Modeling the Effects of Peak-Load Pricing on Metropolitan Network and Activities

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ABSTRACT

Peak-load pricing has long been seen as a way to internalize externalities and, at the same time, as a set of incentives to shift some peak-hour trips to off-peak periods. The policy has also been viewed as a mechanism to generate revenues. But it is an open question how travelers trade off time for money and respond to peak-off-peak pricing differentials. This generates some timely and related questions, including: 1) How can we model the activity location and traffic implications for multiple time-of-day periods in a major metropolitan area? and 2) What are the network level-of-service and urban development effects of implementing peak-load pricing on selected routes? It is seemingly possible to conduct simulations on actual highway networks to treat these questions, but none of the many existing basic urban models is able to examine the issues of simultaneous route choice and time-of-day choice involving millions of travelers, thousands of traffic network zones, and hundreds of thousands of network links in an equilibrium system. This research addresses these questions by extending the Southern California Planning Model (SCPM) so that it can be used to determine the time-of-day, trip distribution, and network traffic effects of various pricing schemes for the greater Los Angeles (five-county) metropolitan area. The model estimates improvements in levels of services throughout the highway network for various toll charges. It examines how drivers trade off route-choice with time-of-day choice against the option of traveling less. Our approach also estimates the implied revenues by local jurisdiction as well as possible land use effects in terms of altered development pressures throughout the region. The effects for two different toll scenarios are compared and policy implications are discussed.

I. INTRODUCTION AND BACKGROUND

If price does not ration, something else will. For most U.S. roads and highways, the pricing option has been avoided and rationing by crowding results. The recent estimate by The Texas Transportation Institute in their annual reports of congestion costs is that losses amount to $78 billion per year, or about 40 hours per year per urban traveler (TTI 2009). Public transit investments have been the preferred policy antidote, but the available evidence shows negligible effect on road and highway congestion (Baum-Snow and Kahn 2005). The costs of many of these projects can be counted as part of the costs of the policy choice to avoid congestion pricing. The public's reported unhappiness with time spent in slow-moving traffic is apparent in various poll results (Zmud and Arce 2008). In addition, recent research has shown that most peak-hour travel is for non-work purposes (Lee, et al. 2009)[1], suggesting that pricing could be an incentive for some of these trips to move to off-peak hours, making peak-hour capacity available. Finally, many local governments report that they are facing revenue shortfalls; improved auto energy efficiency will further diminish their revenues from cents-per-gallon revenues. Revenues from road pricing have an obvious attraction for officials in many jurisdictions.

For all of these reasons, transportation economists have long argued for the efficacy of a road pricing policy. But they have with rare exception not been able to persuade policy makers. In the eyes of many, pricing is "inequitable". But things may be changing. Recent research suggests changing public attitudes (Ecola and Light 2009; Zmud and Arce 2008). And the Federal Highway Administration (FHWA) had in recent years started promoting High Occupancy Toll (HOT) lanes, especially under the previous administration's Value Pricing Program. In 2007, the Federal Transit Administration (FTA) proposed redefining fixed guideways to include dual use HOT/Bus Rapid Transit (BRT) lanes (Poole 2007). The Southern California Association of Governments (SCAG) provides anecdotal evidence that Metropolitan Planning Organizations (MPO) are responding to a seemingly more favorable view by the planning community and placing HOT/BRT projects into regional transportation plans. Actual congestion tolling has been in place in Singapore since 1975 and has more recently been implemented in Norway, Sweden

[1] Data from the 2009 National Household Travel Survey (NHTS) corroborate these findings. Whereas the 2001 survey showed that 62 percent of all AM-peak (6-9am) person trips were for non-work purposes and 76 percent of the PM-peak (4-7pm) person-trips were for non-work purposes, the corresponding proportions for 2009 were 63 percent and 76 percent. These refer to Monday-Thursday; the Friday patterns are slightly different.

and South Korea, the U.K. as well as on two freeways in California (Sullivan 2006). Congestion pricing may be an idea whose time has come.

Another auspicious development involves the possibility of what some have called “smart mobility”. GSM-positioning and GPS-tracking technologies vastly expand the possibilities for traffic monitoring, congestion fee determination, and fast feedback to drivers. Whereas “Fastrak”-type toll collection has been available and implemented for some years, the possibilities for the application of modern telecommunications devices are just beginning to be explored. And with these new possibilities, the congestion pricing options are greater than ever.

Various studies are available to show the effects of peak-load pricing for a few available trials. In response to a daily charge of 5 British Pounds (or $8.20 at then-currency exchange rates) per vehicle for access to an 8-square-mile zone in central London in February 2003, traffic declined by 15 percent and congestion (measured as the difference between congestion travel time and free-flow travel time) declined by 30 percent within the zone (Transport for London 2004). In Orange County, California, the 15-mile San Joaquin Hills Toll Road, i.e. State Route 73, included a peak-period premium of 25 cents at most entrances to the facility as of February 2002. One analysis reported a net reduction of 2.7 percent in total traffic and a net gain of 5.8 percent in toll revenue in response to these relatively small premium tolls (FHWA 2003). When a variable congestion pricing scheme was put in place for the six tunnels and bridges of the Port Authority of New York and New Jersey (PANYNJ) in March 2001, morning-peak traffic volume in the 5-6AM period declined by 9.0 percent and 6-7AM traffic declined by 5.7 percent, from 2002 to 2003 while evening-peak traffic declined by 4 percent. (Muriello 2003).

What are the advantages and disadvantages of HOT lanes, cordon pricing, toll roads, pricing on freeways, and their various combinations? Recent experiences in Orange County, for example, suggest many questions remain to be answered. Orange County’s initial response to growth pressures might best be characterized as “don’t build it and they won’t come.” Public authorities maintained a deliberate policy of not increasing road capacity, but growth occurred anyway. Faced with a dramatic decrease in network level of service, policy objectives changed. The Orange County Transportation Authority spearheaded interagency efforts to catch up with the demand for transportation by investing in a variety of toll road facilities, among other strategies. Toll road experience has been mixed and these facilities have not delivered the degree of congestion relief hoped for nor predicted by transportation economists.

The planning challenge is that the abstract systemic representation embedded in the standard economic argument in favor of tolls is replaced by a complex physical network in the real world. It is becoming increasingly evident that, as important as pricing mechanisms are likely to become, their impact on levels of service in and the net efficiency of an urban network subject to piecemeal tolling schemes are difficult to predict (Gordon et al., in Richardson and Bae, 2008). In addition, very little is known about how development pressures at various locations throughout a large metropolitan region would be affected.

This research addressed two timely and related questions. 1) How can we model the traffic and development pressure effects of implementing peak-load pricing on selected routes in a major metropolitan area? and 2) What are the network and development pressure effects of selected pricing choices, as discovered via an application of the model to the Los Angeles metropolitan area?

With respect to possible development effects, consider that some analysts have pinned "excessive urban sprawl" on the absence of road pricing. Indeed, in the simplest monocentric models of cities, low transport costs are linked to lower densities. But even in monocentric models the story becomes more complex when the assumption of a homogeneous population is introduced. Various income groups trade off time for money at distinct rates; how they respond to opportunities to choose between time costs and dollar costs is unique to each. And the availability of these options depends on the peculiarities of the road network in their vicinity – as well as which parts of it are priced and what the prices are. This is why simulations on an actual network are required to address the question. Indeed none of the many extensions of the basic urban model can possibly identify the net result when a complex population of drivers chooses between a set of paths each made up of a variety of links, some of which are priced and some of which are not. Route-choice and time-of-day choice are compared and system equilibrium is achieved when millions of drivers are indifferent at the margin.

II. THEORTICAL BACKGROUND

Economists' interest in road pricing goes back to the early work of Pigou (1932), Walters (1961), and Vickrey (1963). It has been elaborated many times. The simple analysis is clear: absent pricing, traffic can grow to levels that are inefficient, where perceived private marginal benefits are just equal to perceived private marginal costs, but where this volume is inefficiently large because congestion externalities are ignored by each driver. The analysis also points to the user fee (toll) amounts that would internalize the externality. Figure 1 repeats the standard analysis. Drivers equate perceived (private) costs to perceived (private) benefits and the resulting level of traffic is V(e). But at this level, there are external costs that cause the actual cost of each trip to be greater than the perceived private cost. The external costs can be internalized via a toll (user fee). The analysis denotes the toll that would internalize externalities at the efficient level of traffic flow V*. But the standard analysis illustrates a partial equilibrium result that, while interesting, cannot replicate costs or results on an actual complex network. The latter is analogous to a market general equilibrium.

Consider also that the standard analysis is often used to make the claim that shadow prices are available by which possible link expansions within any network can be ranked. The largest toll indicates the link that should be expanded first. But this conclusion may not hold if links are part of a network. Any particular link expansion can have unique network effects that would have to be considered in a cost-benefit analysis.

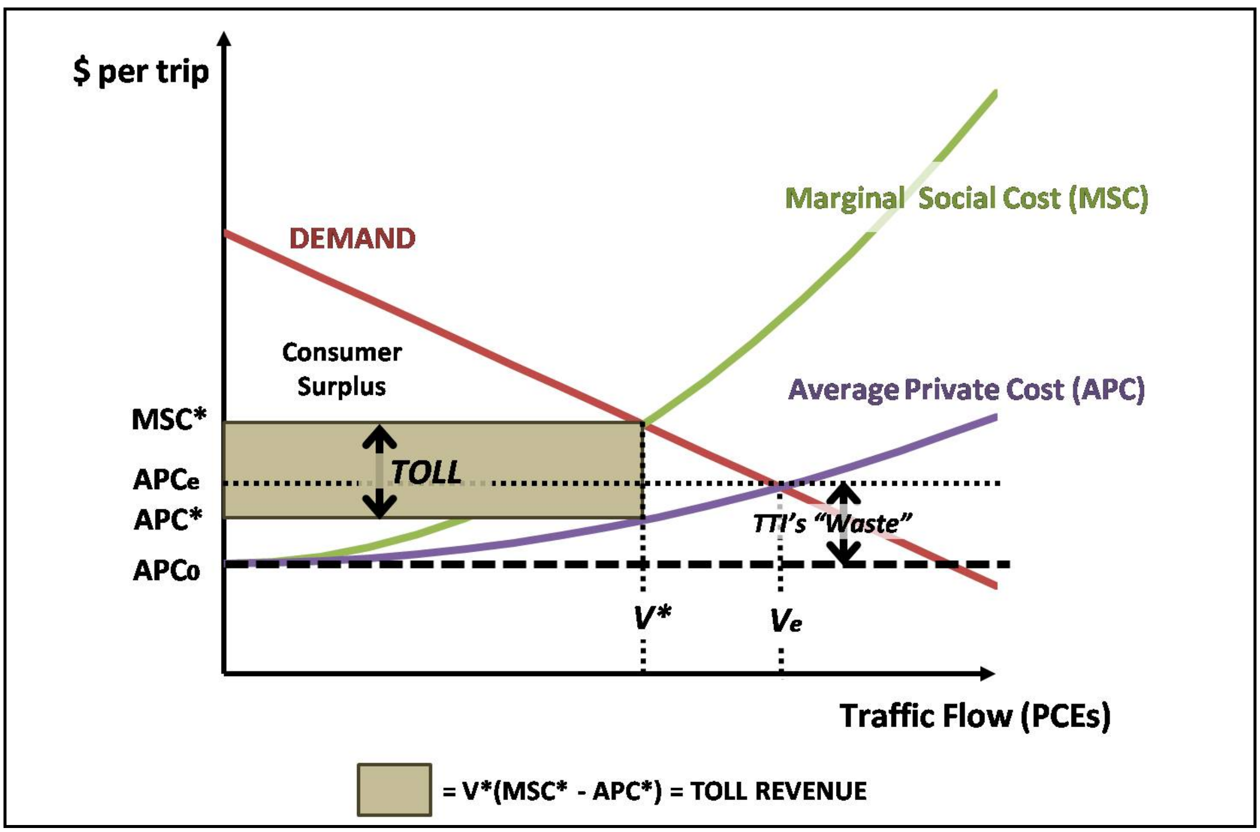

Figure1: Congestion Pricing

III. DATA AND SCENARIOS

DATA SOURCES AND RECONCILIATION

Data from various sources have been used to develop the Southern California Planning Model (SCPM), which is designed to estimate spatially detailed economic impacts throughout the five-county Los Angeles metropolitan area. Data in the model are for 2001, including a transactions table from a regional input-output model, TAZ-level employment data, passenger OD information, a freight OD database, regional transportation network link files, and political jurisdiction boundaries, etc.

The input-output model component in the current (SCPM 3) model is based on the Minnesota Planning Group's well-known IMPLAN model (http://www.implan.com). IMPLAN has a high degree of sectoral disaggregation with 509 sectors, which are to 47 "USC Sectors". The second important model component spatially allocates sectoral impacts including direct, indirect, and induced impacts across 3,191 traffic analysis zones plus 12 "external zones" (that locate shipments to and from the region) throughout region. The TAZs can aggregated to 282 primarily political jurisdictions. SCPM utilizes network data prepared by SCAG for its 2000 base-year regional transportation model with 3191 traffic analysis zones (TAZs) and 89,356 network links.

Employment data by TAZ by sector are compiled from the Southern California Association of Governments' (SCAG) 2000 job data by business establishment by SIC/NAIC code. We estimated a journey-to-services matrix that includes all the trips classified as SCAG's home-to-shop trips, and a subset of the trips classified as home-to-other and other-to-other trips. The passenger trip matrices by trip purpose are extracted from the SCAG 2000 regional transportation model (SCAG 2003).

The SCPM model relies on the specification of exogenous direct impacts (final demand changes) at specific TAZs which allocates the indirect effects to TAZs or political jurisdictions using weighted employment or freight flow matrix estimated from a freight model and distributes the induced effects using a journey-to-work matrix. Both of these result from a highway network equilibrium.

This introduces the third basic model component, a freight model that estimates the freight flow OD matrix. The freight model separates regional commodity flows to intra-regional and interregional flows. Intra-regional freight flows are estimated using 2001 I-O transactions table from IMPLAN and 2000

SCAG employment data by sector by TAZ. Interregional freight data such as imports or exports are collected from WISER Trade 2001 dataset (http://www.wisertrade.org), Waterborne Commerce of the United State (WCUS) 2000 data (http://www.iwr.usace.army.mil/ndc/wcsc/wcsc.htm), airport import/export data in 2000, Intermodal Transportation Management System (ITMS) 1996 package from California Department of Transportation (Caltrans) (http://www.dot.ca.gov/hq/tpp/offices/oasp/itms.html), and Commodity Flow Survey (CFS) 1997 data sets. The IMPLAN 2001 data are used as the basis of control total for the freight model that allows adjusting data in different years and maintaining consistency (Gordon and Pan 2001; Pan 1996; Giuliano et al. 2010). In order to validate the baseline SCPM freight traffic estimates, we used actual truck count data at eighteen regional screenlines collected by the California Department of Transportation (CalTrans) and SCAG as part of their 2003 Heavy Duty Truck Model study (SCAG/LAMTA 2004).

SCENARIOS

Our objective was to test the impacts of implementing externality-internalizing tolls using a network model of the Los Angeles metropolitan area. Fortunately, a recent paper by Parry and Small (2009) provides estimates of what such tolls should be for Los Angeles. These authors suggest the efficient congestion as well as pollution and accident externality costs (less fuel taxes) for peak as well as off-peak hours. Their two estimated congestion charges are $0.26 per mile and $0.03 per mile. The associated total charges are $0.31 and $0.08, respectively. Our simulations focused on congestion charges only and, rounding the Parry-Small suggestions, we tested scenarios involving $0.30 per mile and $0.10 per mile for the two peak periods only. In these tests, we applied the tolls to all freeway links in both peak periods. The dollars per mile congestion toll fees were converted to hours per mile congestion time based on the hourly wage estimated from the IMPLAN 2001 data. The $0.10 per mile tolls was converted to 0.0057 hr/mile or 0.3407 min/mile while the $0.30 per mile tolls was converted to 0.0170 hr/mile or 1.0220 min/mile. In the modeling described below, the peak hours are defined as 6-am to 9-am in the morning and 3-pm to 7-pm in the evening for the five weekdays. We realize that a large number of alternate policies can be tested and we plan to study these in future work.

IV. MODEL AND ALGORITHM

Various versions of SCPM have been developed since the 1990s. The early version (SCPM 1; SAS-based) was a regional input-output model to trace all economic impacts, including those of intra- and interregional shipments, usually at a certain level of sectoral and geographical disaggregation. Like most other inter-industrial models based upon the transactions flows between intermediate suppliers and end producers, SCPM 1 was demand driven to account for losses primarily via backward and forward linkages between economic sectors. Different from many other inter-industrial models, however, it allocated regional economic impacts to geographic zones such as political boundaries (see Richardson *et al.* 1993).

A later version (SCPM 2) was developed using the C programming language in the late 1990s. An obvious enhancement of SCPM 2 was to endogenize traffic flows, which incorporates transportation network model with gravity models to allocate indirect and induced impacts generated by input-output model to the TAZs. When traffic flows are endogenous, any change in economic activity that affects the travel behavior of individuals or the movement of freight will influence how the transportation network is used, and these impacts will work themselves out as change from one network equilibrium to another. This extension allowed use of the freight database in the regional transportation model. Similar to most traditional travel demand model, the transportation network modeling components in SCPM 2 involved consistent, robust, and practical estimates on traveler's route choices. But this version only involved modeling traffic in the three-hour AM-peak period using static user-equilibrium assignment (see Cho et al. 1999; Gordon et al. 2005, 2006; Richardson 2008; Pan 2008). The model structure for these applications is shown in Figure 2.

Instead of modeling the three-hour AM peak period as in SCPM 2, the current SCPM 3 inherits all the capabilities of previous versions and adds time-of-day functions to model AM peak, PM peak, and off-peak traffic. SCPM 3 is developed to facilitate an understanding of the actual effects of peak-load pricing on a complex land use-transportation system, including impacts on transportation network performance at the link level and activity effects at the TAZ level. It replaces the network equilibrium model shown in Figure 2 by a newly developed module for user equilibrium with variable demand (UE-VD).

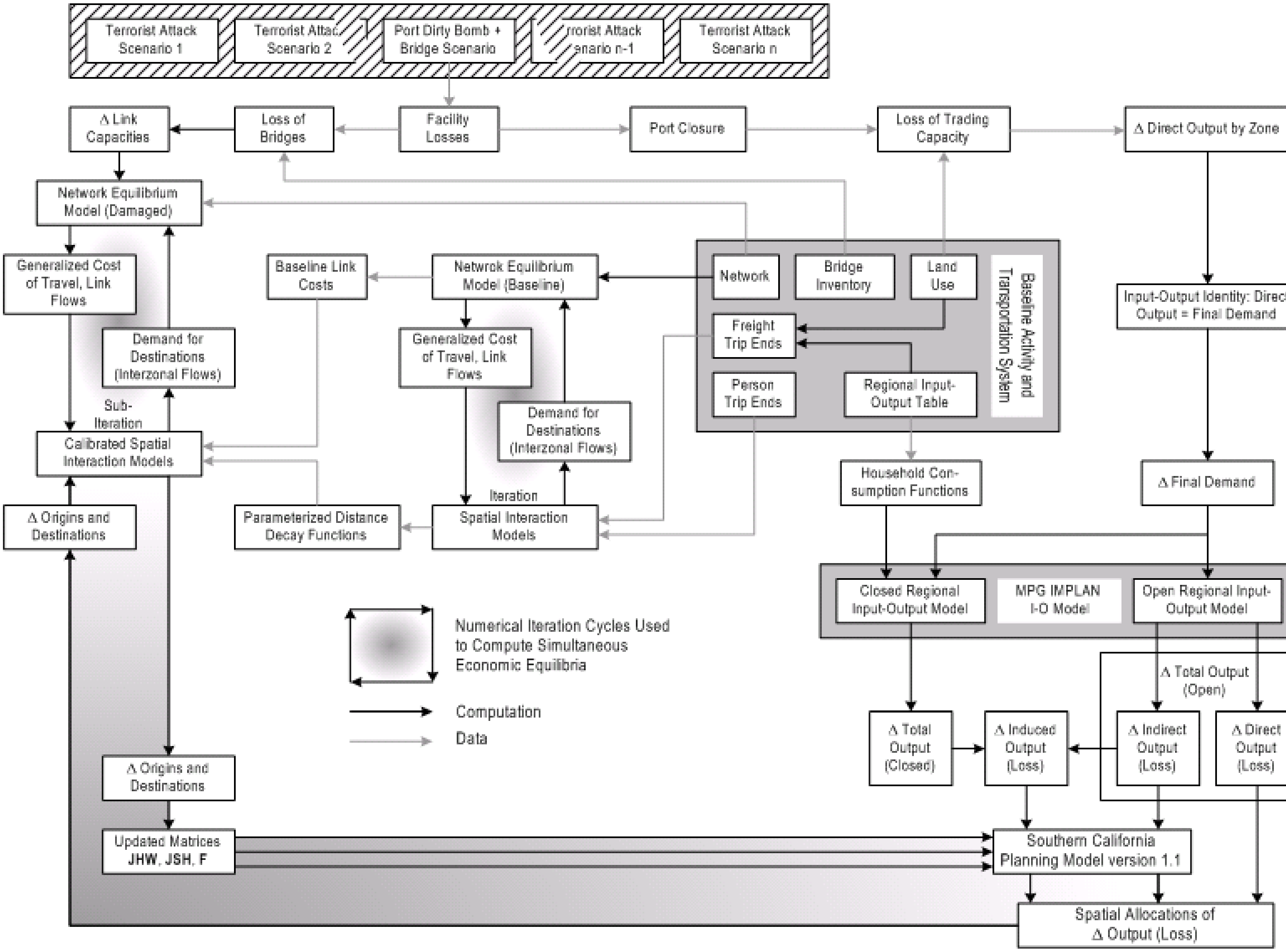

Figure 2. Previous SCPM Data flows and model calculations

In the literature, user equilibrium with variable demand (UE-VD) problems have been discussed for scenarios with trip rates influenced by the level of service on the network, i.e. travelers may change the time of travel to get around traffic congestion. In the variable demand scenarios, the fixed trip rate assumption in user equilibrium algorithm developed for traditional travel demand model is dropped. The trip rate is assumed to be determined by the travel time between origin and destination.

Various demand functions have been proposed and different UE-VD algorithms are developed to find the link flows, the link travel times, and the O-D trip rates under the user equilibrium condition. We adopted the appropriate algorithms for the SCPM model to study the time-of-day effects on travel demand and economic activities.

Based on the algorithms described by Shefi (1985), the user equilibrium with variable demand model (UE-VD) for time of the day choice is formulated as follows:

$$\text{Min } \sum_a \int_0^{x_a} t_a(x)dx - \sum_{o,d} \int_0^{T_{o,d}} D_{o,d}^{-1}(x)dx \tag{4.1}$$

$$\text{subject to } x_a = \sum_o \sum_d \sum_p \delta_{a,p}^{od} h_p^{od} \quad \forall a \tag{4.2}$$

$$\sum_p h_p^{od} = T_{od} \qquad \forall o,d \tag{4.3}$$

$$h_p^{od} \geq 0 \qquad \forall p,o,d \tag{4.4}$$

$$T_{od} \geq 0 \qquad \forall o,d \tag{4.5}$$

$$T_{od} \leq \overline{T_{od}} \qquad \forall o,d \tag{4.6}$$

where x_a is the total flow on link a.

$t_a(x)$ is the cost-flow function to calculate average travel cost on link a.

$\delta_{a,p}^{od}$ is link-path incidence variable; equal to one if link *a* belongs to path *p* connecting OD pair o and d,

h_p^{od} is flow on path *p* connecting OD pair o and d,

T_{od} is peak-hour trip between origin node o and destination node d,

$\overline{T_{od}}$ is the total trip between origin node o and destination node d,

p is a network path, o and d are two end nodes on the network.

$D_{o,d}^{-1}(x)$ is the inverse of the demand function for O-D pair (o,d)

One of the most widely used demand functions is the logit formula that represents the change of demand in terms of congestion time. The peak-hour trips between origin node o and destination node d T_{od} is calculated using a demand function in the logit formula as follows,

$$T_{o,d} = \overline{T}_{o,d} \frac{1}{1+e^{\theta(t_{o,d}-t'_{o,d})}} \qquad (4.7)$$

where, t_{od} is the minimum travel time at peak period between O-D pair o,d,

t'_{od} is the minimum travel time at free flow (or off-peak period) for O-D pair o,d,

$\overline{T}_{o,d}$ is the total trips allocated for peak period using trips-in-motion factors between O-D pair o,d,

Then, the inverse demand function would be,

$$D_{o,d}^{-1}(\bullet) = t_{o,d}(T_{o,d}) = \frac{1}{\theta}\ln(\frac{\overline{T}_{o,d}}{T_{o,d}} - 1) + t'_{o,d} \qquad \forall o,d \quad (4.8)$$

To solve the variable demand problem with an efficient fixed-demand formulation, an excess demand function is derived by replacing the peak-hour trip $T_{o,d}$ with total trips $\overline{T}_{o,d}$ minus excess demand trips $T'_{o,d}$ in (4.8). The excess demand function is shown as follows,

$$W_{o,d}(T'_{o,d}) = \frac{1}{\theta}\ln(\frac{T'_{o,d}}{\overline{T}_{o,d} - T'_{o,d}}) + t'_{o,d} \qquad \forall o,d \qquad (4.9)$$

We also know the variable travel demand can be expressed by the excess demand through a network representation. We can derive the following formula

$$-\sum_{o,d}\int_0^{T_{o,d}} D_{o,d}^{-1}(x)dx = -\sum_{o,d}\int_0^{T'_{od}} w_{od}(v)dv \qquad (4.10)$$

Then, the formula (4.1) will be reformed as follows,

$$\text{Min } \sum_a \int_0^{x_a} t_a(x)dx + \sum_{o,d} \int_0^{T'_{od}} w_{od}(v)dv \tag{4.11}$$

The link cost-flow function in the formula (4.1) is shown as follows,

$$t_a = t_a(0)[1 + \alpha(\frac{x_a}{C_a})^\beta] \tag{4.12}$$

where $t_a(x)$ is the cost-flow function to calculate average travel cost on link a, and $t_a(0)$ is the free-flow travel cost on link a,

x_a is the total flow on link a, including both personal trips and freight trips,

C_a is the capacity of link a,

α and β are parameters, while 1+ α is the ratio of travel time per unit distance at practical capacity D_a to that at free flow. Both α and β are estimated from empirical data. Based on the link capacity function published by Bureau of Public Roads (BPR, 1964), α is assigned a value of 0.15 and β is assigned a value of 4.

If we plugged in the inverse demand function (4.9) with given parameters and the link cost-flow function (4.12) into formula (4.11), we get the objective function of the user equilibrium with variable demand model (UE-VD).

The solution algorithm is summarized as follows,

Step 0: **Initialization**. Perform all-or-nothing approach to assign trips using free flow travel costs $t_a = t_a(0)$, for each link a on the empty network. Initial feasible solutions of link flows x_a and O-D trips $T_{o,d}$ in a given peak period are obtained.

Step 1: **Update**. The travel time on link a is updated as $t_a = t_a(x_a)$ and inverse demand function value $D^{-1}_{o,d}(T_{o,d})$ $\forall o, d$ is calculated using formula (4.8).

Step 2: **Find a feasible descent direction**. Use the updated travel time $\{t_a\}$ for an all-or-nothing assignment for the trips.

Given the minimum travel cost of all the paths connecting o and d at the nth iteration is the travel cost in path m, $C_{o,d}^{m,n}$, where $C_{o,d}^{m} = \min_{\forall k}\{C_{o,d}^{k}\}$, which is also the peak-hour travel time of the O-D trips $T_{o,d}$ between the pair o, d.

(1) If $C_{o,d}^{m} < D_{o,d}^{-1}(T_{o,d})$, then all the trips $T_{o,d}$ will be assigned to this minimum cost path and flows to all the other paths would be 0, i.e. path flow $g_{o,d}^{m} = T_{o,d}$, and $g_{o,d}^{k} = 0 \ \forall k \neq m$,

(2) If $C_{o,d}^{m} \geq D_{o,d}^{-1}(T_{o,d})$, then flows to all the paths would be 0, i.e. path flow $g_{o,d}^{k} = 0 \ \forall k$,

It yields a set of auxiliary link flows $\{u_a\}$ $\{v_{o,d}\}$with trips in PCEs as follows,

$$u_a = \sum_o \sum_d \sum_k \delta_{a,k}^{od} g_{o,d}^{k} \qquad \forall a$$

$$v_{o,d} = \sum_k g_{o,d}^{k}, \qquad \forall o,d$$

Step 3: **Find optimal parameter**. A linear approximation algorithm (LPA) such as Golden section method described in Sheffi (1985, Chapter 4) is applied to obtain optimal parameter α satisfying the UE-VD equation:

$$\text{Min} \sum_a \int_0^{x_a+\alpha(u_a-x_a)} t_a(x)dx - \sum_{o,d} \int_0^{T_{o,d}+\alpha(v_{o,d}-T_{o,d})} D_{o,d}^{-1}(x)dx$$ (Eq. 4.1) or the derived objective function formula (4.11)

Step 4: **Update link flows**. Link flows x_a is changed to be $x_a+\alpha(u_a-x_a)$, O-D flows $T_{o,d}$ is updated as $T_{o,d}+\alpha(V_{o,d}-T_{o,d})$

Step 5: **Test Convergence.** The process stops when a convergence criterion is satisfied and link flows are the optimal link flows at equilibrium condition. Otherwise, go back to Step 1 and continue the process.

As a replacement of the network equilibrium model shown in Figure 2, this UE-VD algorithm is applied to three time periods, AM peak, PM peak, and off-peak, to examine the time-of-day effects of two toll scenarios, \$0.1 per mile and \$0.3 per mile. The delta trips or the excess demands in both AM and PM peak periods, i.e. the difference between the total trips allocated to the peak period using trips-in-motion factors ($\overline{T}_{o,d}$) and the trips estimated by the demand function ($T_{o,d}$), are added to the off-peak period under the assumption that travelers will shift their travel time in response to congestion level in peak hours. The delta trips in the off-peak are removed under the assumption that some travelers will cancel their trips if both peak-hour and off-peak travel costs increase beyond their budgets.

The shortest travel time rather than shortest travel distance is applied to finding the shortest path in the traffic assignment function. The traffic assignment model with UE-VD algorithm runs iteratively to reach equilibrium. The change of travel time and the change of travel distance of trips on both highway and local road are calculated and reported by the model.

V. RESULTS

How would various toll charges improve levels of service on the Los Angeles network? How do drivers trade off route-choice with time-of-day choice – against the option of traveling less? What are the revenue transfer implications? What are the effects in terms of development pressures around the region? Our simulations of two scenarios suggest some of the answers.

A. LEVELS OF SERVICE AND TOLL REVENUES

Table 1 includes a summary of results gleaned from the more detailed findings in Tables 2, and 3. Most trips involve freeways (tolled during two peak periods in our scenarios) as well as surface streets (not tolled). We focus on changes for the total trip (average and total trip times) as well as changes for the freeway and surface street components. We find that, depending on the scenario, the extent to which drivers used tolled vs. untolled segments, varied substantially. The $0.3 per mile high toll scenario shows high shifts of traffic from peak periods to the off-peak period. The AM peak traffic declines by 8.5 percent and the PM peak traffic declines by 5.17 percent (See Table 2a and 2b), which is in line with the findings in the available literature. For example, Muriello (2003) reported the 5.7 or 9.0 percent reduction of traffic in the peak morning period and 4 percent reduction of traffic volume in the peak evening as a result of the congestion pricing program in the PANYNJ.

TABLE 1 Summary of Two Pricing Scenarios Network Effects

Time Period	Type of Road	$0.30 per mile toll			$0.10 per mile toll		
		% Change of Trip Volume	% Change of Total Travel Time	% Change of Average Travel Time	% Change of Trip Volume	% Change of Total Travel Time	% Change of Average Travel Time
AM Peak	Highway		-54.16%	-50.15%		-13.17%	-14.15%
	Local		43.08%	55.61%		12.31%	11.03%
	Total	-8.05%	2.73%	11.72%	1.15%	1.74%	0.58%
PM Peak	Highway		-56.55%	-54.18%		-15.18%	-15.78%
	Local		51.28%	59.53%		12.85%	12.04%
	Total	-5.17%	7.95%	13.84%	0.72%	1.59%	0.86%
Off-peak	Highway		8.29%	2.83%		-1.15%	-0.40%
	Local		7.02%	1.63%		-1.00%	-0.25%
	Total	5.30%	7.53%	2.11%	-0.75%	-1.06%	-0.31%
Daily		-0.42%	6.50%	6.95%	0.06%	0.41%	0.34%

Table 2. Passenger Trips and Travel Time for Baseline and Scenario, AM Peak, PM Peak, and Off-peak

(Toll = $0.3 per mile)

Time Period	Type of Road	Baseline			Scenario			% Change		
		Trips (PCEs)	Total Travel Time (PCE*Mins)	Average Travel Time (Mins)	Trips (PCEs)	Total Travel Time (PCE*Mins)[*1]	Average Travel Time (Mins)[*1]	Total Trips	Total Travel Time	Average Travel Time
AM Peak	Highway		28,796,972	5.84		13,200,017	2.91		-54.16%	-50.15%
	Local		40,596,044	8.24		58,084,184	12.82		43.08%	55.61%
	Total	4,926,850	69,393,016	14.08	4,530,046	71,284,201	15.74	-8.05%	2.73%	11.72%
PM Peak	Highway		34,568,832	4.48		15,021,011	2.05		-56.55%	-54.18%
	Local		51,464,912	6.66		77,855,680	10.63		51.28%	59.53%
	Total	7,724,865	86,033,744	11.14	7,325,475	92,876,691	12.68	-5.17%	7.95%	13.84%
Off-peak	Highway		52,908,392	4.08		57,292,732	4.20		8.29%	2.83%
	Local		79,860,288	6.16		85,469,288	6.26		7.02%	1.63%
	Total	12,959,679	132,768,680	10.24	13,647,125	142,762,020	10.46	5.30%	7.53%	2.11%
	Sum	25,611,394	288,195,440	11.25	25,502,646	306,922,912	12.03	-0.42%	6.50%	6.95%

Table 3. Passenger Trips and Travel Time in Baseline and Scenario, AM Peak, PM Peak, and Off-peak

(Toll = $0.1 per mile)

Time Period	Type of Road	Baseline			Scenario			% Change		
		Trips (PCEs)	Total Travel Time (PCE*Mins)	Average Travel Time (Mins)	Trips (PCEs)	Total Travel Time (PCE*Mins)*1	Average Travel Time (Mins)*1	Total Trips	Total Travel Time	Average Travel Time
AM Peak	Highway		28,796,972	5.84		25,004,728	5.02		-13.17%	-14.15%
	Local		40,596,044	8.24		45,592,360	9.15		12.31%	11.03%
	Total	4,926,850	69,393,016	14.08	4,983,433	70,597,088	14.17	1.15%	1.74%	0.58%
PM Peak	Highway		34,568,832	4.48		29,322,734	3.77		-15.18%	-15.78%
	Local		51,464,912	6.66		58,079,104	7.46		12.85%	12.04%
	Total	7,724,865	86,033,744	11.14	7,780,719	87,401,838	11.23	0.72%	1.59%	0.86%
Off-peak	Highway		52,908,392	4.08		52,301,852	4.07		-1.15%	-0.40%
	Local		79,860,288	6.16		79,063,920	6.15		-1.00%	-0.25%
	Total	12,959,679	132,768,680	10.24	12,862,930	131,365,772	10.21	-0.75%	-1.06%	-0.31%
	Sum	25,611,394	288,195,440	11.25	25,627,082	289,364,698	11.29	0.06%	0.41%	0.34%

Assuming that there are 250 days of the year in which congestion tolling occurs, the lower toll ($0.10/mile) transfers substantially more revenue to the tolling authority than would the higher toll ($0.30/mile), $1,420 million vs. $550 million. Table 4 shows that revenue estimates are available for the various counties of the metropolitan area. Our model also makes them available for spatial units below the county (see King, Manville and Shoup 2006).

Table 4. Toll Revenues for the Los Angeles Region and its Counties ($0.3 per mile) and ($0.1 per mile), AM Peak and PM Peak

County Name	Number of Toll Links	Link Length (Miles)	(Toll = $0.3 per mile)			(Toll = $0.1 per mile)		
			AM Peak ($)	PM Peak ($)	Total ($)	AM Peak ($)	PM Peak ($)	Total ($)
LOS ANGELES	3,401	1,428	601,175	707,760	1,308,935	1,488,699	1,752,712	3,241,412
ORANGE	1466	600	213,876	262,046	475,922	468,197	547,097	1,015,294
RIVERSIDE	632	475	83,079	95,832	178,911	336,731	382,716	719,446
SAN BERNARDINO	632	428	87,163	104,330	191,492	250,927	287,885	538,812
VENTURA	355	187	28,964	35,973	64,937	76,879	88,825	165,704
Sum	6,486	3,119	1,014,256	1,205,942	2,220,198	2,621,432	3,059,234	5,680,667

Note: the total revenue is the daily revenue based on the daily AM- and PM-peak passenger vehicle volume and link length of the tolled lanes.

Overall (24-hour) trip volumes change very little, with a small decrease at the higher toll (-0.42 percent vs. 0.06 percent). The higher toll moves trip volumes from the peaks to the off-peak periods, but the trip volume effects for the lower toll are very minor – and seemingly in the wrong direction. But substitutions from tolled roads to non-tolled roads are a big part of the story. Both tolls cause improvements in average and total freeway travel times, but at the cost of increased travel times on non-tolled surface streets. For the lower toll, this adds up to only minor changes in overall travel times. For the higher toll, aggregate travel times increase as riders try to avoid the toll.

Total and average daily travel time is almost unchanged for the lower toll, but increase somewhat at the higher user fee. The significant changes are, as expected, in the shifts from peak to off-peak. And these shifts are revealed by average and total trip time impacts which are much larger for the higher toll. At the same time, for both tolls, there are substantial shifts from tolled to non-tolled roads in each peak period, more so for the larger toll. Off-peak traffic increases for tolled as well as non-tolled roads for the higher toll, but decreases slightly for both at the lower toll. If we accept the Parry-Small findings (the higher toll), internalizing the externalities has high costs.

The trade-off facing policy makers is complex: internalized externalities vs. improved peak-hour levels-of-service vs. greater revenues collected. Notably, improved levels of service on tolled freeways comes at the expense of greatly increased use of surface roads.

B. LAND USE EFFECTS

The application of SCPM generates detailed network effects as well as information on changed trip production for each of the region's TAZs. Regional maps showing the latter effects are show in Figures 3a and 3b. Trip production can be thought of as an indicator of development pressures. In this way, we get a hint of how regional development patterns might eventually change. We have already mentioned that most analysts expect that a priced network will bring about higher densities and a less spread out (less "sprawled") metropolitan area. But we have also noted that these suggestions do not reflect the large number of trade-offs that occur in a complex network.

Inspection of the two maps shows that patterns of change are hard to discern of summarize, but one thing does jump out immediately: development pressures shift downward, across-the-board, for the higher fee but they shift upward, across-the-board, for the lower toll. We wondered whether there is any association between TAZ population density and changes in trips produced. The two plots shown in Figures 4a and 4b show that there is no link. This supports our argument that studying an actual network can yield surprising results that may not be available from discussions involving abstract models.

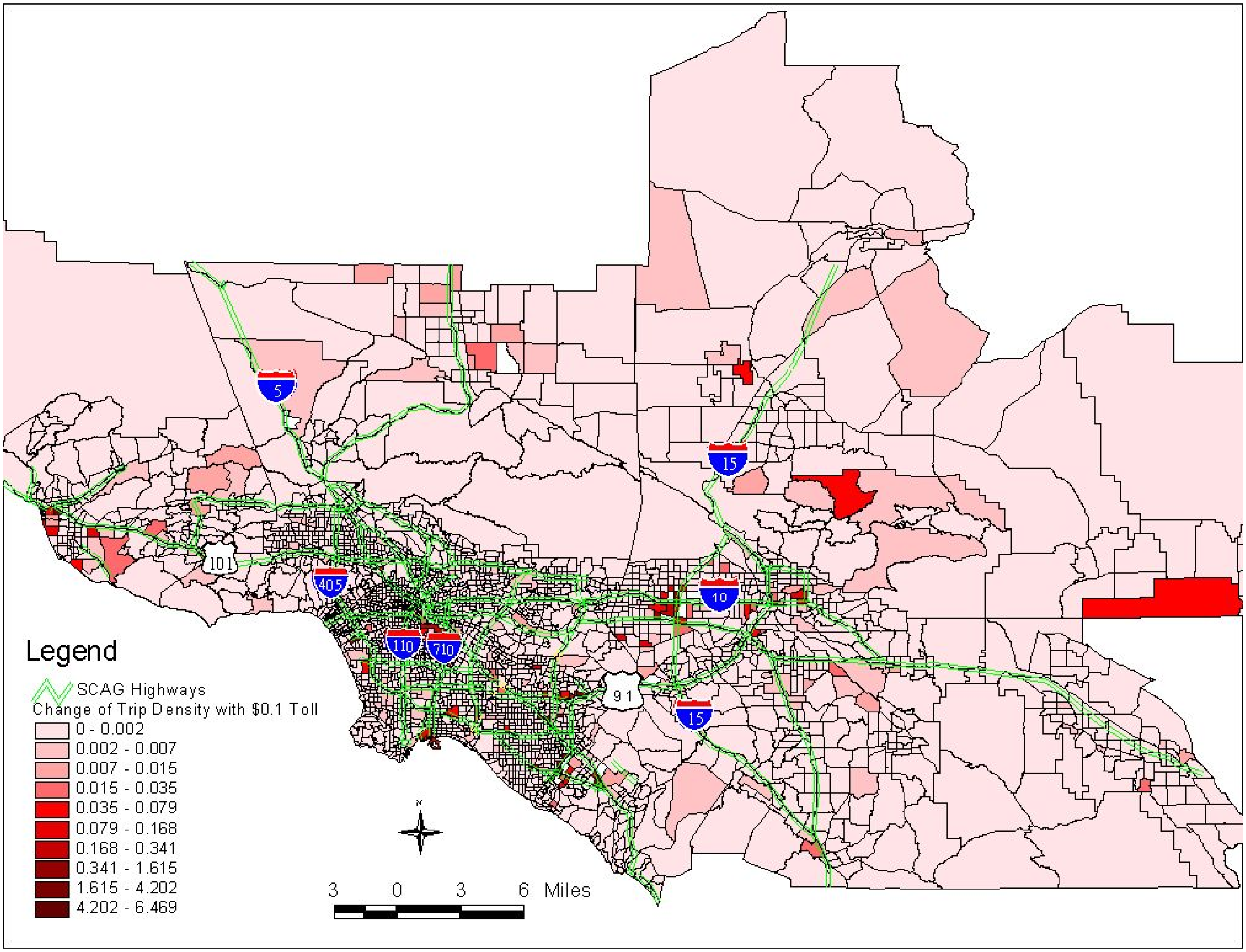

Figure 3a. The Change of Trip Production Densities, $0.1 Toll Scenario

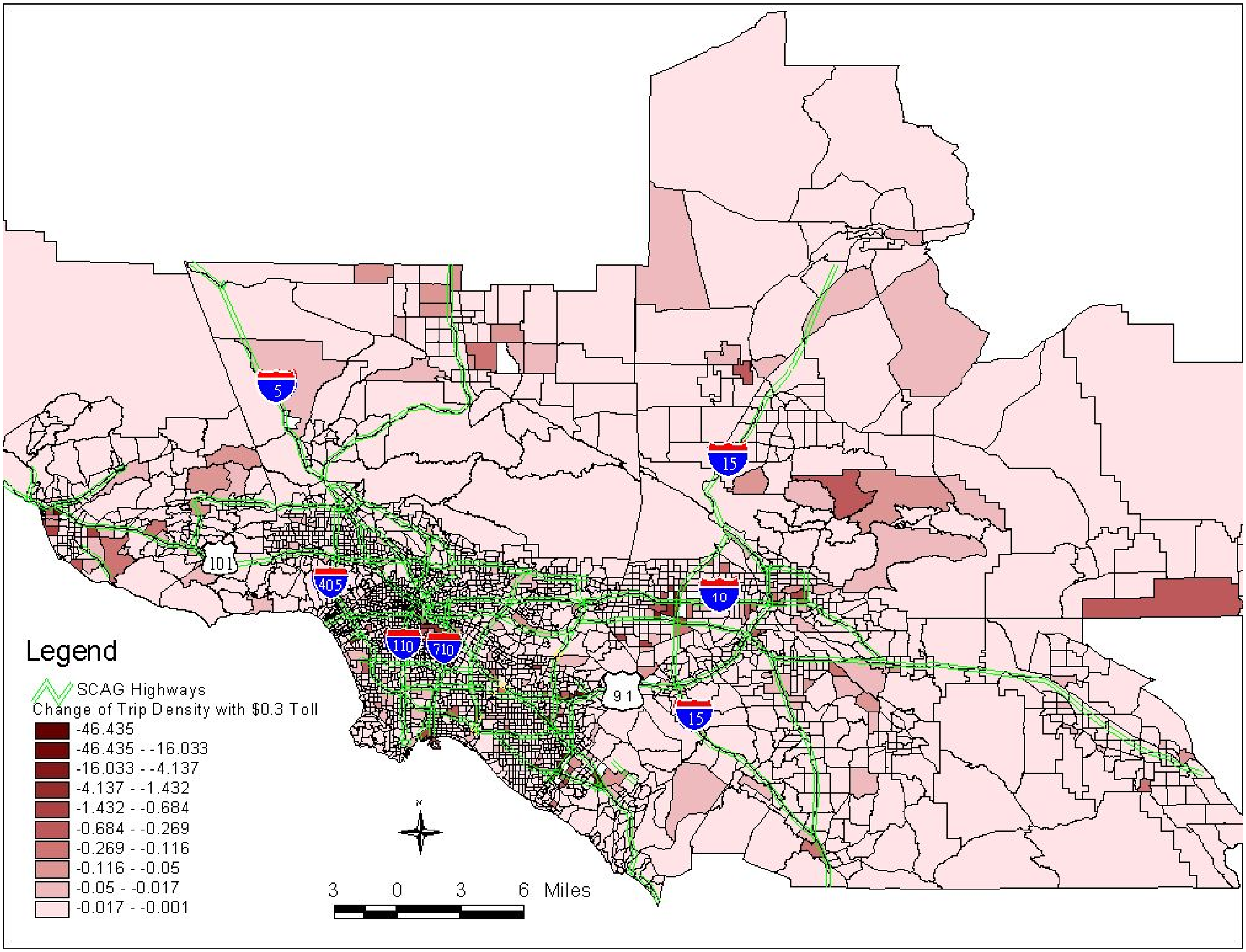

Figure 3b. The Change of Trip Production Densities, $0.3 Toll Scenario

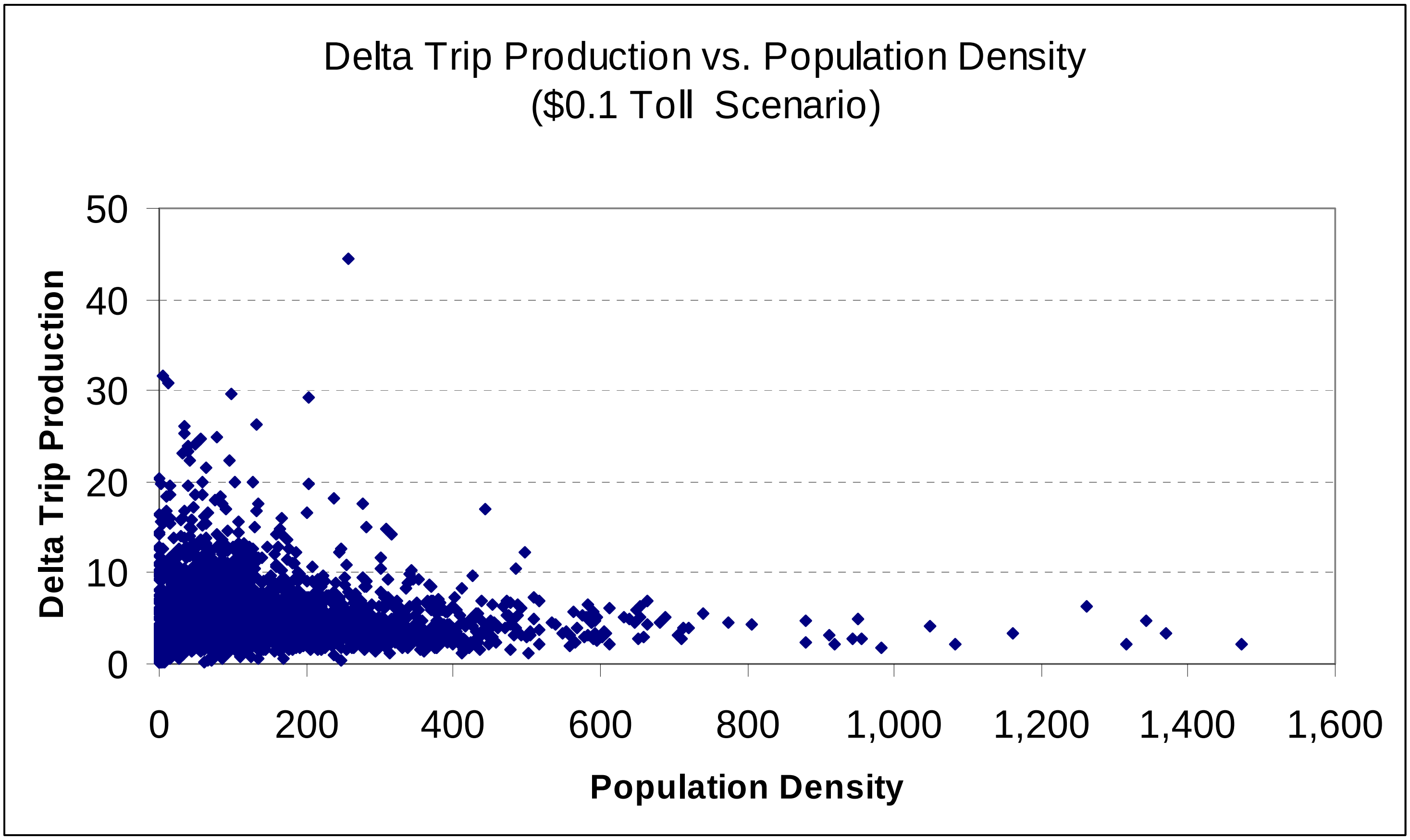

Figure 4a. Delta Passenger Trip Production vs. Population density

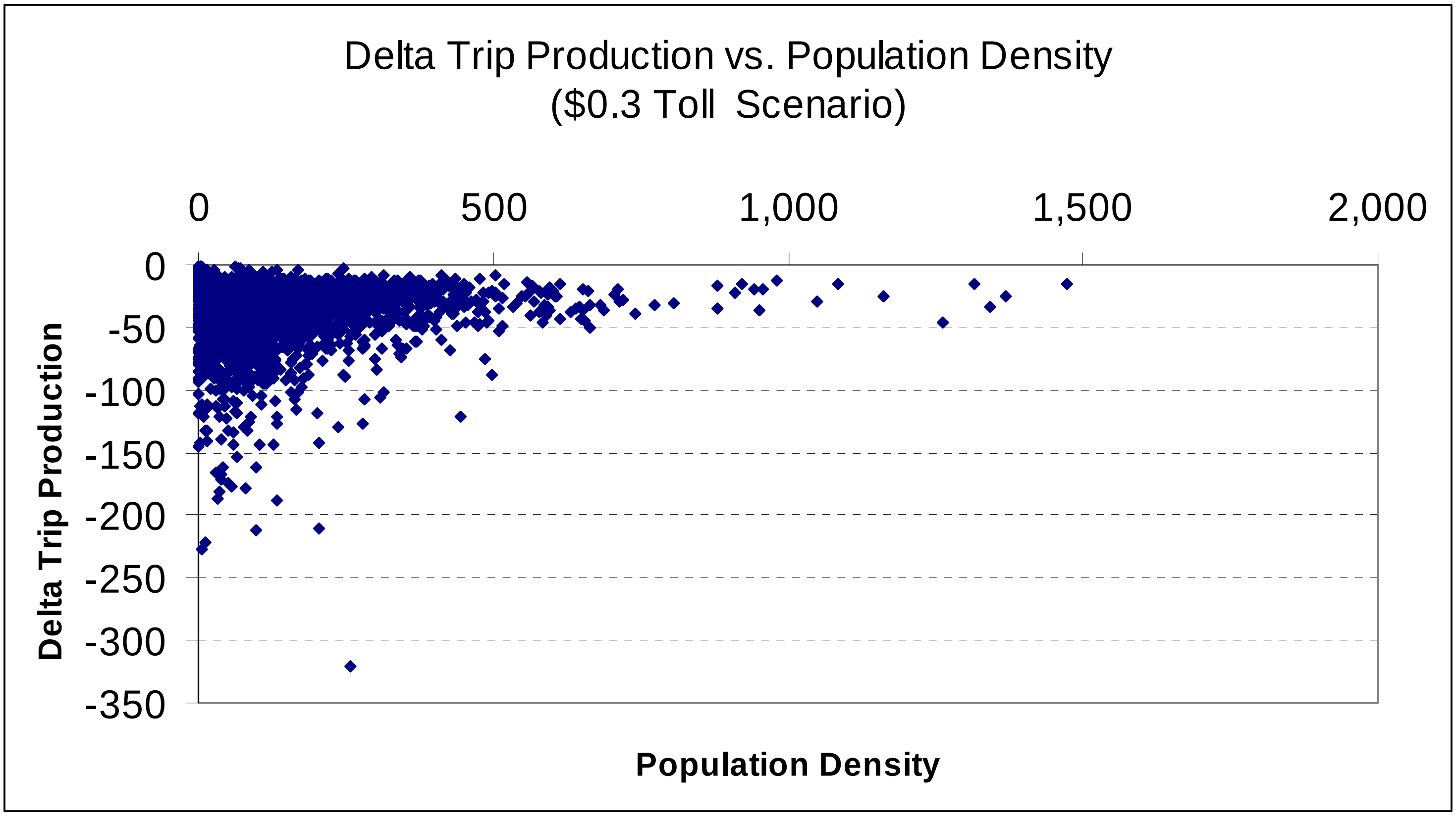

Figure 4b. Delta Trip Production vs. Population Density, the $0.1 Toll Scenario

VI. CONCLUSIONS

Free access to roads and highways is the dominant approach in most of the world's cities. As more and more people reach a level of affluence to enable them to afford an automobile, road congestion spreads. The various proposals to alleviate the problem (invest in public transit, seek transit-friendly high-density development, narrow roads to discourage auto use, etc.) have their roots in the reluctance to price scarce road space. Our claim is that the political aversion to pricing can be challenged via a better understanding of its consequences. To that end, we have developed a modeling approach to do just that. Tolling all freeways can have negative total travel time effects because they prompt increasing use of surface streets. Policy makers may want to consider alternatives to full internalization which involve re-thinking the Parry-Small toll estimates.

Finally, we have not explicitly addressed the discussion of privatization (Roth 2006). But if segments of any highway system are to be auctioned off, both buyers and sellers are better off if informed of the time savings that can be achieved at what level of tolling. Again, these magnitudes are most plausible if estimated from a simulation of traffic and tolls on a network that corresponds to reality and that includes the link or links under consideration.

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