

Road Congestion Pricing in Europe

Implications for the United States

Edited by

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18. Expansion of toll lanes or more free lanes? A case study of SR91 in Southern California

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1 INTRODUCTION

The research reported here builds on our earlier work modeling the regional economic impacts of highway and other infrastructure projects. We are particularly interested in treating the full effects of highway capacity gains and losses, and this application elaborates this work in two important directions. First, we have extended our modeling capability to include highway lanes that are tolled. Second, we apply the new model to an important prototype application, the originally private, now public, lanes in the median of a 10-mile segment of California State Route (SR) 91.

The possible widening of this route with additional tolled or general-purpose lanes has been the subject of considerable controversy. A non-compete provision in the franchise awarded to the California Private Transportation Company (CPTC) had stood in the way of public agencies' efforts to provide additional capacity in the corridor. Our approach sheds light on such controversies and, thereby, may reduce political conflict and misunderstanding. We also show that, whereas congestion tolls are widely presumed to be efficient, the efficiency outcomes are complex when only a part of the network is tolled.

2 CALIFORNIA SR91 EXPRESS LANES

The SR91 express lanes were California's first private toll highway project, which was developed under enabling legislation passed by the California legislature in 1989. A franchise was eventually awarded to the CPTC who financed, built and operated two tolled lanes in each direction along

10 miles of the SR91's unused median strip. Development costs are estimated to have been \$135 million. These lanes opened to traffic on 27 December 1995. Drivers pay electronically via windshield-mounted transponders, a widely used Texas Instruments technology called FastTrak that also serves as a California bridge toll standard, and are billed monthly.

The SR91 toll lanes are an example of value pricing, that is, of providing travelers with an opportunity to pay a premium for access to a higher level of service (Small, 2001). This context provides toll facilities with an attractive policy dimension, but introduces a host of questions ranging from modeling to the politics of congestion.

CPTC developed, refined and applied state-of-the-art pricing and photo-enforcement software and hardware and demonstrated that these perform well. Tolls varied from \$0.60 to \$3.20 in 1998, depending on traffic flow conditions, and the toll schedule was periodically adjusted so that 65 mph average speeds could be maintained. Most recently, peak-hour tolls went as high as \$9.50. Given the target 25-minute time savings, this implies a high valuation of travel time for peak-period toll users. Three-person or larger carpools on the express lanes received free access.

Recent volumes on the express lanes were greater than 30,000 trips per day, 14 percent of weekday SR91 corridor use. Peak-hour use was 1,400–1,600 vehicles per hour per lane. Yet, capping a controversy over how corridor capacity should be expanded to respond to growing demand, the lanes were sold to the Orange County Transportation Authority (OCTA) for \$207 million, with ownership transfer occurring in early 2003. Now OCTA has the flexibility to add to capacity or change the mix of toll and free lanes. To our knowledge, the type of analysis reported below was not done. Detailed results of user surveys are described at http://www.path.berkeley.edu/~leap/TTM/Demand_Manage/pricing.html. Many of the cited descriptive data are from Caltrans's final evaluation report published in 2000 and available at <http://www.ceenve.calpoly.edu/sullivan/SR91/sr91.htm>.

3 THE SOUTHERN CALIFORNIA PLANNING MODEL (SCPM)

Regional economists and regional planners often rely on interindustry models. The details of intersectoral linkages in these models are useful for exploring regional economic structure. However, this approach has not permitted an adequate treatment of transportation costs, not all of which are transacted because most roads are publicly provided. This problem has recently been addressed at the national level by the Bureau of

Transportation Statistics' effort to create Transportation Satellite Accounts (Han and Fang, 2000). Such spatial elaborations require explicit treatment of the resources consumed by flows between origin–destination pairs. While explicit representation of the transportation network is usually less important in multiregional approaches, it is another matter at the intrametropolitan level, because congestion dominates line-haul costs.

Along with the explicit treatment of transport costs, we have developed sub-metropolitan area level disaggregations of the regional economic model. Richardson et al. (1993) developed the Southern California Planning Model-1 (SCPM1), combining a metropolitan-level input–output model with a Garin–Lowry model to spatially allocate induced economic impacts. This model operationalized spatial input–output analysis at the intrametropolitan level. SCPM1 could allocate impacts in terms of jobs or the dollar value of output to the area's 308 sub-regional (municipal) zones. It did not treat the transportation network explicitly. Congestion effects were ignored, and transportation flows were exogenous.

SCPM1 and its successors have been developed for the Los Angeles metropolitan region. The study area includes Los Angeles, Orange, Riverside, San Bernardino and Ventura counties. The area covers almost 34,000 square miles. The 2000 population of the five-county area was over 16.3 million.

In 2000, the urbanized portions of the five-county area extended to 1,668 square miles; population density in the urbanized area was about 7,068 people per square mile, the highest in the US. The urbanized area is described in terms of the Southern California Association of Government's (SCAG's) 1527 disaggregated 1990 traffic analysis zones (TAZs; reduced to 1464 TAZs in the exercise that follows for modeling convenience). The regional highway network includes 22,244 links.

Table 18.1 provides some recent aggregate data describing the region. The total number of households in the area was 5.35 million in 2000. The nonfarm employment in the SCAG region was over 5.11 million in 1999. The employment distribution across industry sectors was: 34.3 percent in services, 16.4 percent in manufacturing, 13.3 percent in government, 9.6 percent in retail and 7.3 percent in Finance, Insurance and Real Estate (FIRE). International exports from the five-county area have been reported to be \$35.7 billion in 1996 (Exporter Location Series, US Bureau of the Census); our analysis suggests, however, that this may be a significant underestimate.

Integrating a transportation network into SCPM1 provides important opportunities. Distance decay relationships (destination choice) can be endogenized, permitting an improved spatial allocation of indirect and induced economic impacts. Also, this integration makes it possible to better

Table 18.1 Socio-economic profile, Los Angeles five-county area

| County | Pop. 2000 | House- holds 2000 | Private non- farm emp. 1999 | Median income 1999 | Mean commute time* (mins) 2000 | Land area (sq. mi.) |
|---------------------|--------------|-------------------------|---|--------------------------|--|---------------------------|
| Los Angeles | 9,519.3 | 3,133.8 | 3,747.8 | \$42,189 | 29.4 | 4,061 |
| Orange | 2,846.3 | 935.3 | 1,331.0 | \$58,820 | 27.2 | 789 |
| Riverside | 1,545.4 | 506.2 | 366.4 | \$42,887 | 31.2 | 7,207 |
| San Bernardino | 1,709.4 | 528.6 | 441.0 | \$42,066 | 31.0 | 20,052 |
| Ventura | 753.2 | 243.2 | 224.8 | \$59,666 | 25.4 | 1,845 |
| Five-county area | 16,373.6 | 5,347.1 | 6,110.8 | \$45,957 | 29.1 | 33,954 |

Note: * Weighted mean; median not available.

Source: See <http://quickfacts.census.gov/qfd/>.

account for the economic consequences of changes in transportation network capacity, such as the prospect of widening portions of SR91.

Recent work resulted in the development of SCPM2, which treats the transportation network explicitly, endogenizing otherwise exogenous matrices describing the travel behavior of households, achieving consistency across network costs and origin–destination requirements, and endogenizing indirect and induced economic deliveries and arrivals (impacts) over zones.

The current research extended the model so that network segments that are tolled can be highlighted and examined. The current version of the model, SCPM2.5, relies on a constrained optimization that combines traffic assignment and trip distribution. A path-flow version of this model is:

$$Z = \min Z(\mathbf{x}, \mathbf{q}) = \sum_a \int_0^{x_a} t_a(w) dw + \sum_p \left[\frac{1}{\beta^p} \sum_r \sum_s q_{rs}^p \cdot \ln(q_{rs}^p) \right] \quad (18.1)$$

subject to:

$$f_{rs}^k \geq 0 \quad \forall p, k, r, s \quad (18.2)$$

$$q_{rs}^p \geq 0 \quad \forall p, r, s \quad (18.3)$$

$$\sum_k f_{rs}^{pk} = q_{rs}^p \quad \forall p, r, s \quad (18.4)$$

$$x_a = \sum_p \sum_{rs} \sum_k f_{rs}^{pk} \cdot \delta_{a,k}^{rs} \quad \forall a \quad (18.5)$$

$$q_{rs}^p = O_r^p \cdot D_s^p \cdot K_{rs}^p \cdot \exp(\alpha^p + \beta^p u_{rs}) \quad \forall p, r, s \quad (18.6)$$

$$O_r^n = \mathbf{O}_r^n + \sum_j b_{ij} \cdot V_r^n, \quad D_s^n = \mathbf{D}_s^n + \sum_j a_{ij} \cdot V_s^n \quad (18.7)$$

where:

- t_a = link performance function of link a ;
- x_a = flow on link a ;
- q_{rs}^p = trip rate of type p between OD pair $r-s$;
- f_{rs}^{pk} = flow of trip type p on path k connecting OD pair $r-s$;
- u_{rs} = travel time between OD pair $r-s$;
- $\delta_{a,k}^{rs}$ = 1 if link a is on path k between OD pair $r-s$, 0 otherwise;
- O_r^n = freight trip generated from industry n in zone r ;
- D_s^n = freight trip destined to industry n in zone s , and its base-line;
- \mathbf{O}_r^n = baseline trip generation from industry n in zone r ;
- \mathbf{D}_s^n = baseline trip destination to industry n in zone s ;
- $\alpha^p, \beta^p, K_{rs}^p$ = calibration parameters; and
- p = number of trip types, $p \in P = \{m, n\}$, $m = 1 \dots 9$, $n = 1 \dots 5$.

Trips are disaggregated into nine types of personal trips (m), and freight trips generated by four industrial sectors (n):

- m 1 = home-to-work, 2 = work-to-home, 3 = home-to-shop, 4 = shop-to-home, 5 = home-to-other, 6 = other-to-home, 7 = work-to-other, 8 = other-to-work, 9 = other-to-other.
- n 1 = Mining, 2 = Manufacturing (non-durable), 3 = Manufacturing (durable), 4 = Transportation, 5 = Communication & Utilities.
- V_r^n Economic impact on industry n in zone r :

$$V_r^n = V_r^{n,D} + V_r^{n,I} + V_r^{n,U},$$

$V_r^{n,D}$ \neq Net direct impact on industry n in zone r ;

$V_r^{n,I}$ \neq net indirect impact on industry n in zone r ;

$$V_r^{n,I} = \frac{\exp(\alpha^n + \beta^n \cdot u_{sr})}{\sum_z \exp(\alpha^n + \beta^n \cdot u_{sz})} \cdot V^{n,I} \cdot \left(\frac{V_s^{n,D}}{V^{n,D}} \right);$$

$V_r^{n,U}$ net induced impact on industry n in zone r :

$$V_r^{n,U} = JHS \cdot (JHW)^U \cdot \frac{\exp(\alpha^n + \beta^n \cdot u_{sr})}{\sum_z \exp(\alpha^n + \beta^n \cdot u_{sz})} \cdot V^{n,U} \cdot \left(\frac{V_s^{n,D}}{V^{n,D}} \right),$$

$$JHW = \frac{q_{rs}^{m=1}}{\sum_r q_{rs}^{m=1}}, q_{rs}^{m=1} = \text{journey home-to-work matrix,}$$

$$JHS = \frac{q_{rs}^{m=3}}{\sum_s q_{rs}^{m=3}}, q_{rs}^{m=3} = \text{journey home-to-shop matrix.}$$

4 DATA INPUTS

Spatially disaggregated modeling requires the preparation of input data at fine levels of geographic detail. Most model input data were collected at the census block level, the base unit for all census data. We assembled detailed spatial and aspatial information for the study area, including Census 2000 population data, SCAG 1997 employment data providing employment by four-digit SIC category by street address, United States Geological Survey (USGS) 1-meter resolution air photos and similar sources. These data are available from the authors.

Because the expansion of SR91 is still a hypothetical project, there are no data on the exact expansion boundaries. However, it is possible to identify the housing and business units likely to be along the freeway alignment by referring to USGS air photos. Unfortunately, the available photos were taken several years ago and do not provide up-to-date land-use information. It was also problematic to match the air photos with the alignment of the freeway because they are represented in different projection systems. To obtain up-to-date information on the land uses most likely to be impacted, we relied on field inspections to update the land uses shown by the USGS air photos. From our field inspections it was determined that 266 housing units are likely to be impacted by the hypothetical freeway expansion project. Most of these are located in low-density residential areas. All of them are in the city of Anaheim. No businesses were found to be located in the likely impact area of the freeway expansion because all existing businesses are set back from the alignment.

Predicting the destination settlements of the relocating households involved two steps. First, an empirically established distribution function was used to generate moving distances (Clark et al., 2002). The mean move was estimated to be 6.28 miles. Second, most likely move-in locations for each impacted household were determined by identifying the center of the census block with average housing unit price closest to that of the census block from which the household would move. This means that each move-out household is relocated to a place with a housing unit price similar to the original residence. Some households might decide to trade up or down. Others might decide to move out of the region. There are no data available on this possibility, so we assumed and modeled a quasi-equilibrium response.

The number of move-out and move-in households in each census block was used together with county, city, TAZ, congressional district and school district information to generate input data for the SCPM runs. As households are relocated, their expenditures, including property and sales taxes, are also relocated. Based on available data, it is possible to determine the median housing value, household income, sales tax rate, property tax rate and other inputs to SCPM. Detailed input data development procedures are available from the authors.

5 MODEL RESULTS: HYPOTHETICAL EXPANSION OF SR91 CAPACITY

Household Relocation Effects

The aggregate regional effects of household relocation are minor (see Table 18.2). Approximately \$24 million in annual household expenditures are removed from the path of the highway expansion and are relocated

Table 18.2 Summary economic impacts of residential relocation, one-lane expansion of SR91 in each direction (1999 \$1,000s)

| \$1000 | Positive | Negative | Net |
|----------|----------|----------|-----|
| Direct | 14,405 | -14,421 | -16 |
| Indirect | 3,621 | -3,635 | -15 |
| Induced | 5,834 | -5,823 | 12 |
| Total | 23,860 | -23,879 | -19 |

Note: Negative impacts are generated at residents' move-out relocations. Positive impacts are generated at residents' move-in relocations.

throughout the region. Aggregate impacts are small. The importance of these calculations is to show spatial redistribution effects. We have been able to calculate the direct, indirect and induced impacts of the relocations by traffic analysis zone (maps available from the authors).

Direct impacts result from displaced households. Negative impacts occur in locations adjacent to the freeway right of way. Positive impacts are more widely distributed as households relocate (Clark et al., 2002). Indirect, induced and total impacts are much more widely dispersed. SCPM2 has the unique capability to estimate these complex spatial effects. SCPM2 results are sector specific, but are reported in terms of total dollars.

Highway Network Effects

Network flow estimates are shown in Tables 18.3 and 18.4. Table 18.3 provides baseline and scenario results, reporting network delay costs and tolls paid. Tolls paid are a transfer from users to owners. However, total user costs are the sum of delay costs and tolls, and it is this total cost to which users respond. About 17 percent of the estimated baseline passenger-car-equivalents on the network consist of freight shipments.

We consider and report on two facility expansion scenarios combined with six operating options for a total of 12 scenarios, plus five operating options for the existing facility. Tolls on SR91 vary by time of day. SCPM2 results are scaled to 24-hour periods. The analysis relies on a composite SR91 toll that approximates a weighted average charge across 24 hours. Ideally, we would also model flow adjustments across time of day. This would increase model complexity very substantially. We account for adjustments in origins and destinations and route choice for multiple modes. Accounting for time-of-day adjustments is a future research activity.

The two facility expansion scenarios are:

- add a toll lane in each direction, providing four general-purpose lanes and three toll lanes in each direction (the 4 + 3 scenario), or
- add a general-purpose lane in each direction, providing five general-purpose lanes and two toll lanes in each direction (the 5 + 2 scenario).

The operating options are defined by varying the composite toll charged on the tolled lanes from values of \$1 to \$11 (as pointed out above, the peak toll is currently \$9.25). Table 18.4 shows changes in network delay costs and tolls collected under alternative scenarios. Turning to the dollar values of impacts, and assuming no shifts in origin-destination demand, annual reductions in travel costs over the network range between \$13.3 and \$14.7 million with high tolls (\$7–11) in the 4 + 3 (toll road added) combination.

Table 18.3 Annual network user costs (\$1,000s)

| Scenarios | Passenger travel time cost | | Toll paid | | Truck travel time cost | Sum | | | |
|-----------|----------------------------|-------------|-----------|-------------|------------------------|------------|------------|-----------|------------|
| | Toll | Drive-alone | HOV | Drive-alone | | HOV | Delay cost | Toll paid | Total |
| 4 + 2 | \$1 | 12,884,798 | 8,512,183 | 7,538 | 1,567 | 27,564,586 | 48,961,566 | 9,105 | 48,970,671 |
| | \$3 | 12,871,093 | 8,508,088 | 19,128 | 4,449 | 27,552,010 | 48,931,191 | 23,577 | 48,954,768 |
| | \$5 | 12,871,840 | 8,506,040 | 19,053 | 6,512 | 27,527,183 | 48,905,062 | 25,566 | 48,930,627 |
| | \$7 | 12,882,848 | 8,507,591 | 7,167 | 4,483 | 27,526,280 | 48,916,718 | 11,649 | 48,928,367 |
| | \$9 | 12,889,804 | 8,511,973 | – | – | 27,525,491 | 48,927,268 | – | 48,927,268 |
| | \$11 | 12,890,056 | 8,512,098 | – | – | 27,526,420 | 48,928,575 | – | 48,928,575 |
| 4 + 3 | \$1 | 12,883,933 | 8,512,319 | 8,471 | 1,722 | 27,568,879 | 48,965,131 | 10,193 | 48,975,324 |
| | \$3 | 12,866,602 | 8,507,884 | 23,543 | 4,650 | 27,561,814 | 48,936,299 | 28,193 | 48,964,492 |
| | \$5 | 12,865,310 | 8,505,624 | 25,152 | 6,851 | 27,555,592 | 48,926,526 | 32,002 | 48,958,529 |
| | \$7 | 12,882,175 | 8,507,708 | 7,737 | 4,283 | 27,526,734 | 48,916,617 | 12,019 | 48,928,636 |
| | \$9 | 12,889,804 | 8,511,970 | – | – | 27,525,458 | 48,927,231 | – | 48,927,231 |
| | \$11 | 12,890,020 | 8,512,077 | – | – | 27,526,283 | 48,928,380 | – | 48,928,380 |
| 5 + 2 | \$1 | 12,884,852 | 8,512,261 | 7,514 | 1,574 | 27,564,714 | 48,961,827 | 9,088 | 48,970,914 |
| | \$3 | 12,870,826 | 8,508,050 | 19,301 | 4,496 | 27,554,968 | 48,933,844 | 23,797 | 48,957,641 |
| | \$5 | 12,871,044 | 8,505,171 | 18,758 | 7,069 | 27,554,310 | 48,930,525 | 25,827 | 48,956,352 |
| | \$7 | 12,888,740 | 8,511,771 | 959 | 431 | 27,553,897 | 48,954,408 | 1,390 | 48,955,798 |
| | \$9 | 12,890,013 | 8,512,339 | – | – | 27,555,199 | 48,957,550 | – | 48,957,550 |
| | \$11 | 12,889,953 | 8,512,321 | – | – | 27,554,505 | 48,956,779 | – | 48,956,779 |

Note: Values of time = \$13.0/hour for drive-alone, \$28.9/hour for carpool, and \$71.0/hour for trucks. On average \$29.44/hour.

Table 18.4 Annual changes in network user costs (\$1,000s)

| Scenarios | Passenger travel time cost | | Toll paid | | Truck travel time cost | Sum | | | |
|-----------|----------------------------|-------------|-----------|-------------|------------------------|---------|------------|-----------|---------|
| | Toll | Drive-alone | HOV | Drive-alone | | HOV | Delay cost | Toll paid | Total |
| 4 + 3 | \$1 | 14,335 | 5,545 | -12,291 | -3,916 | 29,682 | 49,562 | -16,208 | 33,355 |
| | \$3 | -2,997 | 1,110 | 2,781 | -988 | 22,617 | 20,731 | 1,793 | 22,523 |
| | \$5 | -4,288 | -1,149 | 4,389 | 1,212 | 16,395 | 10,958 | 5,602 | 16,560 |
| | \$7 | 12,576 | 934 | -13,026 | -1,356 | -12,462 | 1,048 | -14,381 | -13,333 |
| | \$9 | 20,205 | 5,196 | -20,762 | -5,638 | -13,738 | 11,663 | -26,401 | -14,738 |
| 5 + 2 | \$11 | 20,421 | 5,304 | -20,762 | -5,638 | -12,914 | 12,811 | -26,401 | -13,589 |
| | \$1 | 15,253 | 5,487 | -13,248 | -4,065 | 25,518 | 46,258 | -17,313 | 28,945 |
| | \$3 | 1,228 | 1,276 | -1,461 | -1,143 | 15,771 | 18,276 | -2,603 | 15,672 |
| | \$5 | 1,446 | -1,603 | -2,004 | 1,430 | 15,113 | 14,956 | -574 | 14,383 |
| | \$7 | 19,141 | 4,997 | -19,803 | -5,208 | 14,700 | 38,839 | -25,010 | 13,829 |
| | \$9 | 20,414 | 5,565 | -20,762 | -5,638 | 16,002 | 41,981 | -26,401 | 15,581 |
| | \$11 | 20,354 | 5,547 | -20,762 | -5,638 | 15,309 | 41,211 | -26,401 | 14,810 |

Note: Values of time = \$13.0/hour for drive-alone, \$28.9/hour for carpool, and \$71.0/hour for trucks. On average \$29.44/hour. Value of travel time assumptions are controversial. The Caltrans (2000) SR91 report notes that \$6 to \$14 per hour values were inferred from patterns of tollway use on the SR91. See also Small and Yan (2001).

All other scenarios (lower tolls in the 4 + 3 scenarios and all tolls in the 5 + 2 scenarios) result in higher travel costs in the \$14.4 to \$33.4 million range. The results vary with different values of travel time. They are somewhat counterintuitive because although congestion tolls should reduce congestion overall, in the adjacent toll-free road cases while tolls improve the level of service on the tolled facilities, high tolls prompt drivers to move to the free lanes and intensify demand there. One complication of our results is that we include tolls in total travel costs.

The key to interpreting our results is that from a *network* perspective, adding tolls on selected facilities has indeterminate effects on system performance. Toll, while allowing for more efficient use of the tolled segment, also have the effect of diverting traffic to other parts of the network, resulting in other links carrying greater volumes. Then, the result depends on the magnitude of the tolls and the degree of congestion on alternative routes.

Partial equilibrium effects often differ from general equilibrium effects. System-wide tolls can be set to maximize net revenues and throughput, or to minimize travel delay. Minimizing travel delay delivers efficiency improvements if reductions in total delay are sufficient to offset the administrative cost of collecting the tolls. Limited tolling may create efficiencies along a link, but unless all segments of the network are tolled, it is not clear that such a limited toll strategy will increase network efficiency. Traffic may be shifted to other routes, often with unpredictable results. Indeed, this was one of the sources of the political controversy over the California Department of Transportation's non-compete agreement with CPTC. This agreement precluded expansion of the SR91 general-purpose lanes.

Most of the early academic literature on congestion tolls concludes that they are efficient, with modest attention to imperfections. In recent years, considerable theoretical attention has been directed to the question of second-best toll strategies that are consistent with value-pricing options. In these circumstances, tolls are introduced incrementally on new or existing facilities competing with untolled links. This makes the level of congestion on untolled lanes an important variable or parameter, depending on whether the system of interest consists of the tolled facilities or the network (Verhoef et al., 1996; Small and Yan, 2001).

The standard theoretical discussion examines various public and private objectives given a simple hybrid system consisting of an origin-destination pair, and a toll facility competing with a single, parallel, untolled path. This approach makes it possible to investigate general principles and strategies.

Our examination of the SR91 toll facilities treats these links in the context of the real-world SCPM network described above. While we are able to simulate flows and changes in flows, we do not identify optimal tolls. Nevertheless, similar to the cited literature, our analysis of network flows

suggests that efficiency gains will not necessarily be achieved by selective tolling. Selective tolls again produce a second-best result whereby more efficient use of a particular link occurs at the expense of performance throughout the rest of the system. The more congestion there is on untolled facilities, the greater the possible efficiency loss from value tolls. This has substantial policy relevance, because tolls are inevitably introduced on a facility-by-facility basis. Further, private interests have the greatest incentive to risk their capital on the construction of new facilities when congestion on competing routes is high. The modeling consequences highlighted here include the importance of being able to compare the system effects of adding tolled versus untolled capacity. Our results show that large-scale facility investment decisions require that this be done in the context provided by a model of the complete network examining alternative tolls and alternative road configurations.

The network simulations with our model involve modifying the volume delay functions for network links to include tolls. System cost is the product of link volumes and corresponding travel times summed over all the links in the network. Consider the simplified example provided in Figure 18.1. A fixed demand for travel is allocated over competing links A and B.

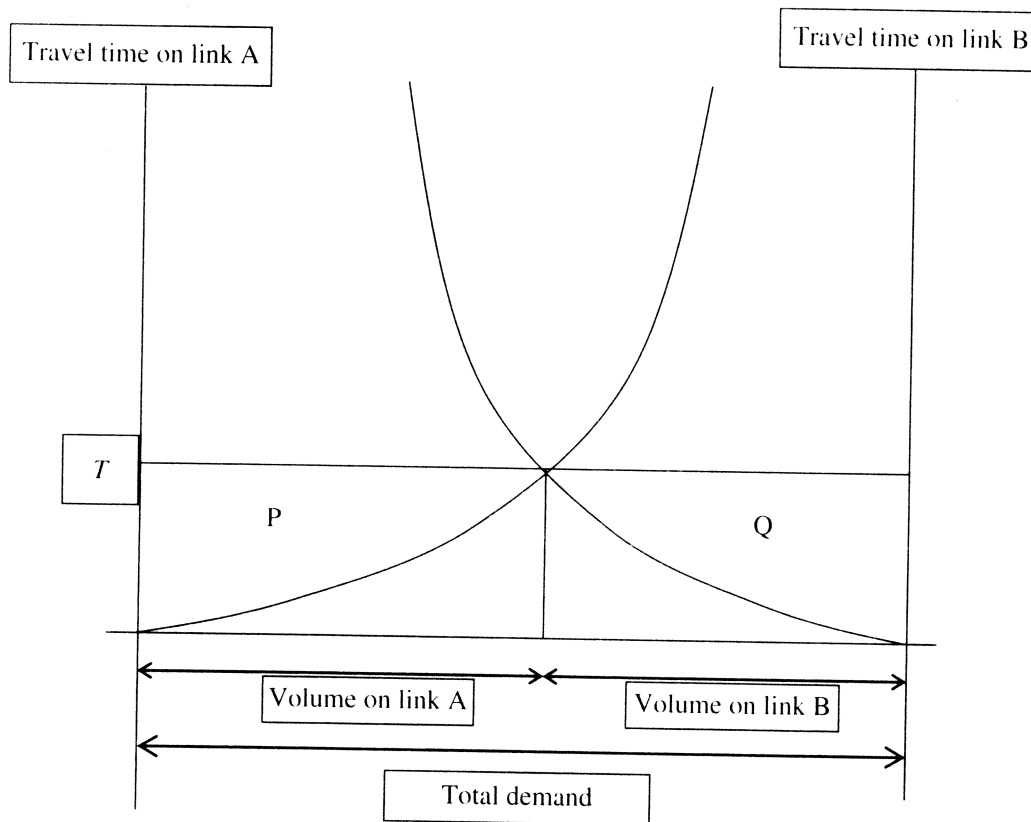


Figure 18.1 Travel demand on competing links

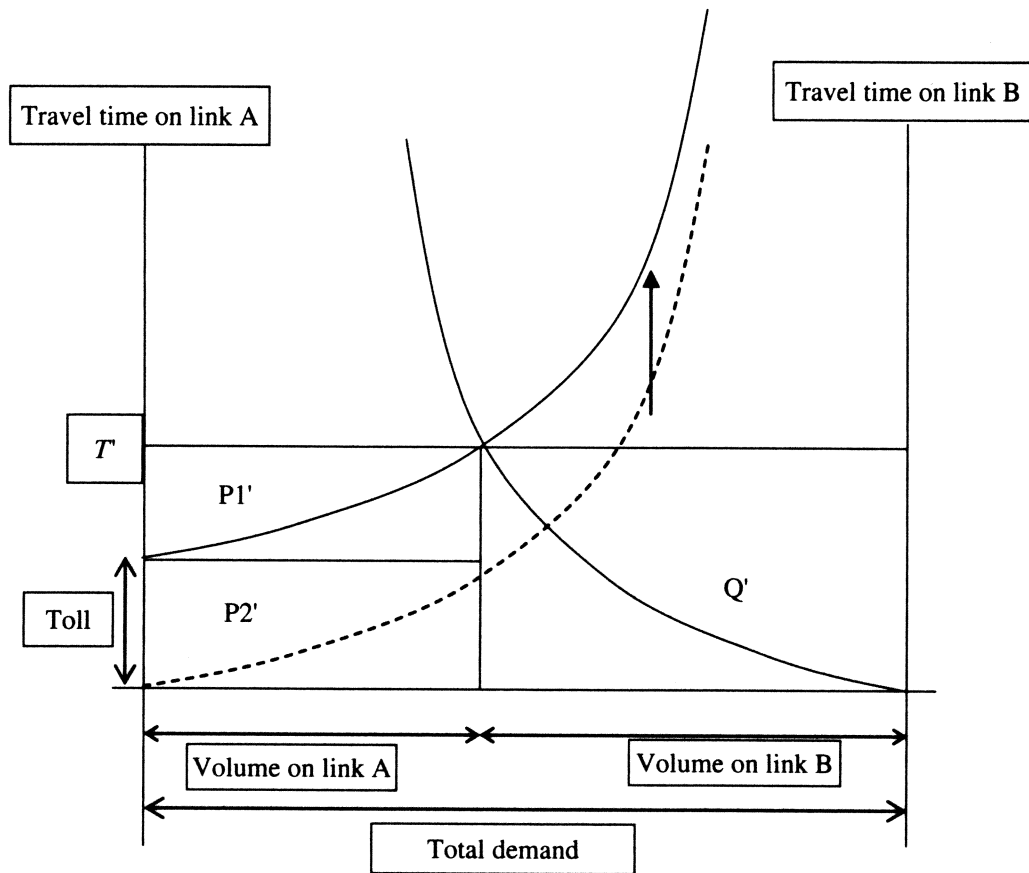


Figure 18.2 The effect of cost increases

Equilibrium flows occur at congested travel time T . In the untolled case, system cost is the sum of areas P and Q .

Time has value. For modeling purposes, imposing a toll on a link is equivalent to modifying the volume-delay function for the link so that all vehicles on the link experience a corresponding increase in travel time. In the case of an ideal toll, this resets average cost to marginal cost. If a toll is applied to link A, the existing volume delay function shifts upward by a value corresponding to the toll.

In this example, the toll is set to keep the congestion on link A low with no consideration given to congestion impacts on link B. If travel demand is fixed, the new equilibrium travel time T' is greater than T . As a result, the system cost increases relative to the untolled case (see Figure 18.2). $P1'$ is the system cost due to congestion on link A. $P2'$ is the revenue provided to the owner of the toll road, expressed in units of time.

Applying SCPM makes it possible to support a detailed cost-benefit analysis of individual projects. We have already calculated the annual network net benefits of various capacity options. The model can also be

used to calculate the spatial and sector incidences of construction expenditures, as well as those of alternative approaches to financing the project. This joint treatment of benefits and costs in substantial spatial and sectoral detail allows a discussion of equity as well as efficiency consequences.

6 CONCLUSIONS

What have we accomplished?

1. We have elaborated a network model to account for the effects of tolls on selected freeway lanes.
2. We have integrated the network model with a spatially detailed economic model of the regional economy.
3. We have applied the model to the hypothetical case of highway widening on a segment of California's SR91, comparing the network-wide effects of adding tolled versus non-tolled lanes. The application included substantial data gathering and analysis so that a single integrated model can be used to analyse: (a) the spatial economic effects of household displacement, and (b) the network effects of various highway widening and tolling alternatives.
4. We have found that system-wide network effects of adding tolled lanes on just a small link of that network reveals a complex set of results. Most research on value pricing has necessarily been of a partial equilibrium nature, and does not consider the full network effects. Substantially more research should be done at the network level.

On the premise that all politics are local, we suggest that our analysis of distributional impacts is useful to policy analysts. While we are able to identify costs and benefits, we are also able to estimate which communities bear the costs and which gain the benefits. Whereas network studies in regional highway analyses are common, none to our knowledge includes the comprehensive results from an integrated model shown here.

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