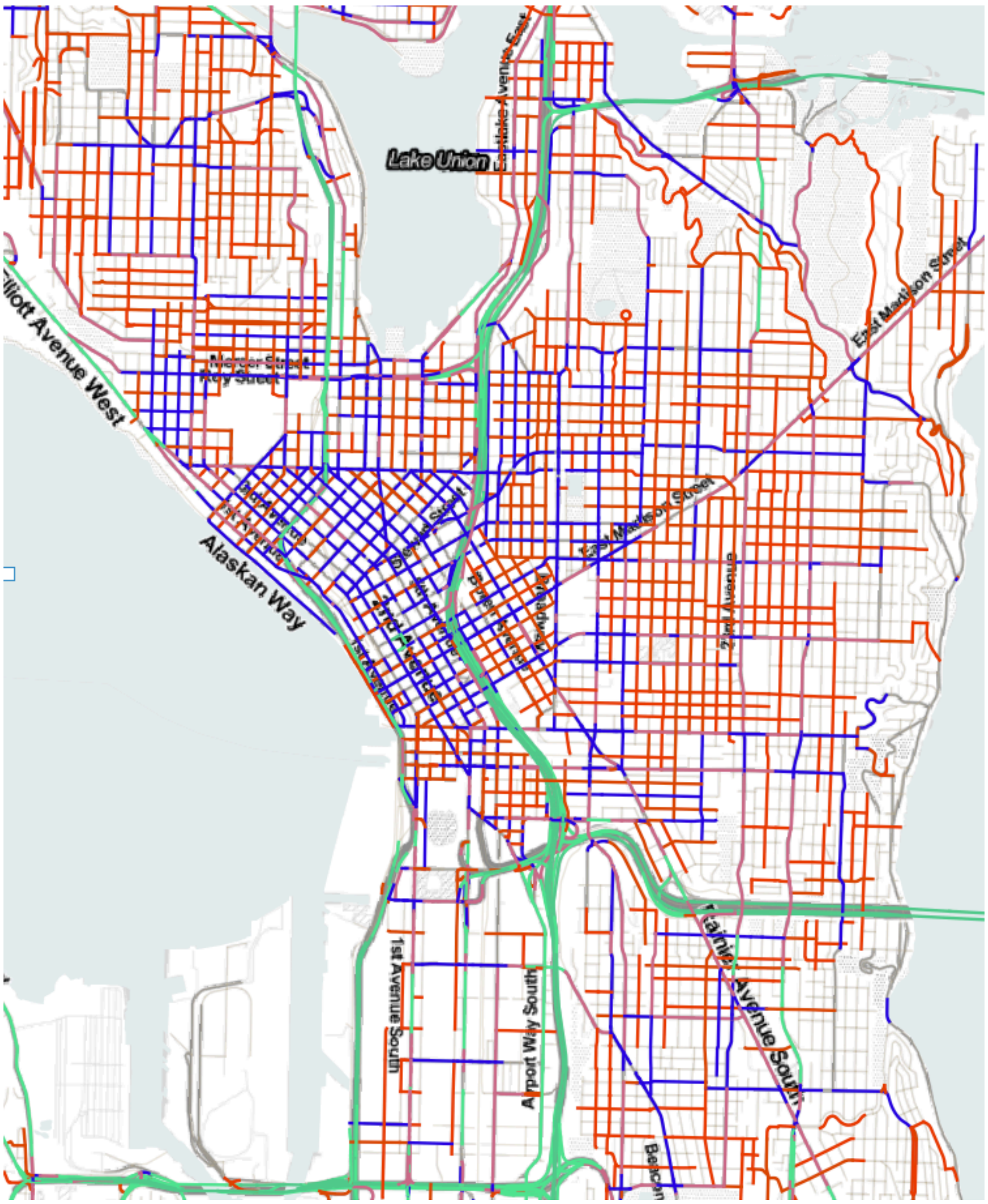
Toll zones must be comprised of road segments that have geographic integrity – they must be interconnected. One test for whether a specific network geography might work well as a tolling zone is to allow the zone to be “discovered” through some objective process that is ignorant of the geographic details of the road segments. We used an algorithmic network partitioning process that identified “clusters” of road segments that “behave” in a similar manner.

Clustering is the process of grouping together a set of objects (in our case road segments) such that objects in the same cluster are more like each other than they are like objects in other clusters. Our intent was to determine if the clustering process would identify a set of road

[12] The Uber Movement data represents a sample of trips in the road network. That sample is large and the calculations of performance, such a speeds, are a reasonable characterization of the network conditions.

segments within the downtown core of Seattle, thus indicating that zone-based congestion pricing might be a suitable remedy for congestion in this vicinity. We used the k-means clustering method in the R *cluster* package, where the attributes of the road segments that we partitioned included the 'mean speeds' and 'standard deviation of speeds' for every hour of the day across the first quarter of 2018. The results of this process are displayed in Figure 3 below. It is clear that most streets within the Seattle downtown core "behave in unison" with respect to the performance of those streets based on the variability of travel speeds.

Figure 3: Road Segment Clusters

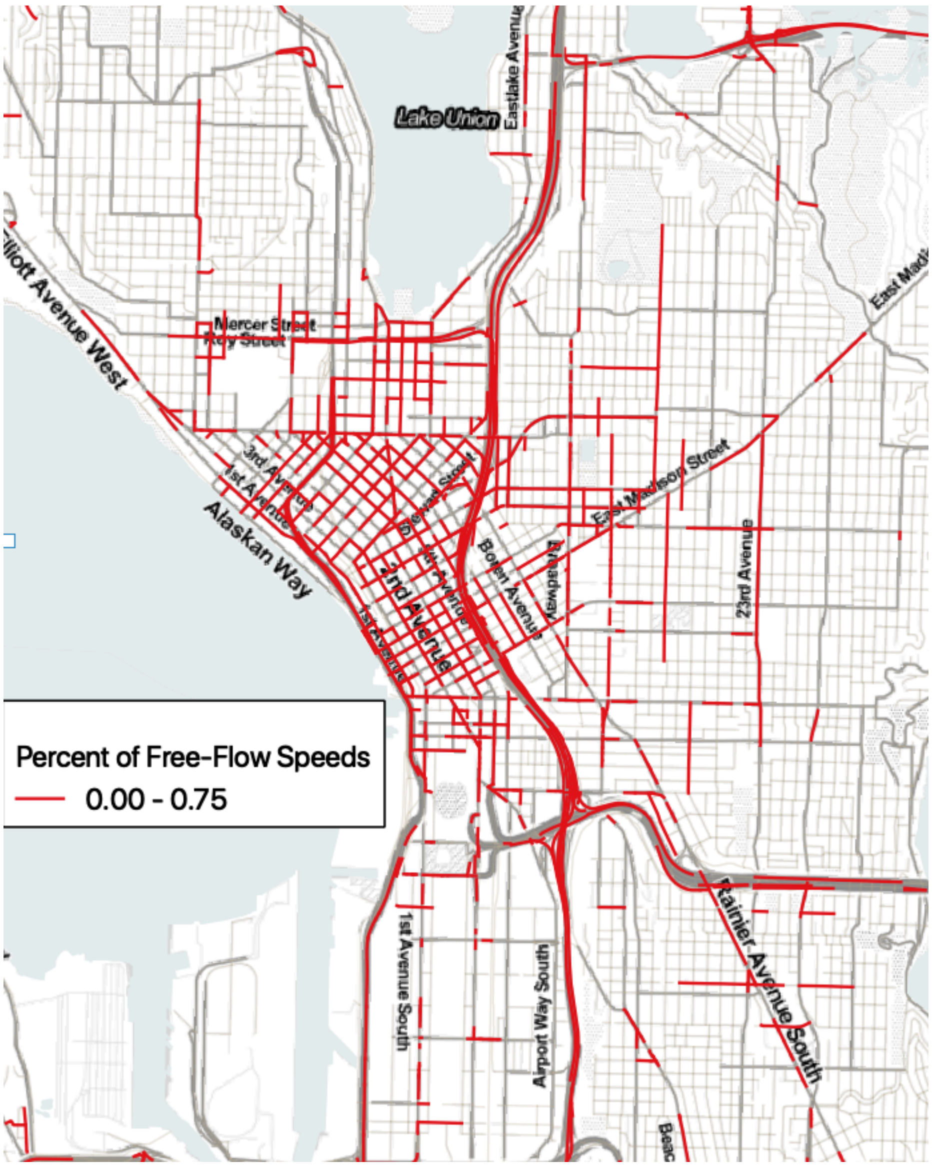


Source: Uber Movement Speeds data, ECONorthwest.
Note: Road segments with the same color are part of the same cluster and "perform" in a similar manner.

Congested Speeds on Urban Streets

An identification of a downtown cluster of road segments is intuitively confirmed by a visual inspection of a plot of segments' speeds as a function of their estimated free-flow speed. See such a plot for the 5pm hour during the first quarter of 2018 below in Figure 4.

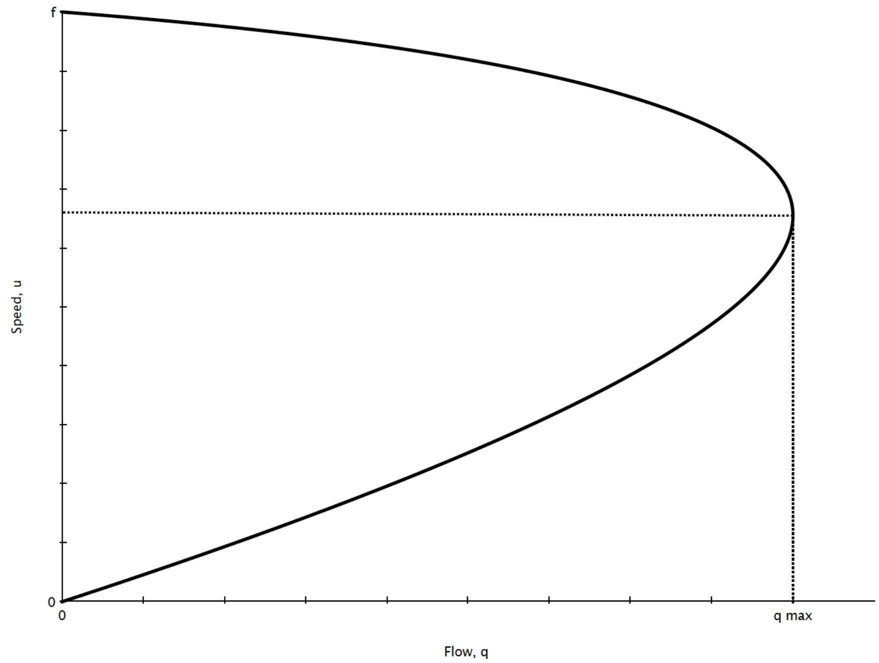
Figure 4: 5PM Speeds Below 75 Percent of Free-Flow Speeds



Source: Uber Movement Speeds data, ECONorthwest.

It is common in traffic engineering literature to represent the relationship between road segment speeds and traffic flow as a function or formula, such as the one below in Figure 5.

Figure 5: Speed-Flow Diagram



Source: ECONorthwest

This classic speed-flow diagram illustrates that as volumes on a road segment increase the speeds decline. The relationship is non-linear such that as volumes increase, the rate of change for speeds also increases. At some point maximum flow is reached, and at this point as the volume of traffic entering a road increases further, both the speeds and the flow exiting the road segment decrease. This is often referred to as a hyper-congested state. While the diagram illustrates a standard road segment with controlled access, it is generally applicable to urban streets as well, but somewhat complicated further by the nature of signalized intersections. In short, signals place other limits on speeds in the upper (free-flow) portion of the diagram and can result in "gridlock" as flows in all directions of travel effectively come to a halt during extreme peak travel conditions.

Streets with travel speeds that are below 75 percent of a free-flow condition are candidates for congestion pricing. Many of these streets will be in a hyper-congested state where reducing the volume of vehicles attempting to use the streets may actually result in an increase in the flow of vehicles in the network. Modest reductions in travel demand (say a 5 percent reduction in vehicle volumes) can result in significant speed improvements for the streets included in the toll zone.

Our analysis established that a set of streets in the downtown core of Seattle behave as if they are almost a single feature in a larger transportation network, and that these streets consistently exhibit travel speeds during key hours of the day that are consistent with a hyper-congested condition. This supports the conclusion that a carefully designed congestion charge, applied to this network of streets, could yield benefits in the form of reduced urban congestion, as well as yield important revenues, while avoiding some of the negative impacts that a less suitable charge for accessing downtown might introduce. However, estimating the toll rates that could yield these results cannot be done with data on facility speeds alone. To accomplish this, we turn to the next steps in our process.

Estimating Other Factors of Performance

Road Segment Volumes and Capacities

Estimating optimal tolls for segments of roads requires an empirical understanding of how quickly speeds decline relative to free-flow speeds as the volume of traffic on a road increases. In the case of freeways, this can often be observed from data on speeds as well as volumes captured by equipment embedded in the roads themselves. In the case of urban streets, such data is rarely available in the abundance, and at the resolution, required to estimate these relationships formally.

For the purposes of this white paper we employ readily available information about speed-volume relationship from the network models[13] that are used in the Seattle region to forecast travel demands. These models make use of what are termed volume-delay functions (VDF). These functions are of a family of functions initially developed by the Bureau of Public Roads (BPR) that take the general form shown below.

$$\text{VDF delay} = t_1 = t_0 + t_0 a \left(\frac{V}{C} \right)^b$$

where

t_1 = delay in minutes per mile

t_0 = freeflow delay in minutes per mile

V = total link volume in PCE

C = total link capacity in PCE

$a\,b$ = parameters of the BPR VDF formulation [14]

We matched Uber Speeds reporting segments to individual network links in the PSRC model's representation of the road network. These network links have attributes that include numbers of lanes, lane capacities, free-flow speeds and parameters (a and b) of the volume delay functions. With this information in hand, it is feasible to estimate segment-level volume-to-capacity relationships and subsequently estimate the implied toll rates. We substituted Uber Speeds

[13] The Puget Sound Regional Council maintains the regional demand models that include Seattle streets as part of the model road network.

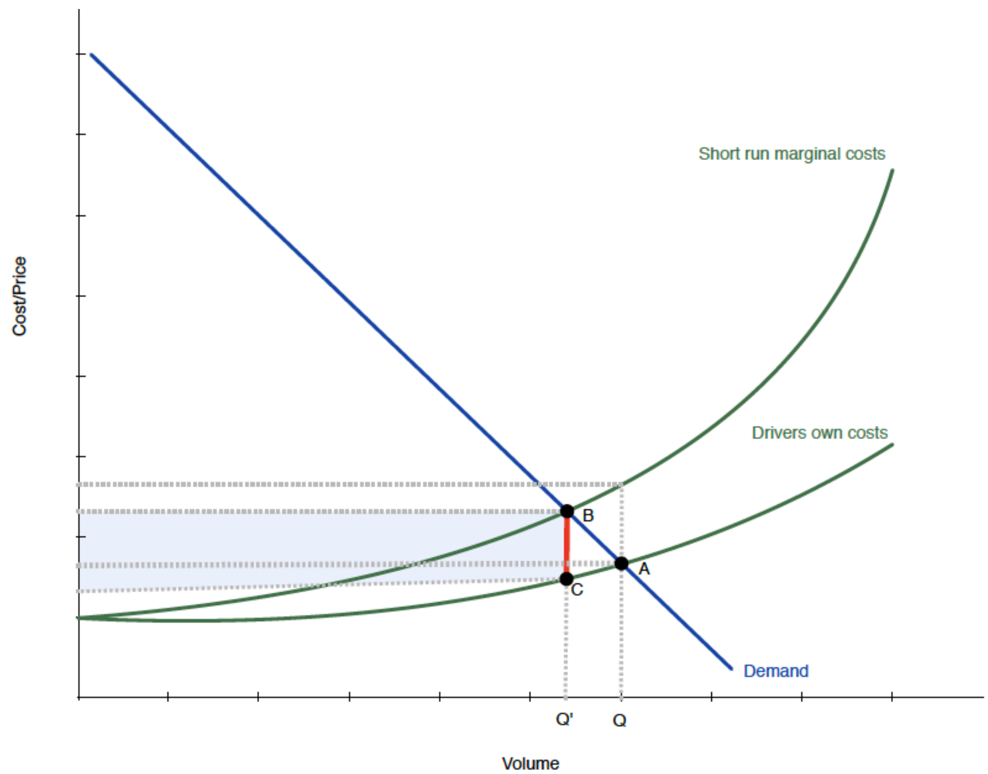
[14] PCE, Passenger Car Equivalent is a measure of the volume of traffic

estimates of free-flow speeds (empirical estimates) for the regional model's free-flow speeds (often a general representation as a function of facility type) in our calculations.

Optimal Tolls

As implied above, optimal toll rates can be estimated as a function of volume-to-capacity relationships and other parameters of the volume-delay function (VDF). This requires a general transformation of the VDF to represent the social costs of travel (congestion externality imposed on other vehicles) as well as the personal costs of travel (the travel time/delay experienced by each individual vehicle). The marginal cost of total travel time imposed on the traffic stream has the same mathematical form as the VDF itself. Hence, we use the term Augmented VDF to describe the relationship between the marginal cost and the V/C ratio. A stylized graphical representation of this relationship is depicted in Figure 6 below.

Figure 6: Standard Diagram of Road Pricing



Source: ECONorthwest

Since the user already bears his or her own costs of delay, the optimal toll is the difference between the marginal cost to the total traffic stream (upper curve) and those own delay cost (lower curve) for each user. Specifically:

$$
\begin{aligned}
\text{Efficient Toll, } P &= \frac{dT}{dV} - t_1 \\
&= \left(t_0 + (1+b)t_0 a \left(\frac{V}{C}\right)^b \right) - \left(t_0 + t_0 a \left(\frac{V}{C}\right)^b \right) \\
&= b t_0 a \left(\frac{V}{C}\right)^b
\end{aligned}
$$

From the above it is possible to calculate initial segment level toll rates for every hour of the day where demand, at each hour, is initially assumed to be fixed. Demand, of course, is not fixed in the real world, but the slope of the demand curve is not known with any certainty at this stage. Once tolls are implemented, two partially offsetting responses to tolls will occur. First, the tolls will result in user behaviors that avoid toll costs (route shifts, adjustment to the timing of trips, and changes in trip destinations). These behaviors will lower the volumes of vehicles on toll facilities. The second behavioral response involves a partial re-convergence of trips onto toll facilities to take advantage of the shorter travel times that result from the lower volume of traffic. The end result will be a new equilibrium traffic volume (Q' in Figure 6) and optimal toll rate (B-C in the same figure). For the purposes of the rest of this white paper, however, the initial toll rates will suffice as suitable approximations of optimal tolling practice.

Evaluating Trip Response

For purposes of further estimating the consequences of tolling practice, these initial toll rates are sufficiently close to the optimal tolls. However, our analysis must contend with the behavioral responses to those tolls. These responses determine many important consequences of toll policy (e.g. traffic diversion, new demands for transit services) as well as have implications for estimating the gross toll revenue.

In order to more fully explore these potential behavioral responses, we adopt a representation of travel demand that explicitly represents key characteristics of the trips that are being made. Trips into downtown Seattle have an origin, are made at certain times of day, in pursuit of some purpose, using specific transportation modes. All these trip characteristics are determined by the characteristics of the people who make these trips, and the households in which they reside, and choices they face.

We acquired data files from the Puget Sound Regional Council that contain lists of trips and tours (a tour is a set of trips that are linked together, e.g. from home-to-work and then from work-to-home) for all the households in the central Puget Sound region. These files are synthesized from household travel surveys, statistical representations of household characteristics, and the application of procedures developed for the SoundCast activity-based travel demand model. These synthetic trip and tour records are estimated from available aggregate information about households, jobs and flows of workers within the 4-county region.

The file of travel tours includes information about each tour including its origin location and time of departure, its destination location and time of arrival, departure and arrival time for the "return" (destination-to-origin) trip, its primary purpose (work, school, shopping, etc.), mode of travel, duration and cost of travel, and other characteristics. We also used the file of trip records (containing an equivalent set of trip characteristics) to add detail to our analysis. Each trip record includes a specific value of time that is derived from the estimation of a destination choice model. With this information, we used trip-specific values of time and employed purpose/mode specific elasticities of demand. And finally, we made use of the file containing synthetic households[15], allowing us to match household characteristics with tour records.

We were able to model the response to tolling by selecting tour records[16] with destination Transportation Analysis Zones (TAZs) in downtown Seattle. The model does not solve for a full equilibrium condition, but it retains segmentation by trip origins, travel mode, trip purpose, and hour of day, allowing estimates of behavioral responses to tolls to vary across those dimensions[17]. The model solves for an adjustment to the number of weekday tours coming into downtown Seattle from each origin TAZ, for each trip purpose, by each travel mode, by each hour, given any toll rate applied as a downtown access cost added to the total generalized cost (time and money costs) of each trip.

Estimating Gross Revenues

At the core of this method's response mechanism is a set of elasticities of demand for travel with respect to travel costs. For auto modes, the elasticities are for auto travel with respect to generalized costs. For non-auto modes, the elasticities are cross-price elasticities for transit use with respect to the costs of auto use. As toll costs increase, auto trips will decline and non-auto trips will increase. This allows for an initial set of travel responses to tolls to be estimated. The approach uses single elasticities (by purpose and mode, which corresponds to our value of time segmentation) to represent the sum of a variety of specific behavior changes (e.g. generation of trips, destination of trips). By calculating an initial demand response to tolls this approach yields estimates of gross toll revenues from any set of toll rates[18]. And gross revenues can be disaggregated by time of day, tour purpose, and origin location of trips paying the tolls.

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15 Synthetic households are a simplified representation of actual households that are derived from survey records and matched to control totals from census data. All SoundCast data represent a year 2014 population base; which we chose not to adjust to a 2018 population total, and as a result all our findings are conservative with respect to revenue findings.

16 The SoundCast trips records include over 14.4 million daily trips organized into 5.8 million tours. Of these, 350,000 tours have destinations that fall within the identified downtown toll zone.

17 While route choice is a typical response to tolls, in the case of cordon or area tolling, route choice factors in only for trips that pass through the toll zone without a destination within the toll zone. These trips are not captured in our analysis.

18 Since point elasticities are employed the toll rates specified must be in a reasonable range, excessively high or fractionally low toll rates will likely yield less realistic results.

A Test of Fair and Efficient Tolls

How Tolling Could Be Implemented

Congestion pricing for urban centers has typically been implemented as a zone-based toll. Vehicles traveling across a cordon line, or traveling within the tolling zone, pay a fixed rate fee. The fee might be levied only during daytime hours but essentially does not vary with level of congestion or by the hour of day.

These kinds of programs (London is the best known) are a fairly crude means of managing the urban congestion problem. Ideal tolls are levied on any part of a path where congestion occurs. In practice this is not always practical. This white paper aims to examine how a zone-based toll might be made as economically efficient as possible. We imagined a tolling program where tolls are applied to vehicle trips with destinations within downtown Seattle. A toll zone was "discovered" from data on the speed conditions on downtown streets, and optimal toll rates (by hour of the day) were estimated as a function of speed-flow relationship for those streets. These "link" tolls were rendered into trip-based tolls that were then applied to a set of travel records that represent the actual travel characteristics of trips that make a stop somewhere in the downtown toll zone[19].

A reasonable question, however, is how might such a program actually be implemented? The main elements of an operating toll program include:

- Registration of Customers
- Declaration and Verification of Vehicle Usage and Application of Toll Charges
- Billing and Payment
- Customer Care
- Enforcement

Current technologies allow for the precise measurement of vehicle locations, if those vehicles are equipped with low-cost devices containing a GPS radio[20]. Even smartphones meet the basic functional requirements. Users might be expected to register their vehicles and tolling

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19 The available trips records do not reveal travel paths that occur within downtown but where no stops occur downtown. In an actual implementation of congestion pricing, these trips should pay a toll associated with their use of the downtown street network.

20 It should be noted that GPS-based tolling technology would also allow for a broader, and more beneficial, form of congestion pricing that applies to the entire congested road network and not just limited to downtown streets. GPS- based tolling is in operation in Europe for heavy vehicles, is being tested as part of mileage fee trials, is used in by-the-mile insurance plans, and is being deployed in Singapore for network tolling.

equipment with the toll operator. Occasional users would likely pay a higher daily fee in lieu of the congestion tolls. Back-office functions would identify vehicles with accounts, or further process non-account holding vehicle records by matching license plates to registration records. Enforcement could involve a combination of stationary and mobile enforcement systems based on video license plate capture. Roadside infrastructure might be kept to the minimum amount necessary to sufficiently process and enforce toll transactions.

For this white paper, we imagine a single charge – per vehicle per day – that reflects the highest toll rate hour in which the vehicle operates within the downtown toll zone. For example, if a vehicle enters downtown prior to the morning peak when the toll rate is $1.00, parks, but then departs downtown during the afternoon peak when the toll rate is $3.80, then the daily charge would be $3.80. This approach maintains the incentive to minimize exposure to toll costs by avoiding the highest traffic times of day while allowing for a single daily charge to be applied to each vehicle. There are many other tolling approaches that are feasible, and that may more precisely target trips that contribute the most to congested conditions.

Tolls could be applied on a per-mile basis as vehicles drive within the toll zone. Alternately, vehicles could pay a downtown toll each time the vehicle crosses (in-bound and outbound) the zone boundary. Or, as in London, the toll could be a single daily rate applied to each vehicle operating within the zone. Each of these approaches will yield different amounts of revenue, different behavioral responses and result in different levels of traffic improvement. The methods outlined in this paper can be applied to each of these variations in toll policy. The specific approach we have analyzed (described above) was selected in order to 1) closely conform to familiar cordon-type tolling implementations, while 2) retaining the time-of-day variations in toll rates necessary to produce traffic relief benefits, and 3) as a means of being conservative[21] in our estimates of gross revenue.

Toll Zone and Toll Rates

The framework described above provides an opportunity to estimate an approximation of optimal congestion toll policy, applied within a downtown toll zone[22]. As described above, using Uber Movement data we established a potential toll zone and estimated downtown weekday toll rates by hour of the day. Figure 7 depicts the toll zone that is used in all the subsequent analysis steps.

It is feasible to refine the single toll zone into multiple zones that would each have different toll rates and schedules[23]. This kind of refinement would allow for a more precise control of

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[21] As an example we tested the revenue implications of levying a charge on both in-bound and out-bound portions of each tour. This variation in toll policy is estimated to increase revenue by about 30%.

[22] The downtown toll zone applies to Seattle surface streets and does not apply a toll for the use of I-5 or SR-99.

[23] There are other alternative approaches to levying an area pricing toll as well, including tolling on a per vehicle mile driven or per trip basis in downtown, with or without a daily maximum toll limit. The toll assumptions we employ in this paper are a

localized traffic conditions, but comes at the expense of increased program complexity for the operator and the users. In this white paper we treat the downtown as a single uniform toll zone where toll rates vary by time of day but not for different locations within the zone.

Figure 7: Downtown Seattle Toll Zone

Source: ECONorthwest

Ideally tolls are applied along each trip path, and wherever congestion occurs. In the case of zone-based tolling, the tolls apply only at the downtown destination. Zone tolls can be applied as a function of the amount of vehicle travel within the toll zone, or they might be a single toll applied to each trip that enters or operates within the zone. For the purposes of this white paper, we recalculate hour-specific per-mile toll rates into a single hour-specific toll applied to each vehicle trip within the toll zone independent of the amount of travel occurring within the zone. This assumption facilitates estimating trip-based demand responses but also partially offsets problems that arise from applying a relatively small (or large) toll to longer (or shorter)

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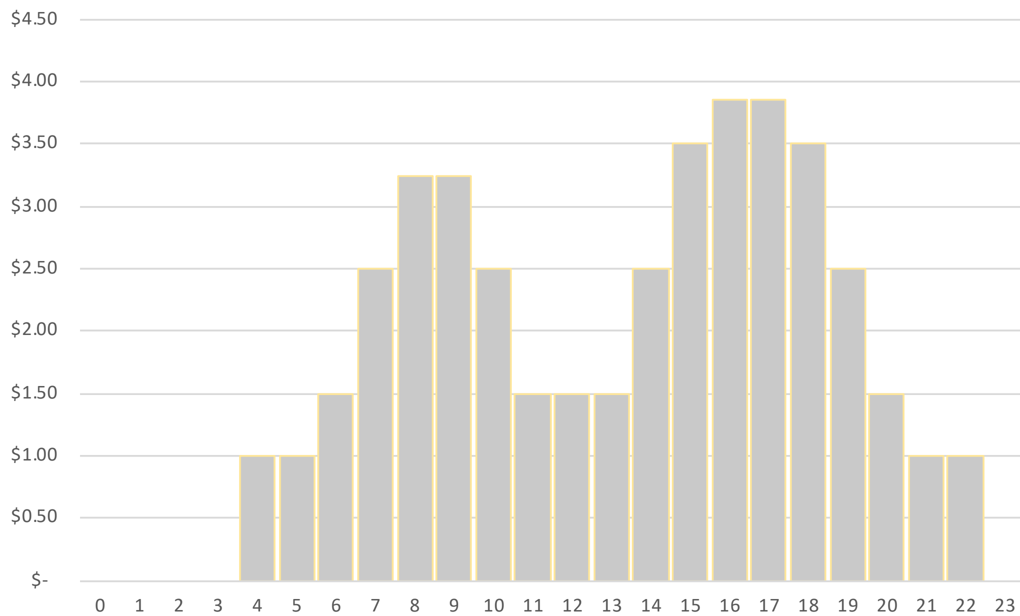
balance between optimal toll rates (that vary across time and space) and ease of understanding for the user and implementation for the toll operator.

distance trips with downtown destinations. Figure 8 displays the toll rates, by time of day, that are evaluated in this white paper.

Figure 8: Toll Rates by Hour of Day



Source: ECONorthwest

The somewhat steep drop in toll rates on either side of peak travel hours is, in part, designed to encourage time-of-day shifts in trip-making activities as one primary response to the toll policy. Alternative toll structures tested included more gradual drops in toll rates during the peak-shoulders but yielded larger than desirable declines in travel during these peak-shoulder hours.

These estimates of toll rates over the day derive from a large-scale synthesized rendering of household trip-making to downtown Seattle and models of how the speeds of different road segments vary with vehicle volumes. We expect that the optimal tolls for area pricing in Seattle would be close to our estimates, but they are unlikely to match exactly. It is also true that travel demand is dynamic over time responding to changes in income, employment, and the relative performance and costs of different modes, among other factors. For these reasons, we favor adopting Singapore's model of quarterly updates to toll rates, and the oversight of a Citizen's Panel, to ensure tolls are not too high or too low. Our toll rates represent a first-order estimate; it's important that policymakers preserve the flexibility to adjust tolls on a regular basis to ensure appropriate performance of the road network and maximum benefits to users of the city's transportation systems.

Findings and Implications

Tolls that are levied on autos accessing downtown Seattle increase the generalized costs of those vehicle trips. At the margin, some of those trips will not have a value high enough to justify the added costs, or other means of completing those trips will now be comparatively less costly. In response to tolls, some drivers will seek alternative means of satisfying their underlying travel needs at a lower cash cost than is possible when paying the toll. Tolls that vary by time of day allow additional options for avoiding high-cost travel conditions by changing the time of travel. And as the volume of vehicles in the toll zone decrease during peak hours the travel speeds increase resulting in further behavioral responses. Responses to tolls include changes in trips activities by:

- time of day,
- mode of travel,
- destination,
- and avoided trips altogether.

Our approach to estimating changes in trip activity collapses across some of these dimensions of response. The analysis employs demand elasticities that depict the aggregation of such behaviors, and independently estimates changes in transit demand in a similar manner. This approach is well suited to an initial evaluation of the magnitude of changes in trip activities and for estimating revenues. A more nuanced understanding of a fuller range of travel behaviors requires a more complex and behaviorally realistic model of travel demands.

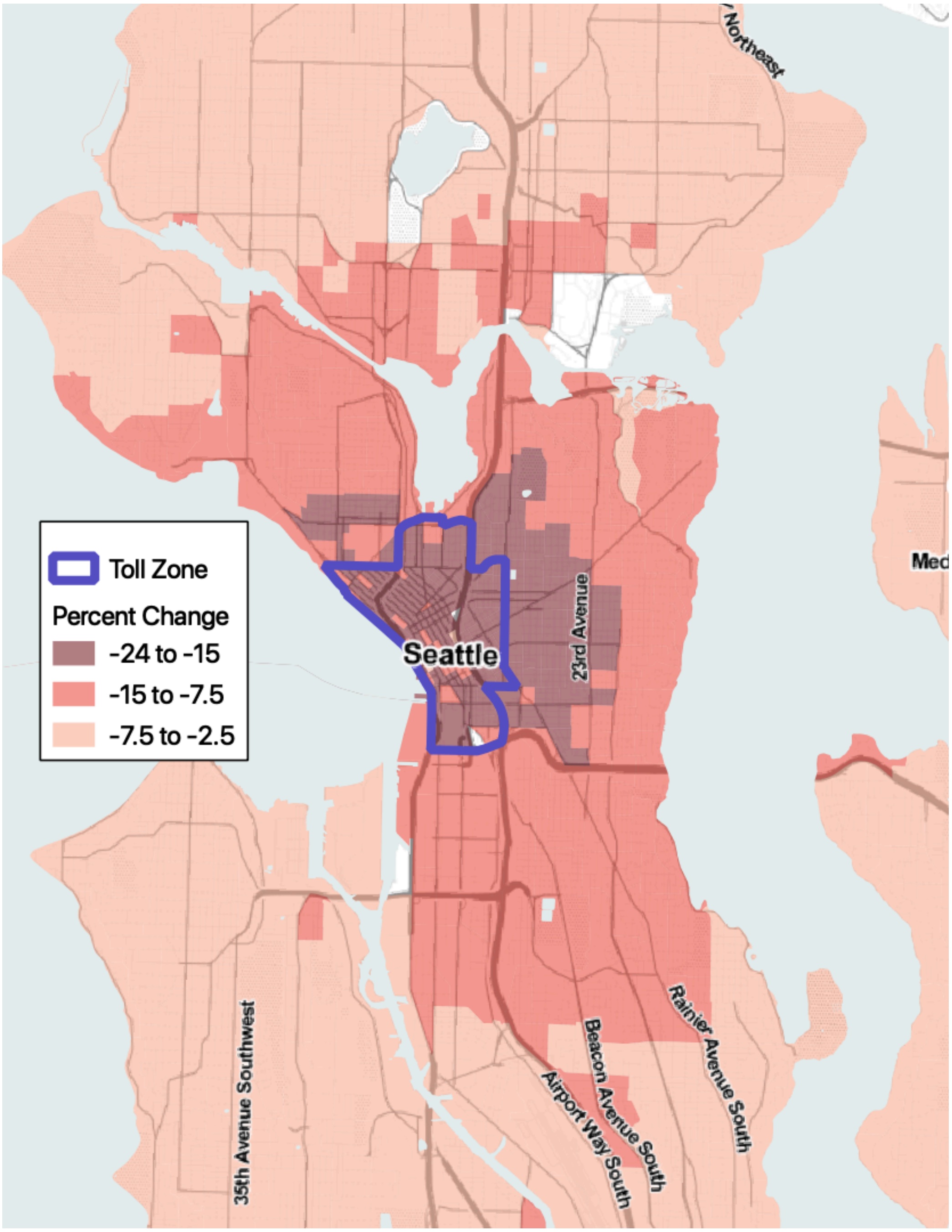
By calculating our demand response at the individual travel tour (or trip) level we isolate travel activities that originate or terminate in the downtown zone. As a result, travel activities that pass through downtown, but do not originate, terminate, or have an intermediate stop in downtown, are not captured in our analysis[24]. An implementation of congestion pricing would apply a toll to these through trips as they are contributing to congestion on downtown streets. Again, this limitation could be resolved through more advanced analysis where demand models and network models are tightly integrated.

Shifts in Auto Demands

Figure 9 displays trip origins (within the city of Seattle) where auto trips into downtown might decline the most (in percentage terms) as a result of zone-based tolls.

[24] This limitation will mean our revenue estimate will be lower than it would be if these trips were captured in our trip records. The effect is likely very modest as the number of these trips will be small.

Figure 9: Percent Change in Auto Trips by TAZ

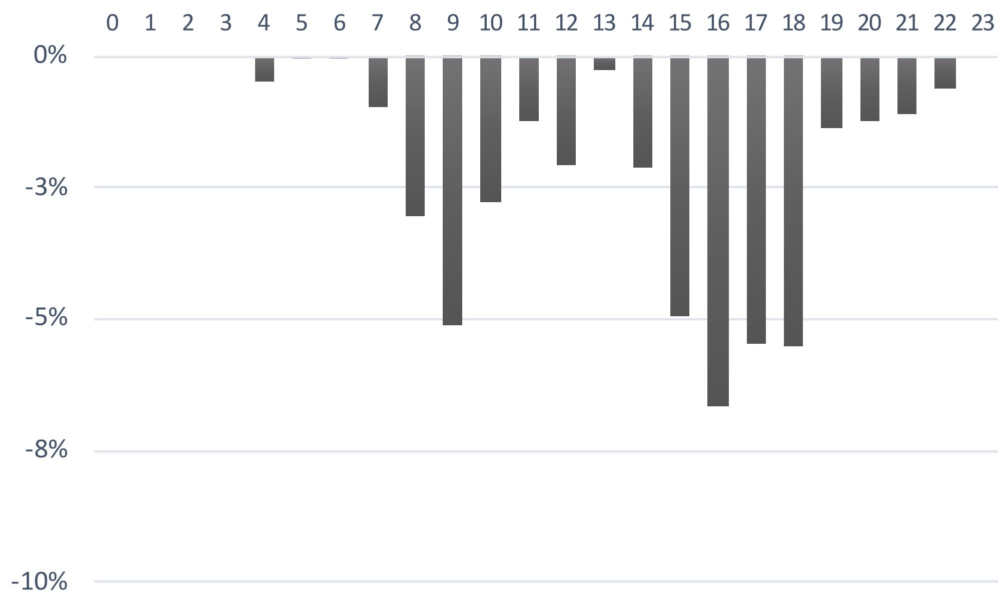


Source: ECONorthwest

Our analysis addresses changes in the timing of trips by identifying tours where the initial toll is above a certain threshold, when compared with the other generalized costs of travel, and shifting tours to an adjacent lower cost hour of travel. The new lower toll is included in the tour generalized cost, and demand elasticities are employed such that the increased travel costs (specific to that hour of travel) yield a reduction in the number of trips that are made into downtown Seattle. The relative flexibility in trip-making behaviors (timing of travel, the route that is chosen, the selection of destinations) is different for each individual traveler and varies over time. Future analysis could provide more detailed estimates of these kinds of behavioral responses.

Our approach to rendering time of day shifts in travel may underestimate the revenue expected from any specific set of time of day specific toll rates. A trip that would have been made in the highest toll period of the day may simply adjust to a shoulder period and pay a slightly lower toll, rather than avoid driving downtown altogether. Second, we may overstate the diversion of trips, especially during the shoulders of the peak. Instead we might expect to see a general flattening and broadening of peak travel. With these points in mind, Figure 10 displays our estimates of the percent change in trip volumes by hour of day, given the toll structure that was analyzed.

Figure 10: Estimated Percent Change in Weekday Auto Trip Demand by Hour of Day



Source: ECONorthwest

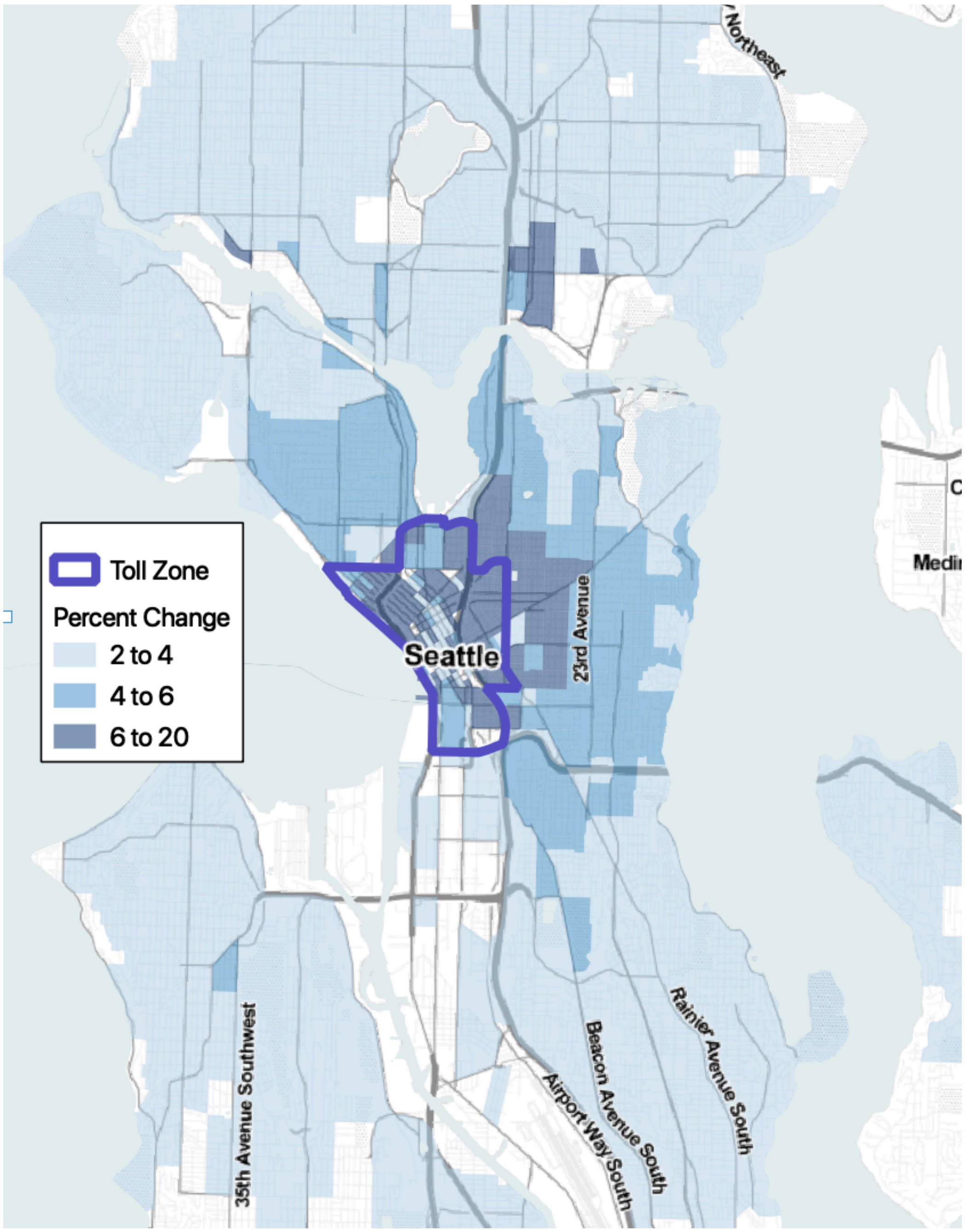
Earlier we described the non-linear relationship between traffic volumes and speeds. Even modest changes in the volume of traffic during peak travel can yield significant improvements in travel speeds and reductions in travel time. When traffic volumes are high, a 5 percent reduction in volume might yield 10-20 percent reduction in travel times, and a 10 percent reduction in volumes as much as 20-30 percent reduction in travel times. Congestion pricing (where toll rates vary by time of day) can therefore yield sizable travel time savings benefits[25].

[25] The full accounting of benefits requires an equilibrium solution for toll rates, traffic volumes and speeds. A partial accounting of benefits to users, based on a non-equilibrium condition, is included in Exhibit 2.

Shift in Transit Demands

Our analysis of potential new transit demand mirrors our analysis of auto trip demand. Figure 11 displays trip origins (within the city of Seattle) where transit trips into downtown might increase the most (in percentage terms) as a result of zone-based tolls.

Figure 11: Percent Change in Transit Trips by TAZ



Source: ECONorthwest

Bus transit speeds would increase and so would ridership. Transit trips into downtown are estimated to increase by 4 percent[26]. The percentage increase in transit usage would be largest for trips that originate from the neighborhoods closest to downtown Seattle. Like our analysis of auto trips, this estimate of potential transit demand does not reflect any changes in the supply conditions. Should transit supply be adjusted in response to, or in anticipation of, tolls transit usage would respond to the new supply condition as well.

Other Potential Changes in Activities

How people respond to tolls applied to trips accessing downtown Seattle will likely evolve over time. As time passes, people have greater flexibility in the travel choices they make. Over long enough time scales, people will not only adjust their time and mode of travel but may also select alternative destinations or engage in other activities that substitute for the activity that necessitated the travel in the first place. Changes in demand for activities that occur within a tolled zone may even result in a relocation, or spatial sorting, of some businesses and households between the tolled zone and other locations. These longer-term effects are hard to predict, or even evaluate ex post, since so many other factors contribute to location choices. It is likely that these kinds of adjustments have occurred in places where zone-based tolls are in place such as London and Stockholm. Land uses, and the activities associated with those uses, within the downtown cores of growing urban places are in constant flux. A congestion charge would introduce just one more set of cost factors into that dynamic process.

Congestion Reduction

The purpose of congestion pricing is to improve traffic conditions. Pricing can moderate trip demands so that less of society's scarce time resources are wasted. Instead, time is exchanged for toll revenue that can be repurposed. A carefully crafted toll policy will minimize the tolling impacts to travelers by ensuring that trips can be made at lower cost times of day or alternative modes of transportation. And during peak hours, vehicle volumes are lowered just enough to get traffic unstuck and flowing at more optimal speeds.

Our preliminary analysis does not solve for equilibrium speeds and volumes but does allow us to make some initial estimates of the likely effects on the amount of travel time savings that might follow from implementation of congestion pricing in downtown Seattle. Figure 12 displays the before (Base Case) and after pricing hours of auto travel time in downtown by hour of day. Our estimate is that time savings might be on average 6 minutes per peak period trip, and worth[27] on the order of $350,000 per weekday, or over $90 million per year.

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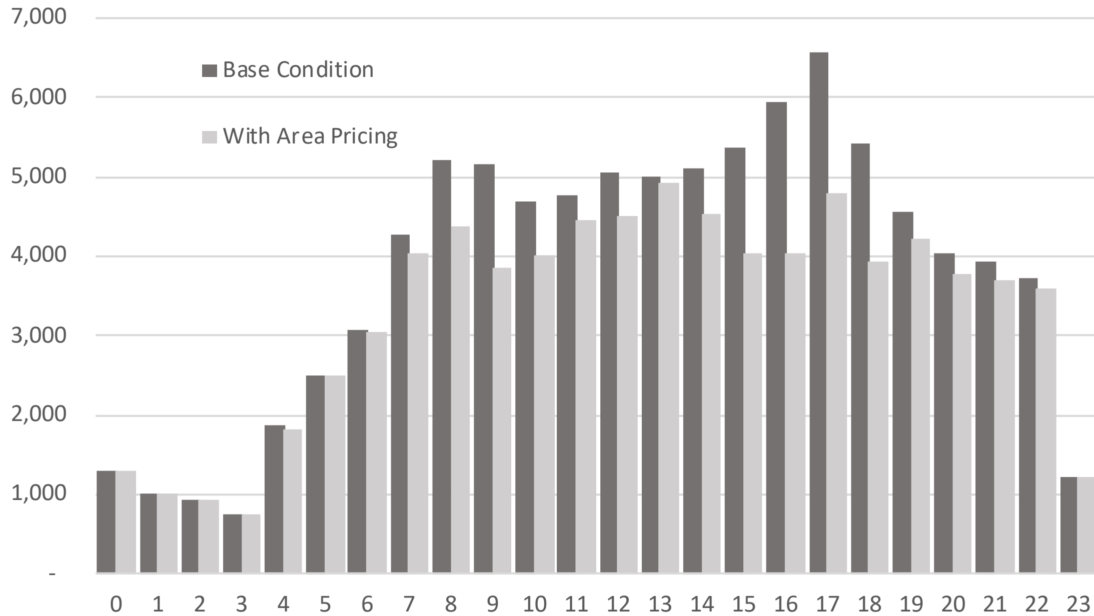
[26] Our analysis method estimates a shift in mode based on individual trips records and cross-price elasticities of demand.

[27] Based on the PSRC trip record estimated value of travel time (with an average of $19.20 per hour).

Figure 12: Before and After Pricing Hours of Auto Travel Time within Downtown by Hour of Day



Source: ECONorthwest

Toll Revenue and Its Uses

Gross Revenue

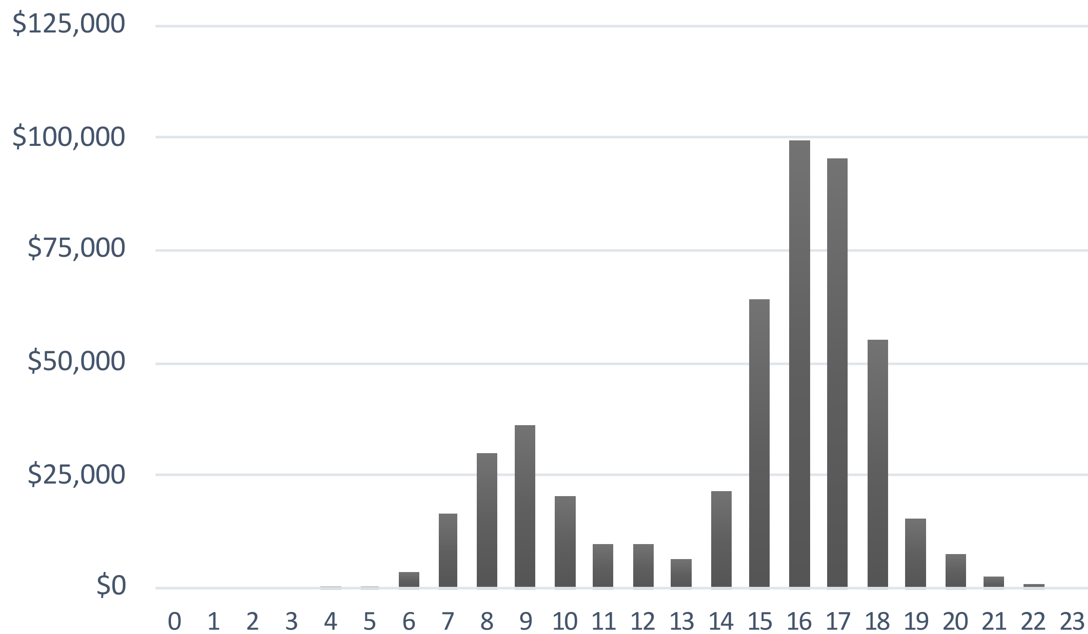
Traffic management through tolling transforms wasted time (a resource that can never be recovered) into revenue (a resource that can be recycled into the broader economy). In this sense the revenue and its subsequent uses will largely determine if the toll policy is socially beneficial. If the revenues are wasted, congestion pricing becomes an unattractive prospect. If the revenues are applied to some socially beneficial purpose, congestion pricing yields large-scale benefits.

Analysis of tolling revenue begins with an estimate of the gross revenue that is collected from the tolling operations. This gross revenue estimate typically reflects some expected behavioral response, or willingness-to-pay the tolls in exchange for accessing the toll zone. The gross revenue estimates are then adjusted to reflect a portion of revenue this is uncollectable. Toll system operating costs are then deducted from the adjusted gross revenue to yield an estimate of net revenues that are available for repurposing. Our analysis provides a measure of gross revenue from implementing zone-based congestion pricing in downtown Seattle. We do not implement the next steps in the process that ultimately translates gross revenue to net revenue.

These steps require a level of additional detail regarding toll system design and operating rules that are beyond the scope of this paper[28].

Our analysis suggests average weekday gross revenue yield in the range of $500,000[29]. For a toll system operating only during weekdays[30] this is an annual gross revenue figure in the range of $130 million[31]. Most revenue is generated during peak travel hours, as is expected. Figure 13 displays daily weekday gross revenue by hour of day.

Figure 13: Estimated Daily Weekday Gross Toll Revenue by Hour of Day



Source: ECONorthwest

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28 We do evaluate the sensitivity of our findings to alternate assumptions about toll rates and demand elasticities. For example, a 10 percent change in toll rates results in gross revenue estimates that are about 9 percent higher or lower than the base case. And a 10 percent change in the magnitude of elasticities results in gross revenue estimates that are about 1 percent higher or lower than the base case.

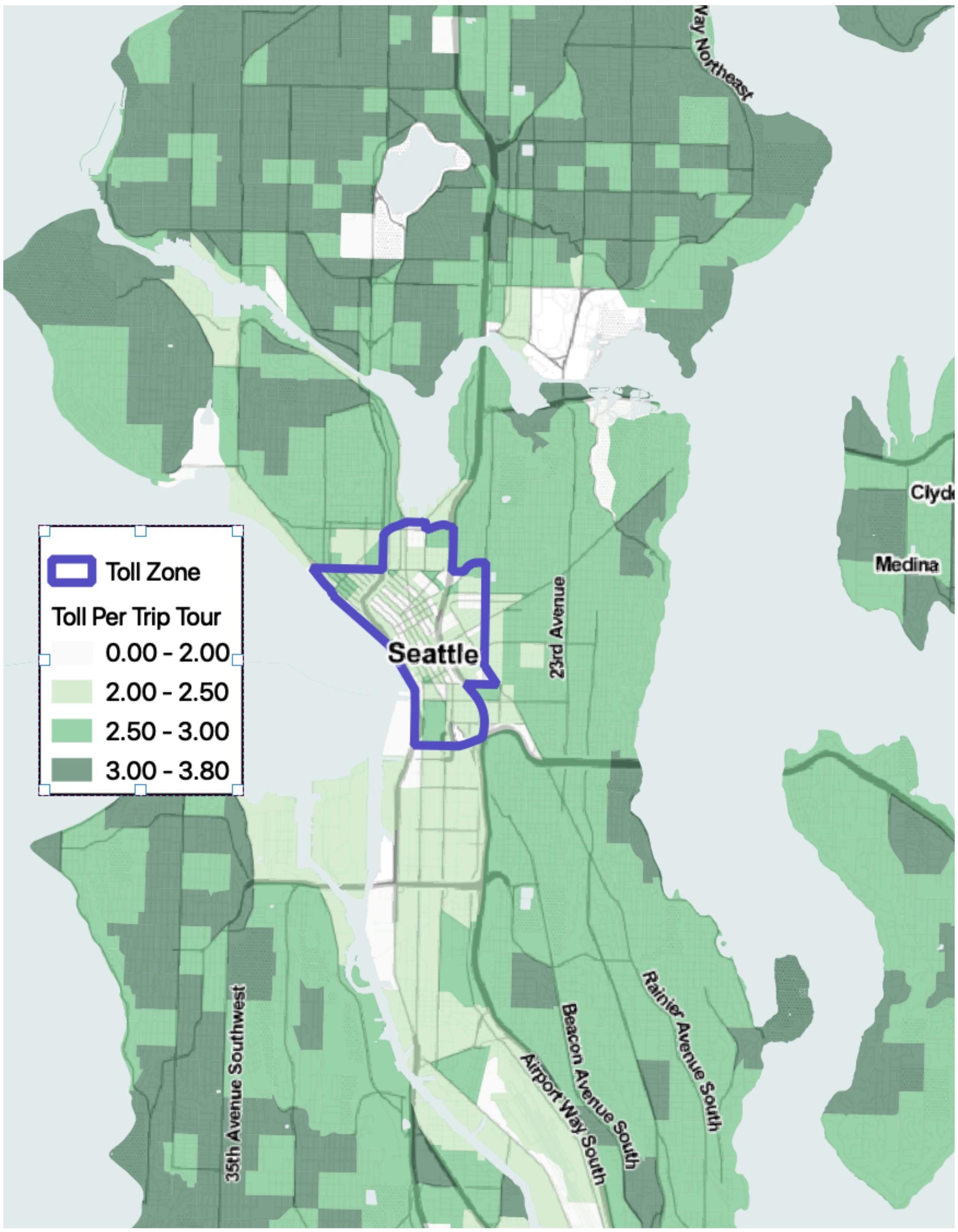
29 This analysis estimates toll revenues from personal travel and does not calculate toll revenues from commercial vehicles. Commercial vehicles operating in downtown might be tolled under different toll rates given their specific use patterns in a downtown setting. A major portion of downtown already has use restrictions on vehicles in excess of 30 feet in length, and commercial operators already attempt to avoid the most congested conditions. And delivery patterns for many vehicles could necessitate a refined toll policy, such as per-mile charges. This is a topic of some importance for further study and may benefit from ongoing efforts to better understand freight traffic volumes in downtown Seattle.

30 A congestion pricing program might choose to apply tolls during weekends as well. We have not estimated weekend toll rates or revenues as the pattern of traffic is significantly different from weekday traffic, and available data is limited regarding weekend travel demand. Future analysis could be designed to address weekend tolling specifically.

31 This specific revenue estimate reflects assumptions for one particular toll policy. Different congestion pricing policies would generate more or less revenue and may require different analytic methods to estimate.

The incidence of toll payments by trip origin can also be summarized from our results. We calculate the average toll paid per tour (linked trips) by the Transportation Analysis Zone of origin. We include both auto and non-auto tours in our analysis and the final toll paid for each tour represents the probability of toll exposure given the various behaviors in response to the tolls that are specific to each location. Average tolls per tour are higher for outlying origins and lower for origins closer to the downtown toll zone. Figure 14 displays average toll per tour (auto and transit) by TAZ.

Figure 14: Average Toll ($) Paid Per Tour by TAZ



Source: ECONorthwest

Potential Uses of Toll Revenue

The initial claims on toll revenues are usually the costs associated with operating the toll system itself. These costs depend on many aspects of program design, but could include the following, at a minimum:

- Toll System Customer Service
- Toll System Maintenance
- Toll System Back Office
- Toll Transaction Processing
- In-Vehicle Toll Transaction Technology
- Uncollectable revenues

The above typically constitute a set of adjustments to, and subtractions from, gross toll revenue to derive estimates of net revenues that are available for other purposes beyond operating the toll system. A formal accounting of operating costs is beyond the scope of this white paper[32]. Secondary claims on toll revenues include paying down any debt incurred to finance the implementation of the toll system, maintaining the underlying transportation assets that are being tolled (the urban road network), and underwriting supplemental services that are designed to increase the effectiveness of urban transportation, such as supporting transit.

Investments in road resurfacing and major maintenance are likely a key ingredient for a successful congestion pricing policy. Levying tolls for accessing downtown streets and failing to adequately maintain the infrastructure used by buses, commercial vehicles, cars, bicyclists, and pedestrians is a recipe for public discord. The City of Seattle has a significant and unfunded backlog of road maintenance needs, some portion of which is located in the downtown core.

As our examination of behavioral response to tolling demonstrates, some auto trips into downtown will be avoided. And transit demand from certain origins will likely increase. In order to minimize the economic harm this behavior may cause it may be helpful to invest directly in improved transit services. Specifically, it will be important to have in place a process that allows transit service to be nimble and respond to new demands as they arise. This highlights the important role for point-to-point service that operates in non-dedicated rights-of-ways.

Finally, it is important to remember that the toll revenue can be used to directly offset any financial hardships that may be disproportionately imposed on lower-income households. Such offsets could be in the form of investments in programs, reductions in regressive taxes, or even in the form of direct cash payments. The most efficient use of toll revenue may be direct distributions of those revenues back to the public.

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[32] A very preliminary estimate of these toll operating costs is in the range of between 10 and 20 percent of gross revenues.

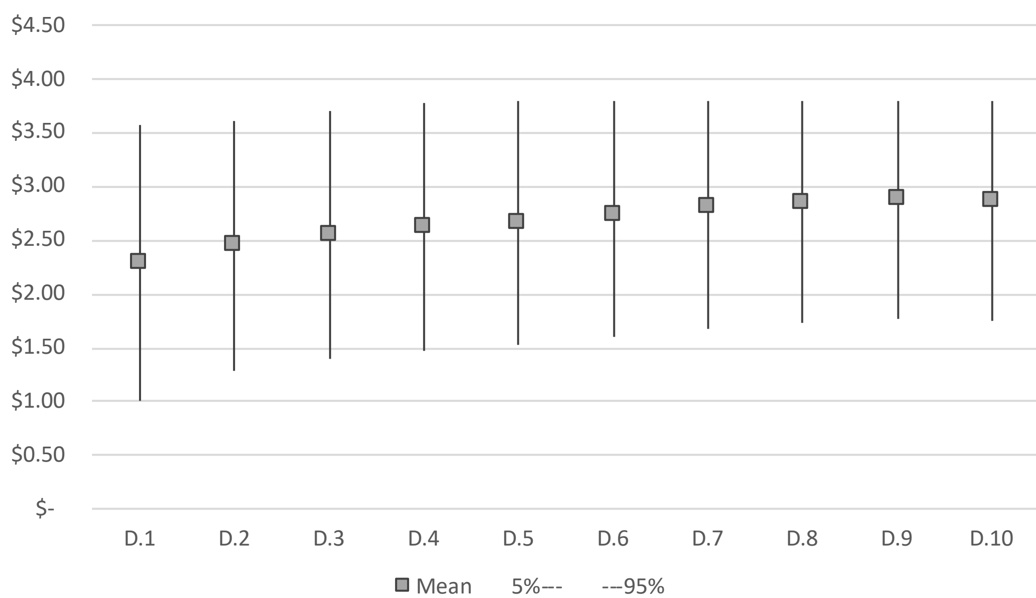
Fairness

Who Pays The Tolls

The primary arguments for road pricing are about reducing traffic congestion and improving investment policy. Yet many people worry that improvements in efficiency will come at the expense of fairness. Indeed, the City of Seattle's recently-released study on congestion pricing places a strong emphasis on how potential road fees might fall on different racial and socio-economic groups, potentially worsening existing economic disparities.

One way to evaluate the fairness of congestion pricing is to look at which groups pay the toll. We examined the toll cost per trip tour (the set of linked trips that take a person from home, to work, to other activities, and then back home) into downtown and the share of total revenue, by various household income[33] categories. Figure 15 displays the average toll paid per tour into downtown Seattle for each regional household income decile. The figure also shows a 90 percent range of the tolls paid by households in each decile. In our analysis the households in the bottom 10 and 20 percent (D.1 and D.2) for household income pay, on average, a lower toll than more affluent households.

Figure 15: Average Toll Per Auto Tour into Downtown by Regional Household Income Decile



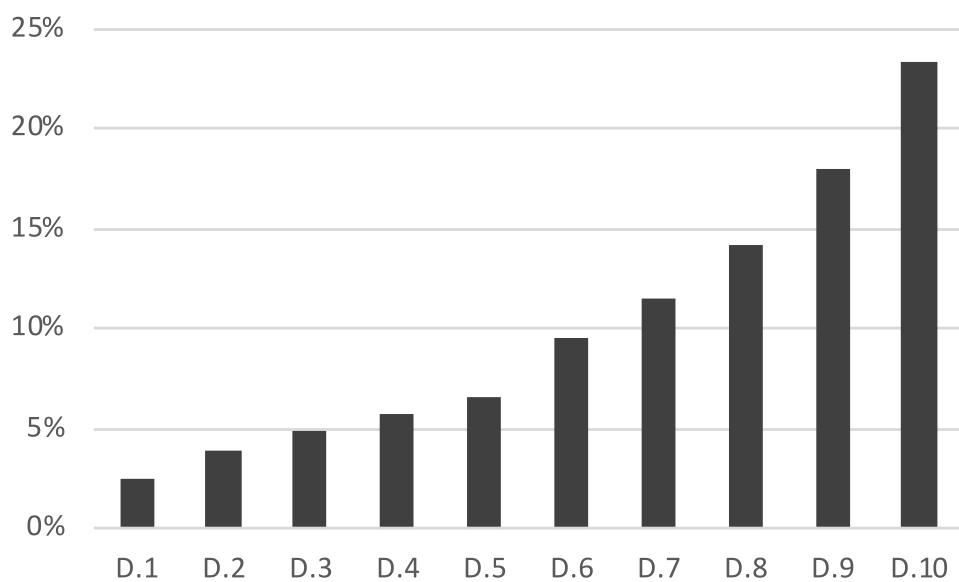
Source: ECONorthwest

33 We calculated income deciles (10 even sized groups) based on the distribution of household income for all the households in the 4-county region.

The variability of the toll rates paid by lower income households is estimated to be higher than for more affluent households, indicating that the actual tolls paid are situational (determined by trip's purpose, time of day, location and other factors), and not solely determined by income. Some lower income households would end up paying relatively high toll rates if they are not able to avoid high-cost travel times or make use of alternatives modes of travel.

When they do pay tolls, lower income households may pay tolls that are only modestly lower than the tolls paid by more affluent households. But the average toll paid per tour is only a part of the story. Households that make regular trips into downtown Seattle are more affluent, on average, than the region's households[34] in general. And in our simulation of downtown tolling, lower income households are estimated to pay a substantially lower share of the total gross toll revenues. Figure 16 shows the shares of total toll revenue generated from each household decile. Households in the lower 40 percent of income earners pay under 20 percent of the total tolls. And the top 10 percent of income earning households pay nearly 25 percent of the tolls.

Figure 16: Share of Toll Revenue by Regional Household Income Decile



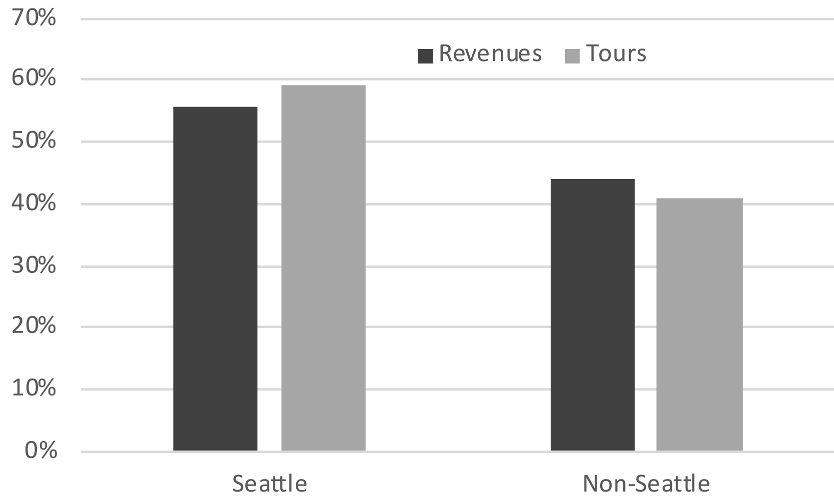
Source: ECONorthwest

Other ways of examining who pays the toll include comparisons by household tenure, type and residential location. Seattle residents make a majority of the toll paying trip tours and pay the majority of the tolls. But households outside of Seattle are estimated to also contribute to the

34 Based on the synthetic household inventory available for this project the households with tour destinations in downtown Seattle had an average income of just over $120,000 while the regional average was just under $90,000.

total toll revenues. Figure 17 displays the share of toll revenues and tours attributable to Seattle residents and to households located outside of Seattle.

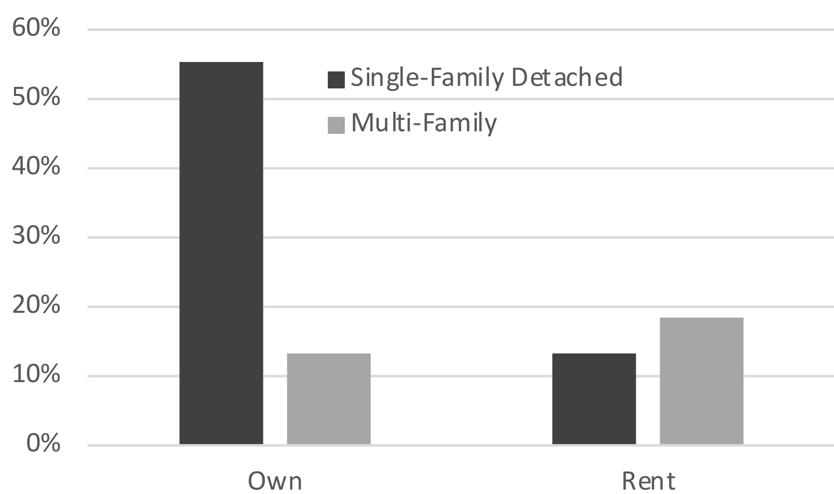
Figure 17: Share of Toll Revenue and Tours by Household Location



Source: ECONorthwest

Most toll revenues (69 percent) are estimated to be associated with households that own their homes while renters would contribute 31 percent of total toll revenues. Figure 18 shows the share of revenues attributable to various households by tenure and type (single-family and multi-family).

Figure 18: Share of Toll Revenue by Housing Type and Tenure



Source: ECONorthwest

Winners and Losers: Who Benefits

While we can estimate how much different groups would pay in tolls, this still does not provide a complete accounting of benefits and costs and how they are distributed. Whenever policies change, it creates potential winners and losers, and this would be no less true of congestion pricing of a city's roadways. In the end, evaluations of fairness depend on:

- Value of travel time savings (one's willingness to pay)
- Income (one's ability to pay)
- Availability of alternatives
- Uses of the revenues

Some travelers will benefit from congestion-based charging only if the transit response is good. Those who are "tolled out" of their vehicles, for example, can benefit only if this is the case. This underscores the importance of removing any institutional impediments to increased bus, vanpool and carpool services. It argues for using some of the congestion-based charging revenue to assist transit.

Second, the pattern of winners and losers does not decompose directly into rich vs. poor, as is sometimes alleged by critics of congestion pricing. Although drivers with low time values are the ones most likely to be "tolled off" the road, many may be better off despite this if the performance of the road-based transit alternatives improve significantly. Those for whom HOV alternatives remain unsatisfactory, however, will be adversely affected.

The primary effect on transit providers from congestion pricing is the improved performance for transit vehicles that operate on previously congested roadways. Other effects would include higher patronage and higher cost recovery opportunities that arise when road usage is more costly during peak hours on urban roadways.

Gomez-Ibanez[35] analyzed the application of congestion pricing to existing roads and identified the most important winners:

1. Motorists who would drive with or without the toll but who place a high value on travel time savings (for these motorists the gains from improved traffic speeds outweigh the toll cost);
2. Travelers who would use HOV services on the tolled road whether or not tolls are charged (they benefit from improved speeds while paying little or no toll); and
3. Recipients of toll revenues (i.e., taxpayers if tolls reduce the pressure for tax increases or, alternatively, the clients of government programs if tolls are used to finance an expansion of government services).

[35] Gomez-Ibanez, J. (1992). The political economy of highway tolls and congestion pricing. Transportation Quarterly. 46. 343-360.

Four other groups are likely losers.

1. Motorists who would continue to drive on the road despite the toll but who place a relatively low value on travel time. (Even though the time savings does not compensate these motorists for the toll charge, they may have to tolerate this loss because alternate routes or HOV services are too inconvenient for trips they are making.);
2. Motorists who shift from the tolled road to a competing untolled facility. (The untolled facility is less convenient otherwise these motorists would have used it even in the absence of tolls.);
3. Other users of the competing untolled roadway (since congestion will increase on that road); and
4. Motorists who choose not to make the trip at all because of the toll (or who, with congestion pricing, now drive at a less convenient time of day when the tolls are lower).

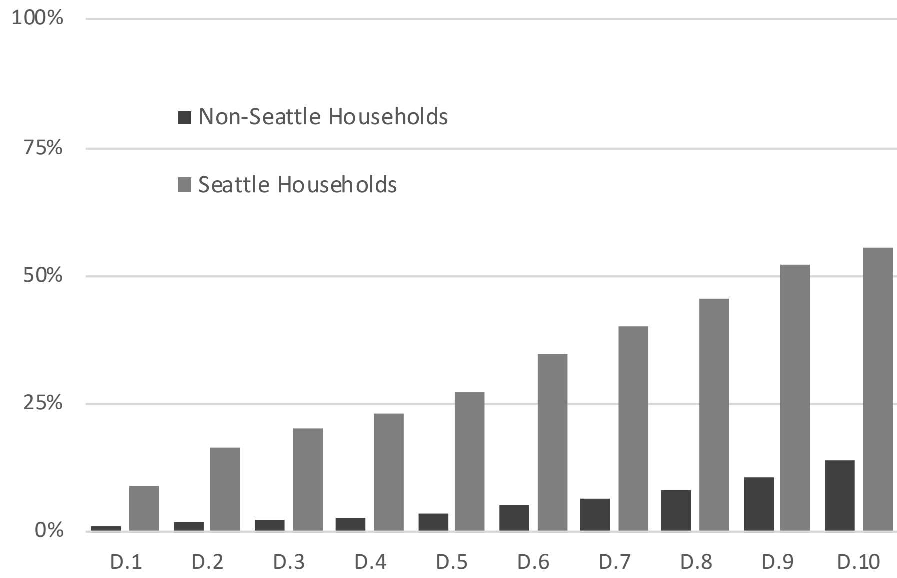
A distinctive feature of congestion pricing is that it generates revenue that can offset the negative effects, by financing transit alternatives where appropriate, or via other compensatory actions. Indeed, the reason economists recommend road pricing over regulatory and land use approaches to congestion problems is because it is a policy that has the potential to make everyone better off through prudent use of the revenues generated by the policy. Other stakeholders affected by congestion pricing are businesses and residences that are already located in certain urban places. Congestion-based charging influences the value and use of land because it changes the cost of access.

Using Revenue to Redress Financial Harm

When examining equity impacts of tolling it is important to keep in mind that not all households pay tolls in our simulation of downtown tolling. Our simulation represents an average weekday condition, and one further interpretation of this finding is that not all households that do pay tolls will pay tolls every weekday. Figure 19 displays the rates at which Seattle and Non-Seattle households of different income deciles pay a toll on an average weekday.

Just under 10 percent of the lowest income Seattle household decile is estimated to pay a toll on an average weekday while over 50 percent of the highest income household decile is estimated to pay a toll. The pattern of toll payment is similar for non-Seattle households while their rate of payment is lower across all household income deciles.

Figure 19: Share of Each Seattle Household Income Decile Paying a Daily Toll



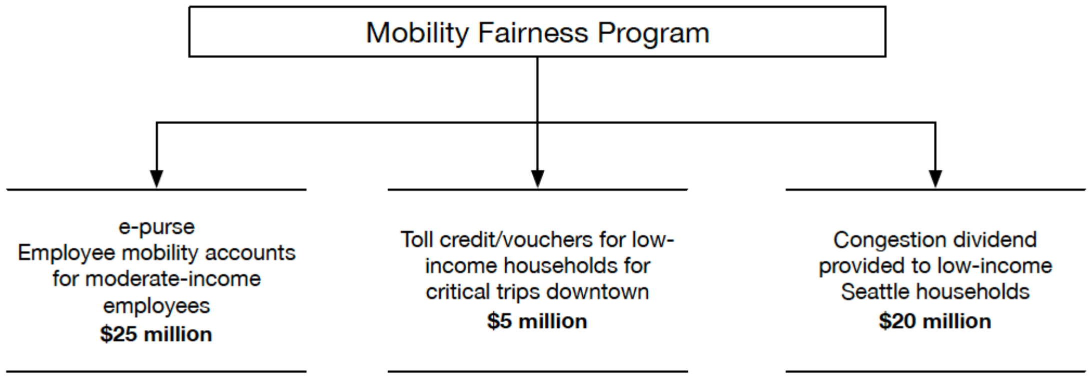
Source: ECONorthwest

If congestion pricing causes financial harm to households or individuals that society wants to protect (for example households with low incomes), then one approach to redressing that harm is to dedicate some portion of toll revenues in a manner that directly benefits those protected groups[36]. There are many different approaches that could be devised to address these concerns. Keeping with our analysis of household income groups (deciles), we have examined the implications of one such program.

For this illustrative analysis we assume a mobility fairness program that has three distinct elements. We assume $50 million of toll revenue per year goes into the mobility fairness program, leaving approximately $80 million per year to cover the costs of implementing the system and serving other public purposes including road and street maintenance and transit improvements. Any benefits to households from spending net revenues on these other public purposes is not included directly in the analysis that follows. Figure 20 depicts the elements of one possible mobility fairness program characterized in this paper.

[36] For a discussion of this issue specific to congestion pricing see *Credit-Based Congestion Pricing: Expert Expectations and Guidelines for Application;* Pradeep K. Gulipalli, Sukumar Kalmanje, and Kara M. Kockelman; Journal of the Transportation Research Forum, Vol. 47, No. 2 (Summer 2008), pp. 5-19 http://www.trforum.org/journal

Figure 20: Mobility Fairness Program



Source: ECONorthwest

The first program element[37] involves all downtown Seattle-based employers administering an e-purse account for employees whose incomes are near, or below, the regional median[38]. Such a program could provide qualifying employees a monthly e-purse starting at about $85 per month, or about $1,000 per year[39]. Eligible service expenses might include transit fares, bike-share expenses, shared-ride expenses, parking charges and tolls. There are many possible variations on this theme where eligibility rules might be tailored to address perceived financial harm imposed by tolling. The key is that all eligible persons would receive a portion of the toll revenues, in the form of the e-purse, independent of whether or not that individual pays congestion tolls. For the eligible employees who daily pay the toll to enter downtown Seattle, this would offset daily expenses[40]. For employees who pay the downtown toll less frequently, or avoid the toll entirely by taking transit, the e-purse disbursements would represent a net financial gain.

The second program element would involve the provision of vouchers[41], rebates or exemptions designed to offset toll charges associated with important trips into downtown, such as medical visits or other critical non-work purposes, for households with very low incomes. As these rebates target critical trips that are already logged by the tolling system the administration of this program element would simply establish qualifying purposes (e.g. visits to hospitals, etc.) and verify income eligibility.

37 Funded through approximately $25 million of the toll revenues

38 In our analysis this is a total of about 40,000 employees earning around $66,000 ($35/hr.) or less.

39 As income increases (beyond the bottom 3 deciles) the size of the e-purse decreases (from $1,000 to $750, $500 and $250 for the 4th through 6th deciles), thus minimizing any threshold effects of the rebate policy.

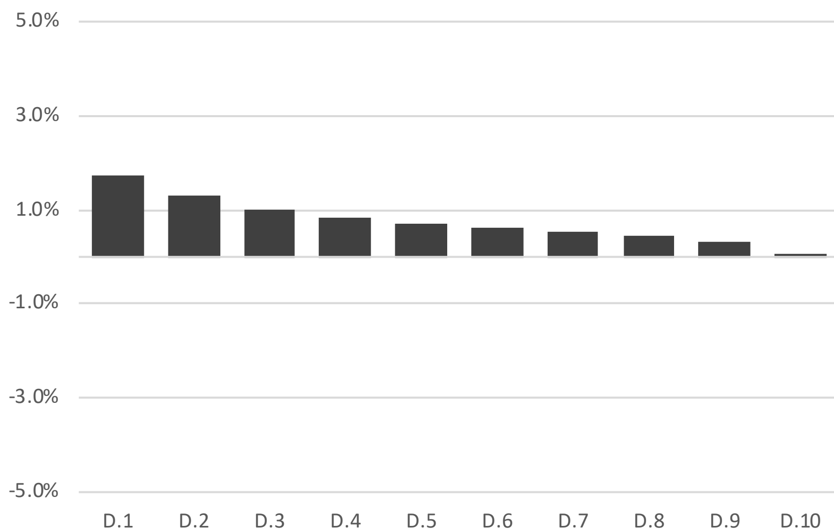
40 Refer back to Figure 15 for average tolls paid per auto tour by household income decile.

41 We estimate these costs in the range of $5 million based on assumptions about rate of personal business trips into downtown Seattle from tour records.

A third program element would involve congestion dividends, also funded by the toll revenues[42], for low income Seattle households[43]. A downtown toll zone may represent a mobility barrier for short distance trips by lower income residents. A targeted rebate for income eligible Seattle residents is a flexible means of supporting the general mobility needs of those households.

We can also estimate the share of income that would need to be dedicated to paying tolls for an average employee in downtown Seattle within each of the regional household income deciles. This result is presented in Figure 21 below and shows that even though the high income deciles pay the large majority of the tolls into downtown, as shown in Figure 16, employees in the low-income deciles would still pay a modestly larger share of their income on tolls than wealthier employees.

Figure 21: Toll Share of Income for an Average Downtown Employee by Income Decile



Source: ECONorthwest

Within each income decile there will be workers who seldom, or never pay tolls, and there will be those who pay them more frequently. But even when controlling for a lower rate of paying tolls the average lower income employee will spend a slightly larger share of income on tolls. If the mobility fairness program approach describe above was introduced, this story would be different. Figure 22 displays the share of income that would be dedicated to paying tolls, net of the e-purse disbursement, for an average downtown employee within each of the regional household income deciles.

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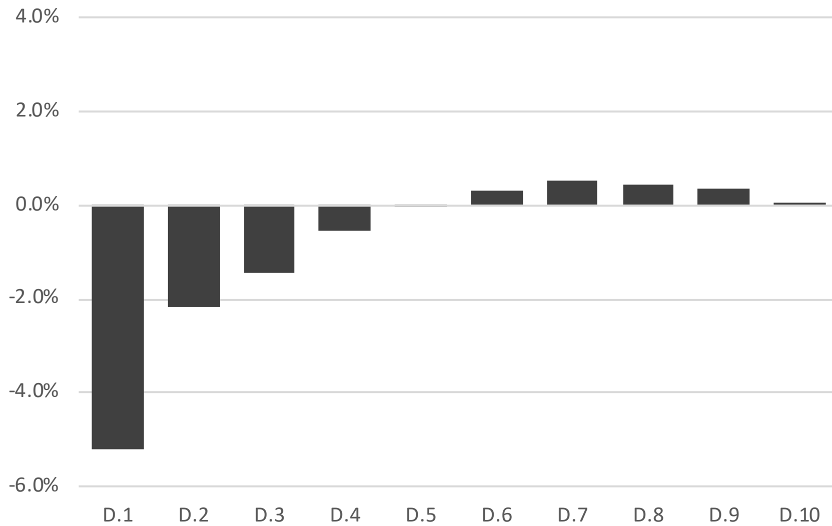
42 The low-income household congestion dividend was analyzed assuming approximately 33,000 eligible households receiving $50 per month.

43 For example eligibility could be based on participation in the City of Seattle's Utility Discount Program.

Figure 22: Toll Plus e-Purse Share of Income for an Average Downtown Employee by Income Decile



Source: ECONorthwest

The employee e-purse program is a means of distributing some of the toll revenue back to eligible moderate-income workers. Administering a rebate in this manner could minimize the regressive nature of the toll policy (as seen in Figure 21). The other mobility account program elements ease the burden of tolls on low-income households that need to make trips into downtown for a wider variety of purposes, such as medical visits and other critical activities. And the congestion dividend for low-income households is a third approach to improving fairness by ensuring that some benefits of tolling are paid back directly to those households. With such a program in place many moderate and low-income households could see a net increase to their effective income, even after paying tolls on trips into downtown.

Privacy

Information systems are becoming increasingly complex. As information is collected, stored and used in increasingly beneficial ways, there are also growing concerns over how information that might be considered "private" is managed and protected against malicious use. Various systems create and store digital records of people's movements through public space and in return, promise benefits ranging from increased convenience to transformative new kinds of social interaction. Society is not likely to stop the cascade of new location-based digital services, nor does it appear that it would want to, as the benefits of such services are often substantial.

Road tolling systems with automated tolling transactions that associate the use of roads with an account holder are just one aspect of modern life that raise issues of privacy protection in the minds of consumers. A road tolling system that collects and stores detailed information about a large extent of the roads visited by all road users is by extension a larger source of the same kinds of concerns. A road tolling system would collect extensive and detailed information about individual users and their travel behavior. It is impossible to imagine such a system being put into operation without significant safeguards in place to secure personal information.

Each of the technologies used for electronic tolling will record data on users' personal travel behavior (if they use a toll road or enter a cordoned area), but the level of privacy concerns varies for each of the technologies. For example, while there is a general concern about theft of the in-vehicle devices or hacking of a user's account, there are fewer concerns with the theft of transponders than with in-vehicle GPS devices, because transponders carry no record of where they've been. On the other hand, transponder-based systems need to store information about where the transponder has been read in a back-end data system, whereas GPS-based on-board units might keep all location data inside the unit, which remains in the user's possession unless it needs to be audited.

Many consumers misunderstand how GPS works and believe that in GPS-based systems, satellites can "see" them and track them as they move around. In reality, the GPS satellites only transmit their identifier and time stamp. GPS receivers use differences in time to calculate their distance to each satellite, and from those, calculate their position on the surface of the earth. Acceptance of GPS-based technology will require educating consumers.

There are also privacy concerns related to the use of cameras for tolling. Many are concerned with the use or sale of personal travel data to entities not directly related to tolling, such as law enforcement agencies, private investigators, or firms seeking to use the data for marketing purposes. There are many ways to protect the privacy of individuals and to inform them of what data are collected and how the tolling agency and its contractors will use information. With proper planning, education, and technology, the protection of privacy need not be a major roadblock to the successful implementation of congestion pricing systems.

Next Steps

Further Analysis and Evaluation

A Refined Framework for Assessment

This preliminary analysis provides insights into the travel time savings and toll incidence for different household groups based on one approach to congestion pricing in Seattle. In particular, this analysis significantly advances our understanding of economically efficient toll rates by time of day, the potential magnitude of gross revenues, and one approach to using a portion of the toll revenue to create net financial benefits for income groups below median income.

Future work should center on developing a fuller set of congestion pricing policy design parameters. The intent of a Seattle congestion pricing program is to ameliorate congested conditions in the downtown core. Subsequent evaluation of congestion pricing can more fully specify the pricing levels required to achieve this outcome and assess the transportation and economic implications of program implementation. In particular, the testing of alternative toll rates, or toll policies, would be instructive. For example, tolls that apply to each mile travelled in the downtown zone would have a different effect on trips of varying length, and on drivers who make multiple daily trips within downtown, than will the tolls tested in this paper. And a specific treatments of commercial vehicle traffic would also add important detail.

A systematic assessment of congestion pricing in downtown Seattle would make use of both information about the performance of the urban streets network as well as information about volumes of traffic demand, patterns of travel and behavioral characteristics of the users of the transport systems. As a result, this work could include customization to existing modeling tools in order to appropriately evaluate traffic and pricing revenue implications at a more refined level of detail. The framework could stand alone or build on existing planning models of the Seattle area. We anticipate that any subsequent traffic and revenue analysis would also involve additional validation and calibration of the model systems that are employed.

Traffic models can be used to test the sensitivity of traffic volumes to various levels of generalized cost impedance in the pricing area. This is accomplished by applying varying toll rate equivalent generalized costs to the network features of the priced region. Other tests might include variation in the impedances on outlying parts of the road network that are alternative route options for traffic using the priced region. This work could include procedures for discovering cost minimizing and revenue maximizing toll rates in these kinds of model network settings. The revenue maximizing toll rates as well as lower toll rates are then used in this manner to estimate travel demand under alternative toll cost conditions.

The estimation of local elasticities of demand with respect to toll rates follows naturally from this analysis. Once elasticity measures have been estimated for each vehicle type using the tolled facilities these results can be generalized and integrated in order to estimate total traffic and gross revenue response to alternative toll rate policies. If the evaluation framework does not involve a 4-step demand model implementation, then behavioral parameters can be identified from empirical literature and incorporated into the analysis appropriately.

Tolling Operational Concepts

Future work could endeavor to provide details around the tolling operational concept. An operational concept would evaluate a full set of policy choices for the design and implementation of a congestion pricing program for downtown Seattle. Such an effort would support more detailed gross revenue estimates for implementation of congestion pricing, and also support the conversion of gross revenues to net revenues. The gross revenue estimates can utilize standard practices for extension of toll revenue beyond the analysis years as needed, along with reasonable operating assumptions. At a minimum, some operating assumptions can be employed to arrive at a general range of operating costs, while more detailed analysis of these factors will need to wait for subsequent work by the City of Seattle. Toll operations might also include assumptions about how revenues get reprogramed into transportation improvements, including new transit services.

Key Tolling Operational and Policy Issues

Future work could also evaluate a select set of key policy concerns regarding congestion pricing implementation, such as:

- The performance of the downtown street network – congestion pricing will result in notable speed/travel time improvements on downtown streets. These performance improvements should be characterized.
- The economic implications of congestion pricing – properly implemented, it will yield sizable benefits to transportation system users, both households and commercial enterprises. A general summary of these benefits should be produced.
- The incidence of benefits and costs – congestion pricing will have different outcomes for various categories of transportation system users. While a full accounting of costs and benefits by user type is a significant undertaking, further work could include a more detailed discussion of this topic and assess the general implications for fairness.
- The disposition of pricing revenue – much of the benefit of pricing is “tied up” in the revenue that is generated. The use of the pricing revenues is a key ingredient to making a successful program; future work should discuss this topic and itemize some promising approaches to using revenues in a beneficial manner.

Exhibit 1: Primary Data Files

Uber Movement Data Files

Speeds.csv

Variable	Description
year	year
quarter	quarter
hour_of_day	hour of the day
segment_id	Uber defined road segment
start_junction_id	Uber defined segment start node
end_junction_id	Uber defined segment end node
speed_mph_mean	mean value of speeds observations
speed_mph_stddev	standard deviation of speeds observations
speed_mph_p50	50th percentile of speeds observations
speed_mph_p85	85th percentile of speeds observations

Travel_Times.csv

Variable	Description
sourceid	origin geography (in this case TAZ)
dstid	destination geography (in this case TAZ)
hod	hour of the day
mean_travel_time	arithmetic mean value of travel time observations
standard_deviation_travel_time	arithmetic standard deviation of travel time observations
geometric_mean_travel_time	geometric mean value of travel time observations
geometric_standard_deviation_travel_time	geometric standard deviation of travel time observations

The Speeds.csv file has 2,051,987 records.
The Travel_Times.csv file has 13,191,108 records.

PSRC SoundCast Data File

Tours.csv

Variable	Description
day	diary / simulation day ID
fhtindx1	1s half- fully joint half tour index
fhtindx2	2nd half- fully joint half tour index
hhno	household id
id	internal daysim record ID
jtindex	hh joint tour index
parent	parent tour id
pdpurp	prim.dest.purpose
person_day_id	internal daysim record ID
person_id	internal daysim record ID
phtindx1	1st half-partial joint half tour index
phtindx2	2nd half-partial joint half tour index
pno	person seq no on file
subtrs	number of subtours
tardest	time arrive tour dest
tarorig	time arrive tour origin
tautocost	tour 1-way auto distance
tautodist	tour 1-way auto cost
tautotime	tour 1-way auto time
tdadtyp	tour destination address type
tdpcl	tour dest parcel
tdtaz	tour destination TAZ
tlvdest	time leave tour dest
tlvorig	time leave tour origin
tmodetp	tour main mode type
toadtyp	tour origin address type
toexpfac	trip expansion factor
topcl	tour origin parcel
totaz	tour origin TAZ
tour	tour id
tpathtp	tour main mode path type
tripsh1	1st half tour # of trips
tripsh2	2nd half tour # of trips

The Tours.csv file has 5,770,547 records.

Exhibit 2: User Benefit Summary

The analysis summarized in this white paper involved estimating tolling implications on individual records of travel activities. This approach allows for the calculation of user benefits for categories of trips, tours and households within the central Puget Sound region. User benefits include travel time savings (a consumer surplus measure), toll payments (a negative benefit), and the rebate program distributions. Net toll revenues that remain after any rebates are provided would be available to invest in other programs such as street maintenance and improvements or transit services. These investments could also yield additional benefits to transportation system users. Without more specifics about how revenues get repurposed, we do not attempt to account for these additional benefits.

Many categories of trip activity are not relevant to our analysis, such as trips and tours that begin and end outside of the downtown tolling zone. Figure 23 below displays benefits accruing to auto and transit tours with destinations in the toll zone and with origins from within Seattle and outside of Seattle. What we describe in the body of this paper as a Seattle low-income household congestion dividend would generate approximately $16 million in benefits for other low-income household tours not represented in this table.

Figure 23: Annual User Benefits for Downtown Tours by Household Location and Income Category

	HH Count	Time Benefits	Toll Revenues	Rebate	Total	Total Per HH
Auto & Transit Tours to Downtown						
From Outside Seattle						
Income Decile 1	2,479	$ 149,000	$ (1,033,000)	$ 1,000,000	$ 116,000	$ 47.00
Income Decile 2	3,344	$ 322,000	$ (1,788,000)	$ 1,832,000	$ 366,000	$ 109.00
Income Decile 3	4,295	$ 489,000	$ (2,318,000)	$ 1,595,000	$ (234,000)	$ (54.00)
Income Decile 4	4,878	$ 660,000	$ (2,772,000)	$ 1,758,000	$ (354,000)	$ (73.00)
Income Decile 5	5,950	$ 953,000	$ (3,531,000)	$ 1,636,000	$ (941,000)	$ (158.00)
Income Decile 6	8,805	$ 1,643,000	$ (5,421,000)	$ 1,476,000	$ (2,303,000)	$ (262.00)
Income Decile 7	11,414	$ 2,412,000	$ (7,066,000)	$ -	$ (4,655,000)	$ (408.00)
Income Decile 8	13,176	$ 3,261,000	$ (8,563,000)	$ -	$ (5,302,000)	$ (402.00)
Income Decile 9	17,004	$ 4,850,000	$ (11,201,000)	$ -	$ (6,350,000)	$ (373.00)
Income Decile 10	21,065	$ 7,698,000	$ (14,130,000)	$ -	$ (6,432,000)	$ (305.00)
From Seattle						
Income Decile 1	10,089	$ 1,207,000	$ (2,211,000)	$ 5,202,000	$ 4,199,000	$ 416.00
Income Decile 2	8,771	$ 1,894,000	$ (3,221,000)	$ 5,964,000	$ 4,637,000	$ 529.00
Income Decile 3	10,044	$ 2,648,000	$ (4,115,000)	$ 4,237,000	$ 2,770,000	$ 276.00
Income Decile 4	10,697	$ 3,191,000	$ (4,662,000)	$ 3,919,000	$ 2,448,000	$ 229.00
Income Decile 5	10,760	$ 3,695,000	$ (5,145,000)	$ 2,769,000	$ 1,318,000	$ 123.00
Income Decile 6	13,941	$ 5,790,000	$ (6,978,000)	$ 2,098,000	$ 910,000	$ 65.00
Income Decile 7	15,434	$ 7,063,000	$ (7,942,000)	$ -	$ (879,000)	$ (57.00)
Income Decile 8	18,329	$ 9,627,000	$ (10,060,000)	$ -	$ (433,000)	$ (24.00)
Income Decile 9	21,593	$ 12,687,000	$ (12,321,000)	$ -	$ 366,000	$ 17.00
Income Decile 10	27,719	$ 21,124,000	$ (16,458,000)	$ -	$ 4,666,000	$ 168.00
Total	**239,787**	**$ 91,363,000**	**$ (130,936,000)**	**$ 33,486,000**	**$ (6,087,000)**	**$ (25.00)**

Source: ECONorthwest