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This work explores the traffic, land use and welfare impacts of road pricing in the Austin region, applying tolls to existing bridges, instituting a tolled cordon around the downtown area, and introducing planned toll roads. Different toll scenarios are examined, including fixed versus variable tolling, and tolls based on time of day, traffic, and travel distance. Austin-calibrated DRAM-EMPAL models are used to predict the future residential and work location distribution. Land use model outputs are used in a four-step travel demand model (TDM), and the resulting travel times are fed back into the TDM as needed, in order to obtain converged results. Joint mode and time of day choice models and multinomial destination choice models are used. The results include, traffic redistribution over time and space, location choice changes in the long term, and traveler welfare implications. In summary, the newly proposed toll roads in Austin are revenue generating and welfare improving. Bridge tolls would be successful in redistributing traffic, while the downtown appears highly sensitive to cordon tolls, which would be hard on commuters.

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ROAD PRICING SIMULATIONS:
TRAFFIC, LAND USE AND WELFARE IMPACTS

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Research Report SWUTC/04/167242-1

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ABSTRACT

This work explores the traffic, land use and welfare impacts of road pricing in the Austin region, applying tolls to existing bridges, instituting a tolled cordon around the downtown area, and introducing planned toll roads. Different toll scenarios are examined, including fixed versus variable tolling, and tolls based on time of day, traffic, and travel distance. Austin-calibrated DRAM-EMPAL models are used to predict the future residential and work location distribution. Land use model outputs are used in a four-step travel demand model (TDM), and the resulting travel times are fed back into the TDM as needed, in order to obtain converged results. Joint mode and time of day choice models and multinomial destination choice models are used. The results include, traffic redistribution over time and space, location choice changes in the long term, and traveler welfare implications. In summary, the newly proposed toll roads in Austin are revenue generating and welfare improving. Bridge tolls would be successful in redistributing traffic, while the downtown appears highly sensitive to cordon tolls, which would be hard on commuters.

EXECUTIVE SUMMARY

Traffic congestion looms large in most cities, as travel demand outpaces infrastructure and operational improvements. Supply side improvements and demand management are the two ways to alleviate congestion. Road pricing can either be implemented in the form of congestion pricing (CP) – largely as a demand management strategy – or in the form of standard road tolls, typically to generate revenues for supply side improvements.

This work explores the traffic, land use and welfare impacts of road pricing in the Austin region, applying tolls to existing bridges, instituting a tolled cordon around the downtown area, and introducing planned toll roads. Different toll scenarios are examined, including fixed versus variable tolling, and tolls based on time of day, traffic, and travel distance. Austin-calibrated DRAM-EMPAL models are used to predict the future residential and work location distribution. Land use model outputs are used in a four-step travel demand model (TDM), and the resulting travel times are fed back into the TDM as needed, in order to obtain converged results. Joint mode and time of day choice models and multinomial destination choice models are used.

Different tolling strategies yield distinct results. The results include, traffic redistribution over time and space, location choice changes in the long term, and traveler welfare implications. In summary, Austin toll roads seem to be headed in the right direction. They are estimated to increase welfare uniformly across the region and provide impetus for land development along the tolled corridors. Fixed tolls can be as effective as marginal cost pricing in redistributing traffic on congested downtown bridges. Cordon tolls may limit downtown accessibility but do result in less downtown congestion. A variety of tolling options are available to Austin and other urban regions.

Potential improvements to this work include analyzing policy impacts across heterogeneous user groups. Moreover, toll road provision and roadway pricing affect location choices, of businesses and households, and these could be modeled more explicitly. Property value models also may be used to predict the effects of road pricing on land prices. The land use models used here (DRAM and EMPAL) could be enhanced through recognition of more site specifics (such as topography and natural amenities) and structure characteristics (such as age of improvements). And a better procedure is needed to model the growth over time of trips using external zones and their distribution. Another useful extension is to explicitly accommodate proposed HOT and HOV lanes, in the networks and the choice models. It is hoped that these enhancements are undertaken in the coming years.

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DISCLAIMER

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ROAD PRICING SIMULATIONS:
TRAFFIC, LAND USE AND WELFARE IMPACTS

CHAPTER 1. INTRODUCTION

Traffic congestion looms large in most cities, as travel demand outpaces infrastructure and operational improvements. Schrank and Lomax (2003) report the 2001 cost of congestion in 75 U.S. urban areas to average $517 per person. Supply side improvements and demand management are the two ways to alleviate congestion. Road pricing can either be implemented in the form of congestion pricing (CP) – largely as a demand management strategy – or in the form of standard road tolls, typically to generate revenues for supply side improvements[1]. CP policies such as system-wide marginal cost pricing (MCP) are directed at redistributing traffic over different times of day, modes and routes to maximize system efficiency. By charging the road user the difference of the social cost imposed by his/her driving and the personal cost of driving itself, MCP eliminates the congestion externality. Another pricing option, cordon pricing is designed to limit traffic flows into a cordoned area, such as a downtown zone, in order to ameliorate local congestion and pollution levels.

Pricing also provides funds for loans that allow near-term construction of facilities, along with longer-term maintenance, rehabilitation and expansion. While Houston and Dallas offer some toll roads (including HOT lanes in Houston), road pricing will be new to Austin and the plans are currently in place for distance-based, flat tolls. For last three years, Austin has been the most congested medium-sized city in the U.S. (Schrank and Lomax, 2003). The Colorado River flows easterly alongside Austin's downtown, and is crossed by various bridges, including the heavily used Interstate Highway (IH) 35. Such bridges are ripe for CP, since they are traditional bottlenecks in most urban systems, and also revenue tolling, since they are much more expensive (per lane mile) to build than roads (Kockelman et al., 2001). The region's popular and densely developed downtown also may benefit from some form of CP.

This work examines the traffic, land use and welfare impacts of various pricing policies for bridges, new toll roads and downtown access for the Austin region in Texas.

1.1 Case Studies

This section discusses case studies of bridge tolling, road tolling and cordon pricing, in the U.S. and around the world. Chartered in 1792, the Pennsylvania Turnpike was the first U.S. toll road. During the 19th Century most private U.S. toll roads vanished due to insufficient revenue generation (Lindsey, 2003). There now are roughly 5,000 centerline miles of tolled highways (including bridges and tunnels) in the United States. Some facilities charge differential tolls based on distance, vehicle type or other characteristics. California's Orange County introduced innovative tolls based on demand, time of day, and vehicle occupancy on State Route 91's new tolled lanes. The tolls vary hourly from $1.00 to $4.75 in 5-cent intervals. (Sullivan, 2000) In Canada, the all-electronic Highway 407 was built as an alternative to the highly congested Highway 401. Its tolls vary based on distance, time of

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[1] Road tolls are a funding mechanism to construct projects earlier than if funded with gas taxes. For example, the under-construction SH 130 toll road project in Austin has been built as much as 15 years ahead.

day, vehicle type and transponder use. (Lindsey, 2003)

There are many instances of bridge tolling in the U.S. In Lee County, Florida, the Cape Coral and Midpoint Bridges (which connect a high number of homes to jobs) use differential peak and shoulder period tolls. The toll discount of 50 percent during shoulder periods encourages users to alter their arrival times to reduce trip cost. (Burris et al., 2000; and Cain et al. 2001) Between New York and New Jersey, the Port Authority raised tolls on two tunnels and four bridges in 2001 to generate revenue for construction and maintenance of these facilities. The pricing varies for vehicle class, off-peak periods and EZPass users. This change in pricing policy caused peak to off-peak shifts and EZPass patronage. (Muriello and Jiji, 2004)

Among all the U.S. CP projects, only Fort Myers Beach, Florida involves cordon pricing. (Lindsey, 2003) In contrast, many European countries such as Norway (Odeck and Brathen, 2002) and Italy (Perkins, 2002) have opted for such pricing, and have been successful in reducing congestion and generating revenues. While cordon tolls are less optimal than paying as one drives, they are relatively straightforward for drivers and generally easier to implement for administrators. A recent example is London's £5 cordon toll (weekdays between 7:00 am and 6:30 pm). It has been estimated to have reduced zone travel delays by one-third while significantly shifting mode choice (e.g. bus ridership increased by 14%). (See, e.g., Litman 2004, and TFL 2004) London's toll revenues have been used to improve transit services to the central London area. Outside Europe, Singapore city has tried a number of congestion relieving strategies since the early 1970's, including its Vehicle Quota System, heavy vehicle and fuel taxes, an Area Licensing Scheme, and tolls. In 1998 it moved towards an Electronic Road Pricing (ERP) system for vehicles entering the Central Business District (CBD)[2]. The tolls vary with congestion and time of day, and are intended to closely match the marginal cost. (Goh, 2002)

A number of toll road projects are under consideration for Austin, and several are under construction (and slated to be operational by December 2007). Many of the proposed toll roads have non-tolled lanes; hence the tolled lanes are not expected to be congested for those who are willing to pay. The tolled lanes also are expected to reduce congestion on the non-tolled lanes, potentially providing benefits for all travelers. However, there is presently little consideration of CP options for Austin. And there is no comprehensive study of how tolling on these newly built facilities will impact the region's traffic and its residents' welfare. It is also of interest to study pricing on existing facilities such as bridges and downtown access links as prospective congestion management strategies. Thus, this work examines a variety of tolling strategies for a number of locations in the Austin network, for traffic, welfare and land use impacts.

The following chapter describes data sources and methodologies in detail. The results for different applications and analysis of impacts are presented in Chapter 4. Finally, Chapter 5 highlights the important findings of this study and identifies limitations of the current approach.

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[2] The ERP system has helped distribute daytime traffic and relieve arterial congestion. Average peak-hour vehicle speeds have improved, rising from 45 to 65 km/h on expressways.

CHAPTER 2. METHODOLOGY

2.1 Data Sources and Details

The Austin Capital Area Metropolitan Planning Organization's (CAMPO) planning region, covering Travis, Williamson and Hays counties, is represented as 1074 traffic serial zones (TSZs) and 43 external zone stations. The Austin network data (CAMPO, 2004) specifies the network from 1997 to 2030.

CAMPO data was used to calibrate the travel demand models (TDMs) (Kalmanje and Kockelman, 2004) and land use models (Krishnamurthy and Kockelman, 2003). Data used include the 1996 Austin (Household) Travel Survey (ATS, 1996), Austin demographic dataset and level-of-service (LOS) data. The LOS data includes the inter-zonal automobile travel times for peak and off-peak times and transit travel times based on service type and transit access. Other data sources include the 1990 and 2000 Census of Population data and the 2000 CAMPO-maintained City of Austin land use data set. Details about the proposed toll plans, amendments to the existing CAMPO's 2025 Mobility plan and 2030 Mobility plan were also provided by CAMPO.

2.2 TDM Application

The Austin-calibrated integrated transportation-land use models (ITLUMs) were used to model traffic, land use and welfare impacts of different pricing scenarios. The TDM and land use models are applied sequentially starting with 1997 as the base year. The results from the TDM application are fed into Krishnamurthy and Kockelman's (2003) DRAM-EMPAL land use models, which predict future land use demand in time steps of five years.[3] The bridge tolls, cordon pricing and toll road scenarios are analyzed beginning in 2007. The ITLUM feedback process continues until 2032; by that time, all toll roads should be in operation. The ITLUM results are used in our welfare computations for various scenarios in the years 2007 and 2032. Land use changes under different scenarios also have been studied.

The Austin TDM models rely on four trip purposes: home-based work (HBW), home-based non-work (HBNW), non-home-based work (NHBW), and non-home-based non-work (NHBNW). Kalmanje and Kockelman's (2004) multinomial destination choice models use attraction factors, as well as logsums of travel times, travel costs and choice-specific constants (across modes and times of day, from the joint mode-time of day model). The joint mode-time of day models are calibrated for four modes (drive alone, shared ride, transit and walk/bike) and five times of day (late night and early morning (before 7:15 a.m. and after 8:15 p.m.), morning peak (7:15 to 9:15 a.m.), mid-day (9:15 a.m. to 4:15 p.m.), evening peak (4:15 to 6:15 p.m.), and evening off-peak (6:15 to 8:15 p.m.)).

The production-attraction (PA) matrices were converted to origin-destination (OD) matrices for home-based trips using return trip rates across the five time periods. Vehicle trip matrices

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[3] The TDM application and feedback process has been executed using TransCAD (Caliper, 2004). The land use models are applied using GAUSS (Aptech, 1999) statistical modeling software.

were obtained using constant vehicle occupancies by trip purpose. The vehicle trip matrices[4] for the 5 time periods were assigned to the network in TransCAD (Caliper, 2004) using the user equilibrium (UE) traffic assignment module. A generalized cost function based on the Bureau of Public Roads' (BPR) volume-delay equation was used in traffic assignment.

$$c_i(x) = k_i + \delta \times L_i + \varphi \times t_i \left[1 + \alpha \left(\frac{x_i}{C_i} \right)^{\beta_i} \right]$$

where $c_i(x)$ = generalized cost,

k_i= fixed toll cost for link i

δ= vehicle operating cost assumed as 30¢/mile (Edmunds, 2004)

L_i= length of link i,

φ= value of travel time (VOTT) (assumed to be \$8/hour)[5],

x_i = flow level, C_i = capacity of link i,

α_i and β_i are link characteristics (default values of 0.15 and 4 used when data not provided).

The resulting time and cost skims[6] from traffic assignment were fed back into the destination and mode-time of day choice models until link flows from consecutive feedbacks stabilized[7]. The TDM feedback process is run separately for each pricing scenario. Work locations for the HBW trips were held constant for all pricing scenarios in 2007, since toll scenarios should not influence the destination choice of work trips in the short term.

The inputs into Krishnamurthy and Kockelman's (2003) land use models are base year household distributions by income, employment distributions by job type, household and employment growth rates (3.3% and 3.1% respectively [CAMPO, 2002]), base year peak and off-peak travel time skims from a TDM application, and zonal household and employment density caps. Wherever applicable, the time skims include tolls translated into units of time (via an \$8 VOTT). Based on these inputs, the models compute future zonal household and employment distributions, which are used as inputs to the trip generation model in the TDM application for the next modeling period (five years into the future).

2.3 Tolling Scenarios

The network tolling scenarios examined here are tolling on newly built toll roads and pricing on existing facilities in the form of bridge tolls and downtown cordon tolls.

Toll Roads

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[4] Only auto trips were considered in obtaining the vehicle trip matrices since the transit shares were too low.

[5] Since the VOTT estimated from the mode-time of day choice models were very low (ranging from \$2.35 to \$3.36), a higher value was assumed for traffic assignment and for calculating MCP tolls. (For further information on the mode and time-of-day choice model, please refer to Kalmanje and Kockelman [2004].)

[6] The transit travel times from one TDM iteration to another are adjusted in the same ratio as the auto travel times. The walk and bike travel times are assumed constant.

[7] The method of successive averages (MSA) was used for all scenarios except when modeling MCP, when direct feedback was used. The external-external (E-E), internal-external (I-E) and external-internal (E-I) trips were left unchanged from one feedback to another and were added to the larger O-D trip matrix before traffic assignment. The E-E and E-I trips were proportionally increased based on Texas population forecasts (Census, 1996) and I-E trips were inflated according to Austin population forecasts (CAMPO, 2002) for future year scenarios.

The proposed toll roads can be divided into two sets as shown in Figure 1 (Appendix B). The first set includes toll roads adopted by CAMPO on June 12, 2000, which will all be operational by the year 2007. This set includes SH 130, SH 45 (both north and south of the city), a Mopac/Loop 1 extension, and US 183 A and SE 45, all of which are currently under construction. CAMPO (2004) expects a flat, distance-based toll of10¢/mile. The traffic, welfare and land use impacts of building these toll roads are analyzed in the short term by comparing the build scenario to the no-build alternative, and to a hypothetical MCP tolling alternative.

The second set of toll roads analyzed in this study are those operational after 2007. Some of these were adopted by CAMPO on July 12, 2004. Since coded networks are only available for the years 2007, 2017 and 2030, these were used for the TDM runs between 2007 and 2032. The 2030 network was used for the 2027 TDM run assuming that all toll roads are operational by then. Therefore, the 2032 ITLUM results were used to study the traffic, land use and welfare impacts of building the second set of toll roads.

Bridge Tolls

The centrally located Austin bridges connect the northern and southern portions of the region. There are ten such bridges, crossing the Colorado River at Redbud Trail, Pleasant Valley Road, Loop 1 (Mopac), Lamar Blvd., Congress Avenue, South First Street, IH 35, US183, RM 620 and Loop 360 (Capital of Texas Highway) as shown in Figure 1 located in Appendix B. The bridges identified for tolling are those at Redbud Trail, Loop 1, Lamar Blvd., Congress Avenue, and South First Street, henceforth referred as “Bridge Toll Candidates”. The federally funded IH 35 bridges are also of interest but there are issues with tolling federally financed roads. US183, RM 620 and Loop 360 bridges offer almost no substitute routing, and are distant from the region’s center, so they also were not considered for tolling. Pleasant Valley Road is not congested during any time of day, so it is not a candidate for CP.

Various fixed-toll combinations and congestion-based tolls (using marginal cost pricing) were tested, along with differential peak and off-peak tolls, in order to ascertain time of day shifts and traffic congestion levels.

Cordon Pricing

A downtown cordon was constructed to bind the region’s downtown at Martin Luther King (MLK) Blvd., Lamar Blvd., IH 35 S frontage road and Cesar Chavez Blvd, as shown in Figure 1 (Appendix B). Fixed tolls ranging from $1 to $5 were applied between 7:15 am and 6:15 pm on all links entering the cordon. This work does not account for the presence of downtown parking costs. However, changes in both downtown congestion and downtown accessibilities are examined.

CHAPTER 3. RESULTS AND DISCUSSION

This chapter discusses the results of road pricing simulations. The traffic impacts are analyzed for introducing the new planned toll roads and pricing the existing facilities (bridges and downtown cordon). For relevant scenarios, the welfare, accessibility and land use impacts are also studied.

3.1 Toll Road Plan 2007

Traffic

Toll road locations and the type and level of tolling have a direct bearing on network traffic patterns. It is expected that the new toll roads will draw traffic from other facilities, thereby improving overall travel conditions. Percentage changes in link-length-weighted average V/C ratios between the toll road and a no build scenarios were estimated for different facility types, as shown in Table 1 located in Appendix A. One finds that there are slight V/C drops on all major roads, including freeways, expressways and arterials, thanks to the new toll roads. IH 35 is predicted to experience just a 2.5% drop during peak hours, which could be largely due to SH-130's construction. If we compare V/C ratios only on freeway segments that have a tolled lane, significant drops are observed on the competing free lanes. The biggest winners appear to be travelers on US 183 and Loop 1, which are to receive parallel tolled lanes.

For comparison purposes, MCP[8] tolls were tested on all planned toll roads, instead of the expected 10¢/mile toll. Under MCP tolls, tolls are considerably smaller, so greater V/C reductions are observed across most facility types. Moreover, the toll roads are expected to carry more traffic than under the planned 10¢/mile tolls. MCP revenues are predicted to be much less (just $1,523/day) than the 10¢/mile alternative ($26,248/day). Other distance-based tolls, ranging from 7¢ to 15¢ per mile, also were tested. And an 11¢/mile toll was estimated to be the region's revenue-maximizing distance-based toll. This is surprisingly close to CAMPO's proposed tolls.

Welfare Impacts

Estimates of daily travel-related benefits from building toll roads were estimated as consumer surplus, at the destination choice level for the average person residing in each zone. (Readers may refer to Kalmanje and Kockelman [2004] for more information on this approach.) Consumer surplus is the difference in the maximum expected utility of one's destination choice opportunities before and after a change in the travel environment, as shown in equation 1.

$$CS_{i,p} = \frac{1}{\alpha_p}\left(E(Max(V_{i,p}))^{ps} - E(Max(V_{i,p}))^{np}\right) \tag{1}$$

where α_p is the marginal utility of money (specific to each trip purpose) and is the product of the estimated coefficients on cost (in the mode-departure time model) and generalized cost or

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[8] MCP is not quite optimal pricing, since free alternative roads are available to the drivers. (Ferrari 2002) MCP is optimal when all relevant "goods" are optimally priced according to their marginal (social) costs.

logsum (in the destination choice model), *ps* and *np* denote the pricing and no pricing (status quo) scenarios, and $E(Max(V_{i,p})) = \ln\left(\sum_{j\in C} e^{V_{i,j,p}}\right)$.

$V_{i,j,p}$ denotes the utility of person at origin *i* choosing destination *j* for trip purpose *p*, with *C* denoting the full choice set of all possible destinations.

In this work, this measure of consumer surplus is not applicable for HBW trips since the destination choice is fixed. Instead, equation 2 is used to compute consumer surplus for HBW trips. It is the difference in expected maximum utility levels derived across all modes and departure times for a particular destination, and is multiplied by the probability of choosing that destination (*P*(*j*)).

$$CS_{i,p} = \sum_{j\in C} \frac{P(j)}{\beta_c}\left(LOGSUM_{i,j,p}^{ps} - LOGSUM_{i,j,p}^{np}\right) \tag{2}$$

where, $LOGSUM_{i,j,p}$ is the generalized cost between an origin-destination pair (*i*,*j*) and is defined as the negative of the maximum expected utility derived across all mode and departure time combinations for a trip purpose *p*.

$$LOGSUM_{i,j,p} = -\ln\left(\sum_{m,t} e^{\beta_{t,p}Time_{i,j} + \beta_{c,p}Cost_{i,j} + \beta_{m,t,p}}\right) \tag{3}$$

where β_t, β_c and $\beta_{m,t}$ are the coefficients on time, cost and the alternative-specific constants in the joint mode-departure time choice model.

Average daily consumer surplus is calculated for an individual residing in zone *i* by aggregating consumer surplus for home-based trips using the average daily number of trips per individual.

Figure 2, placed in Appendix B, illustrates the geographical variation in estimates of consumer surplus under the MCP and 10¢/mile toll road scenarios. Clearly, neighborhoods along the toll roads are expected to experience positive welfare changes, due to improved accessibility through system expansion (and therefore lowered travel times). The northwest corner of the Austin region also is found to gain, due to improved access to those areas.

Average welfare gains under 10¢/mile tolls are predicted to be less than under MCP tolls. Under a 10¢/mile toll road policy, less than 1% of the population is predicted to experience a daily gain of more than 10¢, as compared to 12% of the population under MCP. Around 75% of Austin's population is predicted to experience welfare gains of less than 3¢ per day under a toll road policy of 10¢/mile; whereas under MCP, 42% of the population has gains exceeding 3¢/day. These daily gains seem small, of course, but the tolls are applied to a relatively small set of new roads and their effects are averaged across all residents. The yearly traveler benefits are on the order of $18 million. And, depending on travel needs, some persons will benefit much more and others hardly at all.

The welfare gains are positive for all zones under MCP; however, distance-based tolls are predicted to impose slight average losses on 14 small central zones. The welfare loss in these 14 zones is estimated to be less than 2¢ per day per individual and the total loss is negligible when compared to the region's overall welfare gain. The drops could be due to travel shifts induced by toll roads that somewhat congest these zones' neighborhoods. Overall, the new toll roads are improving region-wide welfare with higher welfare gains along the toll road corridors. Households and employers are expected to relocate themselves in the welfare improving areas. The model-predicted residential and commercial development effects (after a five-year period of toll road operation) are discussed below.

Land Use Impacts

Toll roads are expected to influence the future land use patterns around the region, through shifts in households and employment. Figure 3 (Appendix B) shows percentage household and employment changes as a result of 5 years of toll road operation, based on DRAM-EMPAL-type model applications. These numbers are obtained from comparing predicted distributions for the year 2012 under the toll road and the no build scenarios.

From Figure 3 in Appendix B, one observes that there is a small percentage growth in households located near the proposed toll road corridors, which could be due to households moving closer to tolled corridors. Most other locations are predicted to experience less than 1% change in household counts. Employment also is predicted to increase slightly in areas close to toll roads, but only in a few instances are the changes (relative to the non-tolled status quo) greater than 1%.

3.2 Toll Road Plan 2030

Travel welfare impacts of building the post-2007 toll roads were computed by comparing average changes in region-wide consumer surplus between the 2032 scenario in the presence of all proposed toll roads to a 2032 no-build scenario, as shown in Figure 4 in Appendix B. Most locations' residents are expected to benefit by less than 10¢ per day. Those in the southwestern portions of the region gained most, thanks to the development of a radial toll road (US 290) connecting them to central Austin. Both residential and commercial growth is predicted to be high along this corridor. Land development is expected to spread to the north-west, north-east and south-western parts of the region. Some development is also observed around toll roads in the south-eastern corner of the region. Overall, the toll roads are predicted to enhance traveler welfare and spread land development to the northern and southern corners of the Austin region, as compared to the hypothetical no-build scenario.

The TDM estimates more than a doubling of total system VHT and VMT between 2007 and 2032 due to the projected population growth. The total toll road lane miles would increase 350 percent (from 379 miles in 2007 to 1,327 miles in 2032), while the daily toll road revenue is estimated to grow by a factor of 5.8 (from $26,248/day in 2007 to $151,813/day in 2032). This shows the increased patronage for the toll roads over the years. The new toll roads do improve welfare as compared to the no build scenario. But, traveler welfare is predicted to fall between 2007 and 2032 because network improvements do not keep up with the population increase. It may be interesting to investigate demand management strategies to enhance welfare and improve traffic conditions for that future year.

3.3 Bridge Tolls

According to our models, most Austin bridges (i.e., IH 35, Loop 360, US 183, Lamar Blvd., Loop 1 and Redbud Trail) are congested during peak periods. The evening peak's volume-to-capacity (V/C) ratios are highest, and these effects extend into the evening off-peak period. Congestion-based marginal-cost-pricing (MCP) tolls were applied on all toll bridge candidates throughout the day. But MCP tolls on all bridges and all time periods are difficult to implement in practice. Hence, it should be more effective and practical if Austin were able to find a set of fixed tolls that produce comparable results but require tolling on fewer bridges and/or during fewer time periods. To this end, different combinations of fixed tolls across different time periods and bridges were tested.

The Lamar Blvd. and Redbud Trail bridges operate under hyper-congested traffic conditions during peak periods (with V/C's up to 2.15). The peak period MCP tolls for these are roughly 10¢ and 40¢ respectively, while tolls on the other bridges were found to be around 5¢. After experimenting with different fixed toll combinations (varying levels of toll applied across different sets of bridges during different times of day) it was determined that best results would be obtained by levying tolls only on Lamar Blvd. and Redbud Trail bridges during peak and evening off-peak periods. Table 2, located in Appendix A, compares the current V/C ratio estimates for bridge toll candidates to scenarios following imposition of MCP tolls and "best" fixed tolls. One finds that during the priced periods, the best fixed tolls closely replicate the congestion-reducing impacts of an MCP toll. Even small tolls on the Lamar Blvd. Bridge exhibit significant traffic shifts, while the tolls required on Redbud Trail Bridge are somewhat higher (since there are few reasonable substitute crossings for such trips).

The best fixed tolls found are 15¢ in both directions on the Lamar Blvd Bridge during the peak and 10¢ during the evening off peak (and zero cents at other times of day). On the Redbud Trail Bridge, morning peak tolls are estimated to be 25¢ (northbound (NB)) and 50¢ (southbound (SB)); evening peak tolls are 75¢ (NB) and 25¢ (SB); and evening off-peak tolls are 20¢ (NB) and 10¢ (SB). Proponents of minimum revenue pricing (e.g., Dial [1999] and Penchina [2003]) argue that it is possible to replicate the impacts of an MCP toll with a minimum revenue toll. It is interesting to note that the revenue obtained from the best fixed toll combination ($5,466/day) is nearly half of that generated by the marginal cost pricing ($13,733/day).

The V/C ratios on the bridges are observed to change substantially because traffic from the tolled bridges tends to redistribute onto nearby bridges. This is primarily due to route shifts induced by the tolls, whereas mode and time-of-day shifts are estimated to be negligible (less than 1%). Since downtown bridges are close to IH 35, it can be expected that traffic from these tolled bridges will divert to the non-tolled IH 35 and its frontage roads. This will result in increased levels of traffic on a corridor already infamous for its congestion. Such traffic impacts are evident under the MCP tolling scenario examined, where the IH 35 SB frontage road became more congested. However, this same issue did not arise under the best fixed toll scenario, since the bridges adjacent to IH 35 were left un-tolled. Fortunately, the best fixed tolls examined are not estimated to have any significant negative effect on the traffic on other Austin bridges, as compared to status quo.

Thus, considering the impact on bridges alone, the fixed toll combination offers better results than MCP tolls. However, the best fixed tolls appear to add to congestion levels on some roads connecting downtown bridges, such as Cesar Chavez. Thus, MCP for bridge tolls may be more effective from a system perspective, especially since MCP tolls are applied across most of the competitor bridges.

The bridge tolls do not appear to cause any significant land use and welfare changes in the region. Average consumer surplus computed in the presence of bridge tolls was found to be insignificant (ranging from 0 to 1¢ per day per individual). This is because bridge tolls primarily affect routing choices, rather than travel times and cost.

It can be concluded that a combination of fixed tolls on bridge competitors can actually replicate the efficiency-improving impacts of MCP tolls, while also providing ease of implementation. Some externalities, such as impacts on connecting streets remain, but capacity additions and additional tolling can address those issues.

3.4 Cordon Pricing

The downtown cordon tolls examined here are in dollar increments ranging between \$1 and \$5, from 7:15 am to 6:15 pm on all vehicles entering the downtown area. While the traffic and accessibility impacts of downtown cordon pricing are evaluated, welfare and land use are not (because the welfare measures are origin-based, and will not adequately capture the cordon toll effects, and because the land use impacts are not expected to be extensive).

As expected, inbound traffic volumes are predicted to fall during the cordon toll period, and rise during the no-toll period as shown in Table 3 (located in Appendix A). The incoming V/C ratios on roads crossing the cordon fall as the toll is increased; they also increase significantly during the no-pricing periods, as shown in Table 4 in Appendix A. The total daily inflow of traffic into the downtown area falls significantly with the introduction of cordon tolls. A high percentage of daily traffic enters downtown during the no-pricing periods, and shifts to these times of day are evident. Even a \$1 toll is effective in inducing significant shifts. A reason for this could be the low value of travel time implied by coefficients in mode-time of day models.

Any cordon toll increases beyond \$4 do not appear to further influence flows, as shown in Table 3 (Appendix A). This is attributed to downtown workers, who are bound to make trips due to fixity of HBW destination. Revenues also increase with the toll levels, thanks to these captive users. They will be quite negatively affected by such a policy.

The accessibility of downtown zones is affected by such tolls. Accessibility of a destination zone i is calculated using a simple gravity model. For this situation, it is based on the destination zone attracting trips produced by other zones j (P_j).

$$Accessibility_i = \sum_j P_j \times e^{\beta_p LOGSUM_{ij}} \qquad (4)$$

where β_p are assumed to be -0.2884, -0.4681, -0.1181 and -0.3027 for HBW, HBNW, NHBW and NHBNW trip purposes, respectively, based on the corresponding destination choice model coefficients (on the mode-time of day logsums defined in equation 3). As Table 3 (Appendix A) suggests, the accessibility of cordoned zones decreases substantially with toll levels.

CHAPTER 4. CONCLUSIONS AND EXTENSIONS

Roadway tolling is coming to Austin, Texas. This work takes a look at the impacts of new toll roads, as well as possible bridge and downtown cordon toll policies. An integrated transportation-land use model, based on a rather standard TDM process and a DRAM-EMPAL based model for distribution of households and employment, was applied to the Austin region in order to anticipate the traffic, land use and welfare impacts of various pricing policies. Feedback within the TDM model (from traffic assignment back into trip distribution, mode and time of day choice models) was performed using a method of successive travel cost averages. Results from the TDM then were used in the land use models to predict household and employment locations under various tolling scenarios. Resulting changes in travel demand were evaluated to appreciate the TDM-predicted changes in traffic patterns, destination choices, mode and time of day decisions, locational accessibility, network level of service, toll revenues, land use patterns, and travel-based measures of welfare.

Different tolling strategies yield distinct results. In order to repay bonds for planned toll road additions to the Austin network, distance-based tolls are likely needed. Notably, the distance-based (10¢/mile) toll that Austin hopes to implement is very close to the revenue-maximizing toll computed by these models. Model results suggest it is possible to effectively price only a few bridges during select time periods, instead of applying all-day MCP on all candidate bridges. Cordon pricing to access the region's downtown area is found to reduce traffic headed inbound drastically (and therefore outbound). As cordon tolls are raised, inbound traffic is cut off dramatically; those that remain are captive commuters. Downtown access decreases with higher tolls; simply a $1 cordon toll may be sufficient for regulating downtown congestion in Austin.

The assumptions used in the TDM process impose certain behavioral limitations. For example, trip generation is assumed to be inelastic with respect to travel costs and thus unchanged following the introduction of road pricing policies. In reality, some trips may be wholly suppressed, while others emerge (due to latent demand) under the effects of pricing. The static traffic assignment procedure and the choice models employed deal only with homogenous users limiting predictions of policy impacts to the average user level rather than across user groups. The travel time and travel cost skims from traffic assignment are computed based on generalized cost. The procedure may be skimming for the shortest path using toll roads, if they satisfy the generalized cost criterion. This is not a serious limitation; but, in the presence of heterogeneous users, this may bias the welfare computations slightly. A better procedure is needed to model the growth over time of external-external, internal-external and external-internal trips and their distribution within feedback. Another extension is to explicitly accommodate proposed HOT and HOV lanes, in the networks and the choice models.

Toll road provision and roadway pricing affect location choices of businesses and households. The land use models used here for that purpose are gravity-based DRAM-EMPAL-type models and could be enhanced through recognition of more site specifics (such as topography and natural amenities) and structure characteristics (such as age of improvement).

In summary, Austin toll roads seem to be headed in the right direction. They are estimated to increase welfare uniformly across the region and provide impetus for land development along the tolled corridors. Fixed tolls can be as effective as marginal cost pricing in redistributing traffic on congested downtown bridges. Cordon tolls may limit downtown accessibility but do result in less downtown congestion. A variety of tolling options are available to the urban regions. This study illustrates many ways in which their results may be compared by looking not only at traffic but also land use, access, and public welfare impacts. It also offers Austin in particular a vision of its future.

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APPENDIX A

Table 1: Percentage change in average V/C ratios by facility type after toll roads are operational (as compared to the no-build alternative)

Facility Type	Late Night/ Early Morning (before 7:15 a.m and after 8:15 p.m)		Morning Peak (7:15 a.m. to 9:15 a.m.)		Mid-day (9:15 a.m. to 4:15 p.m.)		Evening Peak (4:15 p.m. to 6:15p.m.)		Evening Off-Peak (6:15 p.m. to 8:15 p.m.)	
	MCP	10¢/mile	MCP	10¢/mile	MCP	10¢/mile	MCP	10¢/mile	MCP	10¢/mile
IH 35*	-4.2%	-1.2%	-4.0%	-2.6%	-4.1%	-0.9%	-4.3%	-2.4%	-3.8%	-1.0%
US 183**	-48.0%	-7.0%	-44.7%	-18.7%	-50.2%	-5.5%	-47.8%	-12.6%	-43.4%	0.7%
Loop 1**	-69.6%	-24.1%	-57.3%	-15.1%	-68.5%	-22.3%	-55.8%	-12.5%	-65.0%	-15.0%
Other freeways*	-10.8%	-2.3%	-7.0%	0.1%	-10.9%	-1.5%	-8.0%	1.6%	-11.8%	-1.3%
Expressways	-1.2%	-1.1%	-0.8%	-0.4%	-0.8%	-0.4%	-0.7%	0.2%	-0.2%	0.3%
Principle Arterials	-4.0%	-1.9%	-4.4%	-2.9%	-3.5%	-1.7%	-4.3%	-1.8%	-3.1%	-1.3%
Minor Arterials	-2.2%	-1.7%	-2.0%	-0.6%	-1.8%	-1.5%	-2.2%	-0.5%	-1.8%	-1.3%
Collectors and Locals	0.5%	-0.3%	2.5%	1.7%	1.1%	-0.1%	2.9%	2.3%	2.1%	1.1%

* Including Frontage Roads

** Competing non-tolled lanes

Table 2: Changes in V/C ratios on toll bridges

	Late Night/ Early Morning (before 7:15 a.m. and after 8:15 p.m.)		Morning Peak (7:15 a.m. to 9:15 a.m.)		Mid-day (9:15 a.m. to 4:15 p.m.)		Evening Peak (4:15 p.m. to 6:15p.m.)		Evening Off-Peak (6:15 p.m. to 8:15 p.m.)		Average	
Base Case	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB
Redbud Trail	0.63	0.70	1.48	1.96	1.14	1.05	2.15	1.64	1.60	1.39	1.40	1.35
South 1st St.	0.12	0.14	0.91	1.28	0.27	0.26	1.24	0.81	0.41	0.36	0.59	0.57
Loop 1	0.27	0.33	0.93	1.45	0.50	0.53	1.55	1.16	0.75	0.70	0.80	0.83
Lamar Blvd.	0.71	0.67	1.54	1.52	1.28	1.23	2.14	2.05	1.66	1.52	1.47	1.40
Congress Ave.	0.28	0.24	1.08	1.11	0.55	0.41	1.06	1.13	0.70	0.66	0.73	0.71
Average V/C	0.32	0.34	1.06	1.38	0.60	0.57	1.49	1.22	0.83	0.76		
Marginal Cost Pricing	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB
Redbud Trail	0.58	0.74	1.21	1.47	1.09	0.86	1.62	1.30	1.24	1.12	1.15	1.10
South 1st St.	0.12	0.14	0.68	1.04	0.30	0.28	1.42	0.90	0.90	0.87	0.68	0.65
Loop 1	0.28	0.34	0.94	1.38	0.51	0.55	1.49	1.11	0.79	0.75	0.80	0.83
Lamar Blvd.	0.72	0.68	1.28	1.45	1.07	1.09	1.49	1.66	0.79	0.72	1.07	1.12
Congress Ave.	0.28	0.25	1.32	1.20	0.60	0.47	1.15	1.03	0.80	0.67	0.83	0.72
Average V/C	0.32	0.34	1.02	1.29	0.59	0.57	1.41	1.14	0.83	0.76		
Fixed Toll	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB
Redbud Trail	0.65	0.73	1.10	1.53	1.15	1.08	1.52	1.27	1.19	1.09	1.12	1.14
South 1st St.	0.12	0.14	0.91	1.27	0.27	0.26	1.45	1.25	0.92	0.9	0.73	0.76
Loop 1	0.27	0.33	0.94	1.46	0.50	0.53	1.57	1.17	0.78	0.74	0.81	0.85
Lamar Blvd.	0.72	0.69	1.32	1.30	1.29	1.25	1.30	1.12	0.70	0.63	1.07	1.00
Congress Ave.	0.28	0.24	1.08	1.11	0.55	0.42	1.32	1.23	0.80	0.67	0.81	0.73
Average V/C	0.32	0.34	1.02	1.33	0.60	0.57	1.46	1.19	0.81	0.75		

Table 3: Variation in accessibility, daily cordon inflow, time-of-day shifts and revenue generation with cordon toll levels

Cordon Toll Level ($/vehicle)	Percentage Change in Downtown Accessibility				Daily Inflow	Daily Inflow during Tolled Period	Daily Inflow during Non - tolled period	% of Daily Inflow during Tolled Period	% of Daily Inflow during Non - tolled period	Cordon Toll Revenues ($/day)
	HBW	HBNW	NBHW	NHBNW						
$0	-	-	-	-	170,663	125,449	45,214	73.5%	26.5%	-
$1	-13.7%	-20.2%	-14.2%	-18.8%	119,767	47,253	72,514	39.5%	60.5%	$35,431
$2	-21.6%	-29.6%	-19.6%	-26.2%	94,901	26,555	68,346	28.0%	72.0%	$53,111
$3	-25.9%	-34.5%	-20.9%	-29.2%	94,076	20,342	73,734	21.6%	78.4%	$61,027
$4	-28.3%	-37.2%	-21.1%	-30.3%	94,479	16,879	77,600	17.9%	82.1%	$67,517
$5	-29.7%	-38.8%	-21.1%	-30.8%	96,737	16,879	79,858	17.4%	82.6%	$84,397

Table 4: Average inflow and outflow V/C ratio for cordon under different toll levels

Cordon Toll Level ($/vehicle)	No toll		Tolled						No toll	
	Late Night/ Early Morning (before 7:15 a.m and after 8:15 p.m)		Morning Peak (7:15 a.m. to 9:15 a.m.)		Mid-day (9:15 a.m. to 4:15 p.m.)		Evening Peak (4:15 p.m. to 6:15p.m.)		Evening Off-Peak (6:15 p.m. to 8:15 p.m.)	
	Incoming	Outgoing	Incoming	Outgoing	Incoming	Outgoing	Incoming	Outgoing	Incoming	Outgoing
$0	0.09	0.08	0.59	0.42	0.16	0.18	0.49	0.69	0.27	0.31
$1	0.12	0.09	0.21	0.14	0.04	0.07	0.12	0.28	0.32	0.36
$2	0.15	0.1	0.14	0.13	0.03	0.06	0.1	0.21	0.35	0.4
$3	0.14	0.13	0.11	0.12	0.03	0.05	0.13	0.12	0.4	0.34
$4	0.15	0.13	0.09	0.11	0.03	0.04	0.11	0.1	0.41	0.35
$5	0.16	0.14	0.09	0.11	0.03	0.04	0.11	0.1	0.41	0.35

APPENDIX B

Figure 1: Austin bridges, downtown cordon and planned toll roads.

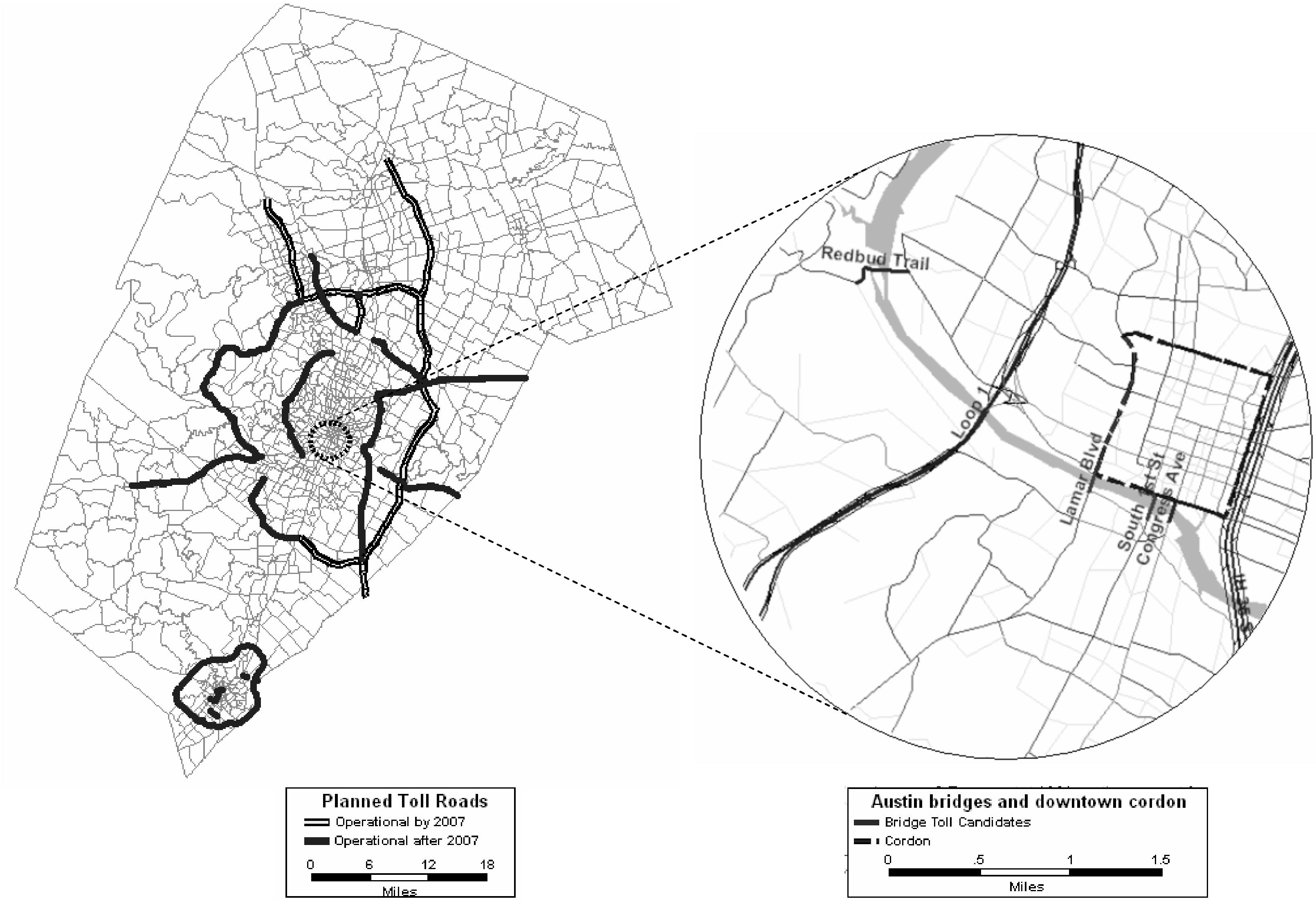

Figure 2: Welfare (by origin) for an Austin resident with toll roads, as compared to the no-build alternative.

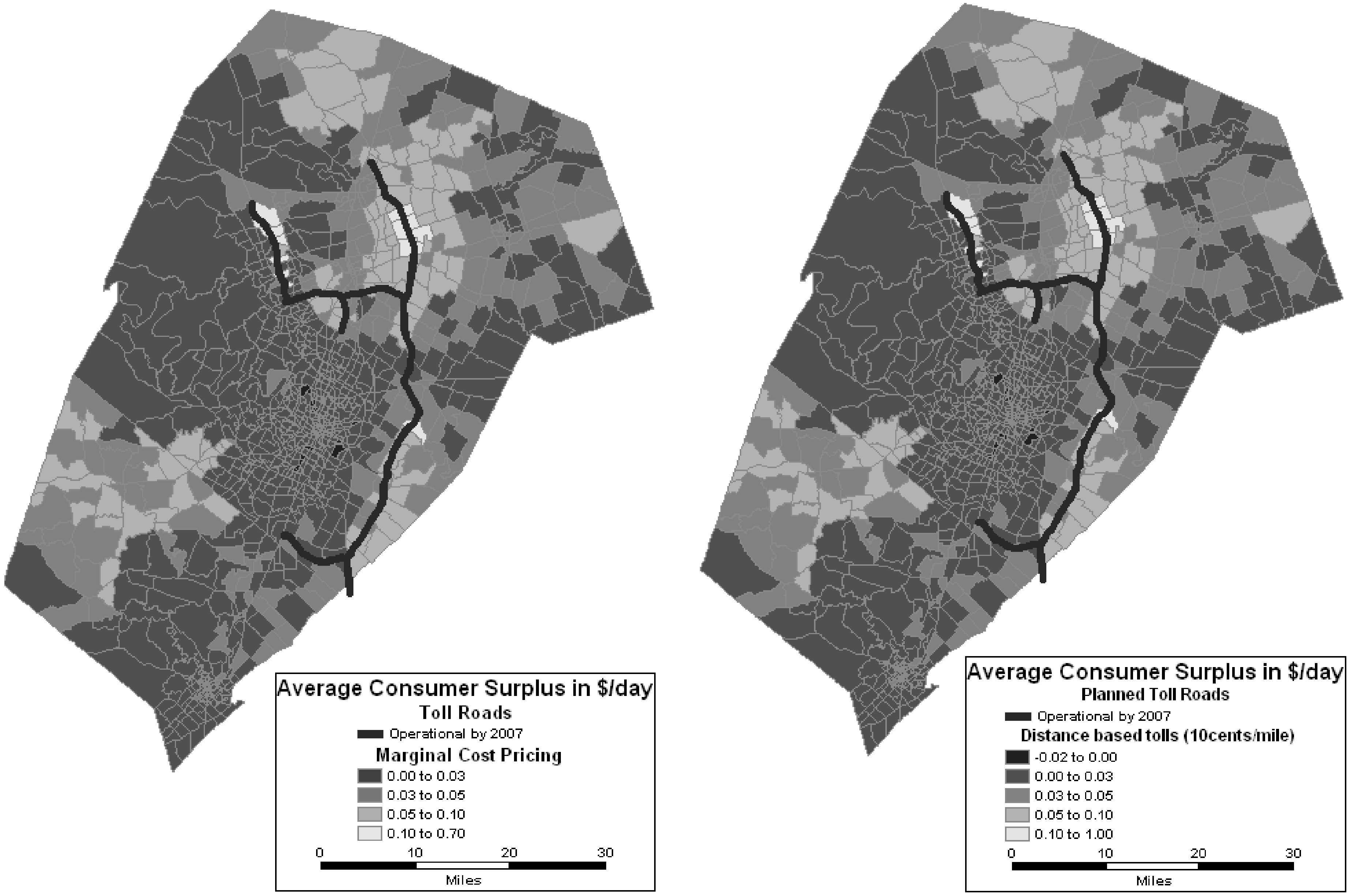

Figure 3: Percentage change in zonal land use distributions for the year 2012 under proposed tolls of 10¢/mile on toll roads, as compared to no-build option

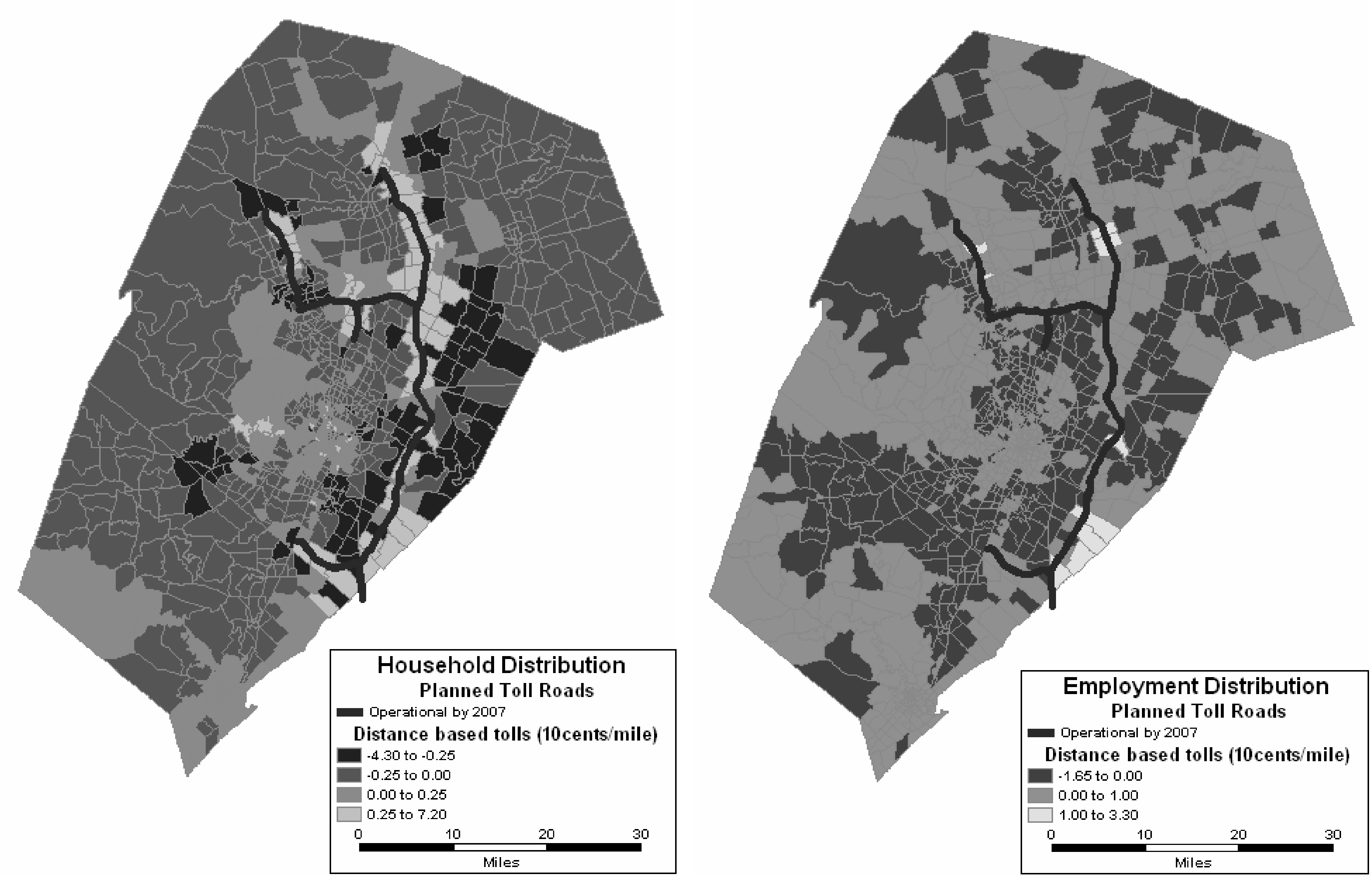

Figure 4: Welfare (by origin) for an Austin Resident for the year 2032 under proposed tolls on post 2007 toll roads, as compared to the no-post 2007 toll roads alternative.