A Review of the International Modeling Literature: Transit, Land Use, and Auto Pricing Strategies to Reduce Vehicle Miles Traveled and Greenhouse Gas Emissions

Caroline Rodier, Ph.D. Senior Researcher (corresponding author)
Transportation Sustainability Research Center
Innovative Mobility Research
University of California, Berkeley
1301 S. 46th Street, Richmond Field Station (RFS), Bldg. 190, Richmond, CA 94804
(510) 665-3524 (phone) and (510) 665-2183 (fax)
caroline@tsrc.berkeley.edu

August 1, 2008

Submission to the 2009 Transportation Research Board Annual Meeting

Word Count: 7,500

ABSTRACT

As the media document very real evidence of global climate change and the debate over humans' role precipitating this change has ended, California led the nation by passing the first global warming legislation in the U.S. California is tasked with reducing green house gas (GHG) emissions to 1990 levels by 2020 and 80% below 1990 levels by 2050. The California Air Resources Board estimates that significant GHG reductions from passenger vehicles can be achieved through improvements in vehicle technology and the low carbon fuel standard; however, these reductions will not be enough to achieve 1990 levels if current trends in vehicle kilometers traveled (VKT) continue. Currently, most operational regional models in California have limited ability to represent the effects of transit, land use, and auto pricing strategies; efforts are now underway to develop more advanced modeling tools, including activity-based travel and land use models. In the interim, this paper reviews the international modeling literature on land use, transit, and auto pricing policies to suggest a range of VKT and GHG reduction that regions might achieve if such policies were implemented. The synthesis of the literature categorizes studies, by geographic area, policy strength, and model type, to provide insight into order of magnitude estimates for 10-, 20-, 30-, and 40-years time horizons. The analysis also highlights the effects of modeling tools of differing quality, policy implementation timeframes, and variations in urban form on the relative effectiveness of policy scenarios.

Key Words: Travel modeling; land use modeling; land use and transit measures; auto pricing; green house gas reductions

INTRODUCTION

As the public witnessed media coverage of the very real evidence of global climate change and the debate over humans' role precipitating this change has ended, California led the nation by passing the first global warming legislation in the U.S. The *Global Warming Solutions Act* (AB 32) requires California's green house gas (GHG) emissions be reduced to 1990 levels by 2020, and the Governor's Executive Order (S-3-05) targets an additional 80% reduction in GHG emissions below 1990 levels by 2050. Transportation accounts for 36% of total GHG emissions in California and 27% in the U.S. The California Air Resources Board (CARB) estimates that significant GHG reductions from passenger vehicles can be achieved through improvements in vehicle technology and the low carbon fuel standard; however, these reductions will not be enough to achieve 1990 levels if current trends in vehicle kilometers traveled (VKT) continue. As a result, land use and transport policies strategies to reduce growth in VKT are therefore an important part of achieving California's greenhouse gas emission reduction goals.

Currently most operational models used by state, regional, and local governmental organizations in California have limited ability to represent the effects of transit, land use, and auto pricing strategies. The major metropolitan planning organizations (MPOs) in California are in the process of developing more advanced modeling tools, including activity-based travel models and land use models; however, it is likely to be at least three years before all these models are fully operational.

In the interim, this paper reviews the international modeling literature on land use, transit, and auto pricing policies to suggest a range of VKT and GHG reductions that regions might achieve if such policies were implemented over 10-, 20-, 30-, and 40-year time horizons. As a result, the analysis also provides insights into the effects of varying modeling tools, policy types, regulatory timeframes, and urban form on the relative effectiveness of discrete and combined policy alternatives.

The paper begins with a description of the methods used in the evaluation of the scenarios including the categorization of models, area type, and policy strength. Next, a general overview of the studies reviewed is provided, including the location, models, and number of scenarios by policy type. This is followed by the synthesis of the literature, which presents the results separately for single- and combined-policy scenarios. Finally, key conclusions are drawn from the review.

METHODS

The literature reviewed in this study consists of studies conducted by regional or state government agencies, academic researchers, and community groups. To be included in this review, the study must report VKT and/or GHG effects of a policy alternative relative to a base case (typically a trend or business-as-usual) in the same horizon year. The results are presented as per capita percentage change in VKT and include both personal and commercial vehicle travel. GHG results from reduced vehicle travel are used from one study (Lautso et al., 2004) because VKT results were not available. Most studies provide simulation results for only one or two time horizons (most typically 20 or 30 years); however, the AB 32 legislation has an initial 10-year time horizon, and the Governor's Executive Order has a 40 year time horizon. Incremental progress toward GHG reduction goals will have to be

monitored. As a result, compound annual growth rates were calculated using the current base case (e.g., year 2005) for each future policy scenario time horizon or horizons. The growth rates were then applied to estimate results for all four time horizons (10, 20, 30, and 40 years). However, if a pricing study included only one time horizon, then future overestimates were addressed by applying average extrapolation changes from studies of the same policies in similar regions (i.e., size and transit infrastructure). It is important to note that the timing of implementation could change the estimates for these time horizons and, in general, near term effects may be overestimated and outer-year effects may be underestimated. Study intervals (SI), free from distribution assumptions, are identified for a 68% and 95% range of study scenario results.

Evaluation

In the evaluation of these studies, the type and quality of the model are categorized as described in Table 1. The model types include (1) travel models and/or land use models of varying quality, calibrated to specific regions and used for regulatory compliance and planning purposes; (2) experimental or research models typically of high quality but lacking the more rigorous calibration of official models; and (3) sketch planning or visioning tools used by community-based groups to think about different community development futures, but not to make official forecasts.

Table 1. Model Type and Quality Categories

Model Type	Quality
Poor Calibrated Travel	Limited sensitivity to changes in travel time and cost (zone-based without feedback to trip distribution) (4-step without feedback)
Typical Calibrated Travel	Some sensitivity to changes in travel time and cost (zone based with feedback to trip distribution) (4-step with feedback of uncertain quality)
Improved Calibrated Travel	Better sensitivity to changes in travel time and cost (smaller zones with feedback to trip distribution) and higher geographic resolutions (4-step with feedback and greater sensitivity to transit, walk, and bike variables)
Advanced Calibrated Models	More advanced representation of travel behavior, land use, and economic theories; good sensitivity to modal changes in travel time and costs; land use effects; and high geographic resolutions (Travel and land use models; activity-based models)
Experimental/research models	Similar to advanced models but without the rigorously calibration of official models
Visioning tools	Sketch planning for quick scenario analysis; exploratory analysis of alternative policies (unofficial 4-step model; UPLAN; PLACES; INDEX)

To address generalizability, study results are categorized by area type, defined by population size and transit commute mode share (in approximately the year 2000). A region with a population of seven million or more is categorized as large, between seven million and one million is medium, and less than one million is small. Regions with transit commute mode share greater than or equal to 10% are categorized as having high quality transit, and those with mode share less than 10% have moderate to low quality transit.

The policy type and strength is also identified in this analysis, as described in Table 2. Land use and auto pricing policies are widely considered to be effective policies to reduce VKT; however, historically, in California and the U.S., the adoption and implementation of these policies have been exceedingly difficult for a variety of political and institutional reasons. Some of the literature included in this study attempts to "bookend" or represent extreme ends of the policy-implementation spectrum. For example, some assume all new development over a 20-year period would be accomplished through infill and redevelopment in areas near transit. Others include congestion pricing policies on all roadways with congestion in a region or combine multiple auto pricing polices in one scenario (e.g., fuel pricing, VKT pricing, and parking pricing). In the near term, such aggressive implementation of land use and pricing policies seems unlikely.

Table 2: Policy Strength and Type Categories

Policy Strength	Policies Typically Included
Moderate	Improve transit service; reduce transit fares.
Aggressive	Land use and transportation strategies in official planning documents and/or that represent moderate changes relative to historical development patterns; cordon pricing; pay-as-you-drive insurance; parking pricing in the urban core; widespread carsharing and telecommuting; traffic calming.
Very Aggressive	Land use and transport strategies that depart significantly from historical patterns and are not included in official planning documents; VKT pricing; congestion pricing on all roadways; fuel pricing; and region-wide parking pricing.

SUMMARY OF STUDIES REVIEWED

In Table 3, the studies reviewed in this paper are summarized by source, location, model, and number of scenarios by type.

TABLE 3 Summary of Studies Reviewed by Source, Location, Model, and Number of scenario Types

Size/ Transit	Region	Studies	Models	Scenario #			
				TR	LU	LU TR	PR
Large/High	Chicago	Chicago Metropolis, 2003	LU (CRIEM/GIS)+TDM			4	
	Yorkshire	Simmonds et al., 2006	LU (DELTA)+ TDM	7			5
	Washington DC	Safirova, et al., 2007	LU (LUSTRE)		4		6
		Nelson et al., 2003	START TDM				1
	Philadelphia	DVRPC, 2003	DVPCP TDM		1		
	San Francisco	Deakin et al., 1996	STEP TDM				10
		MTC, 2007	MTC TDM	1	1	1	2
Large/ Moderate	San Diego	Deakin et al., 1996	STEP TDM				10
		SANDAG, 1998	SANDAG TDM			3	
		SANDAG, 2007		1		1	
	Los Angeles	Deakin et al., 1996	STEP TDM				10
		SCAG, 2004	SCAG TDM			1	
		SCAG, 2008		1		1	
Medium/High	Brussels, BEL	Lautso et al., 2004	LU/TDM (TRANUS)	1	1		9
	Naples, ITA	Lautso et al., 2004	LU/TDM (MEPLAN)		1		9
	Dortmund, GER	Lautso et al., 2004	LU/TDM (IRPUD)	1	1		13
		BCI et al., 2006	LU/TDM (Dortmund)				3
	Bilbao, ESP	Lautso et al., 2004	LU/TDM (MEPLAN)	1	1		9
Medium/ Moderate	Austin	ENVISION TX, 2003	NA			3	
	Salt Lake City	Envision Utah, 1998	NA			2	
		Governor's Office, 2000	LU (UrbanSim)+TDM			1	
	Sacramento	Deakin et al., 1996	STEP TDM				10
		Johnston et al., 1998	SACMET TDM	2		1	
		Johnston et al., 2000	LU/TDM (MEPLAN)				1
		Rodier, 2002		2		2	4
		Johnston et al., 2005		1	1	1	2
		SACOG, 2004	LU(MEPLAN)+ SACMET TDM			1	
		SACOG, 2008	SACSIM TDM			1	
	Twin Cities	CEE et al., 1999	GIS + TDM		3		
		Barnes, 2003			1	3	
	Portland	CSI, 1996	METRO TDM			2	
		METRO, 1998				1	
	Seattle	PSCOG, 1990	PSCOG TDM			2	
	Baltimore	BMC, 2002	BMC TDM			2	
	Orlando	HDR, 2003	LU (ULAM)+FSU TDM		1		
Small/High	Helsinki, FIN	Lautso et al., 2004	LU/TDM (MEPLAN	1	1		11
	Edinburgh, UK	BCI et al., 2006	LU (LUTI)+TDM				4
Small/ Moderate	Vicenza, ITA	Lautso et al., 2004	LU/TDM (MEPLAN)	1	1		10
Small/Poor	San Joaquin	Bai et al., 2007	LU (UPLAN)+TDM			1	
	Pee Dee	Pee Dee COG, 2003	TDM		1		

Scenarios: TR is transit; LU is pricing; and PR is auto pricing.
Models: TDM is travel model; LU is land use model; and LU/TDM is integrated.

California

Special attention is paid to recent transport, land use, and/or pricing studies conducted by the four major MPOs in California because of their relevance to the GHG goals of AB 32 and the subsequent executive order. The Sacramento Area Council of Governments (SACOG) has pioneered the "Blueprint" planning in California: an MPO-sponsored participatory planning process used to develop a common land use and transport vision for the region, which is ideally accompanied by high-quality modeling of travel, environmental, and economic impacts. Following SACOG's example with support from the California Department of Transportation, the San Francisco Bay Area Metropolitan Transportation Commission (MTC), the San Diego Association of Governments (SANDAG), and the Los Angeles South Coast Association of Governments (SCAG) have now also conducted blueprint planning processes that are more or less similar to SACOG's approach. The San Joaquin Valley region is currently conducting its blueprint planning process. In a dramatic departure from the past, all four major MPOs have included their land use strategy in official regional transportation planning documents (*1, 2, 3, 4*). SACOG was allowed by the U.S. Environmental Protection Agency to use its land use plan in its official regional transportation plan alternative as part of its air quality conformity process. The results of earlier visioning studies of land use and transportation scenarios in these regions are also presented in this study (*5, 6, 7)*. These studies typically simulate scenarios for a 30-year time horizon. However, the earlier SACOG Blueprint study (*5*) simulated a 50-year time horizon.

Deakin et al. (*8*) use an advanced calibrated travel model (the STEP model) to conduct analyses of a common set of pricing policies across the San Francisco, Los Angeles, Sacramento, and San Diego regions. The STEP model (separately calibrated to the four regions) is particularly well suited evaluate pricing policies because of its disaggregate representation of the costs experienced by travelers. This study simulates pricing policies for a current base year as well as a 20-year future time horizon.

Rodier and Johnston conduct a series of simulation studies using the Sacramento region's improved travel demand model (SACMET) (*9*) as well as an experimental land use and transportation model (the Sacramento MEPLAN model) (*10,11*) to explore a range of transit, land use, and pricing policies in the region. These studies simulate scenarios for a range of time horizons (10, 20, and 50 years).

More recently, Bai et al. (*12*) use an experimental modeling framework that includes the UPLAN land use model and the TP+/Viper travel demand model to examine transit and land use scenarios in the San Joaquin Valley region for a 25-year time horizon.

Other U.S. States

Outside of California in the U.S., simulations have been conducted in three large regions in the U.S. with high quality transit. Safirova et al. (*13*) and Nelson et al. (*14*) use the experimental LUSTRE land use model and/or START travel model to simulate a range of transit, pricing, and land use scenarios in the Washington, D.C., region for a 20-year time horizon. Thirty-year visioning studies of land use and transit scenarios are conducted for the Chicago region using an advanced land use and travel model. In the Philadelphia region, which is part of the states of Delaware, Pennsylvania, and New Jersey, a travel model of

uncertain quality is used to evaluate alternative land use and transit scenarios for a 20-year time horizon.

Numerous studies have been conducted in medium-sized city regions with moderate quality transit. In Portland, Oregon, an improved travel demand model is used to simulate land use, transit, and pricing scenarios in the famous LUTRAQ study for a 20-year time horizon (*15)*. Later, in an official planning study, the improved travel model is used to simulate future land use scenarios for a 50-year time horizon (*16)*. In Salt Lake City, Envision Utah explores land use and transit scenarios as part of a regional visioning planning process for a 20-year time horizon (*17*). Later, like Portland, an official regional planning document includes the results of a modified land use and transport plan, with roots in the Envision Utah process, and simulated with an advanced land use model (UrbanSim) and an improved calibrated travel model for a 20 year time horizon (*18*). Visioning studies are also conducted in the Twin Cities (*19, 20*), Austin (*21*), Baltimore (*22*), Seattle (*23*), and Orlando (*24*).

International

Several studies simulate consistent sets of policy scenarios across European regions. In the PROPOLIS study, advanced calibrated land use and travel models (MEPLAN, TRANUS, and/or IRPUD) are used to simulate the effects of common transit, land use, and auto pricing policies for 10- and 20-year time horizons in six European regions (*25*). Dortmund, Naples, and Bilbao are medium-sized regions with high quality transit. Helsinki is a small sized region with high quality transit, and Vicenza is small with moderate transit quality.

In Europe, the STEPS study, also uses advanced land use and travel models to simulate the effect of common policies in Dortmund and Edinburgh for 20 year time horizons (*26*). The Dortmund model and the Edinburgh SPM model are advanced calibrated land use and travel models. Edinburgh is categorized as a small sized city with relatively high quality transit.

Simmonds et al. (*27*) use an advanced land use and travel model calibrated to the Yorkshire region (SWYSM which includes the DELTA, START, and DTM sub-models) to evaluate a range of transit and pricing policies in an official planning document for a 25-year time horizons. The Yorkshire region is large with high quality transit.

SYNTHESIS

Single Policy scenarios

Transit

In the four major regions of California, scenarios are simulated that represent transit service improvements ranging from 2.9% to 475% (*2, 4, 9, 10, 11, 28*). Scenarios simulated in six European cities (*25*) reduce transit travel time by 10%. In Yorkshire, (*29*) transit service is expanded incrementally over subareas with a 30% reduction in fares and a 20% increase in frequency. Percentage change in VKT for the four time horizons (as illustrated in Figure 1) for these transit scenarios (N=9) is as follows:

- 10 years: median -0.3%; 68% SI -1.1% to -0.1%; 95% SI -3.7% to -0.0%

- 20 years: median -0.7%; 68% SI -2.1% to -0.2%; 95% SI -6.0% to -0.0%
- 30 years: median -0.9%; 68% SI -3.1% to -0.2%; 95% SI -8.9% to -0.0%
- 40 years: median -1.0%; 68% SI -3.5% to -0.3%; 95% SI -10.4% to -0.0%

Figure 2 illustrates the distribution of transit results for the most frequent time horizon represented in these studies, the 20-year horizon. Most scenarios were simulated with land use and travel models. Those simulated with travel models only, in San Diego, San Francisco, and Sacramento, tend to fall around the median within the 68% SI (*2, 4, 9*). Interestingly, scenarios with similar transit investment are simulated in both the Sacramento MEPLAN model (*10*) and the official calibrated travel model (*9*) but produce very different VKT reductions: 6.0% versus 0.3%. The extreme ends of the distribution are represented by a very aggressive transit investment scenario simulated with the Sacramento MEPLAN model (*11*) and a transit and highway scenario simulated with a calibrated travel model in the Los Angeles region, which actually indicated a 0.5% increase in VMT (*9*). The transit scenarios simulated with a land use and travel model in Yorkshire tend to rank with the level of improvement in the transit service, and most results tend to fall above the median within the 95% SI. Yorkshire is a large region with high quality transit, and thus the relative level of transit service improvement may be small compared to existing services in the region (*29*).

Land Use

Aggressive to very aggressive land-use-only scenarios are simulated in regions ranging in size and quality of transit. In the Washington, D.C., area, Safirova (*13*) simulates a number of land use scenarios: high preference for living inside the beltway (25% more attractive); increased residential housing density (20% more dense inside the beltway); live nearer your work program (closing cost assistance of $8,000 for first-time home buyers living near work); and an inclusionary zoning program (increased stock of affordable housing). Elsewhere, simulations include a land use plan developed as part of the blueprint process in the San Francisco region (*4*); a recentralized land use scenario in an official Philadelphia region report (*30*); transit-oriented development policies in six European regions (*25*); visioning scenarios in the Twin Cities (*19, 20*); and finally a very aggressive urban growth boundary policy in the Sacramento region (*11*). Percentage change in VKT for the four time horizons (as illustrated in Figure 1) for these land use scenarios (N=19) is as follows:

- 10 years: median -0.5%; 68% SI -2.0% to -0.1%; 95% SI -3.1% to -0.0%
- 20 years: median -1.1%; 68% SI -4.0% to -0.0%; 95% SI -6% to 0.1%
- 30 years: median -1.4%; 68% SI -5.9% to -0.1%; 95% SI -7.5% to 0.1%
- 40 years: median -1.7%; 68% SI -7.7% to -0.1%; 95% SI -9.8% to 0.2%

Some interesting patterns develop in the ordering of scenarios around the median. See Figure 2. Scenarios simulated with integrated land use and travel models of relatively moderate policy strength in regions with high quality transit (Washington, D.C., Helsinki, Brussels, Vicenza, and Naples) tend to show very small reductions in VKT distributed widely above the median (*13, 25*). VKT is actually increased in two scenarios, one in Washington D.C. and the other in Helsinki (*13, 25*). These integrated models use relatively large zones and thus have coarse geographic resolutions, which may overestimate the share of vehicle trips relative to walk and bike trips from transit oriented development policies. The exception to

this trend, however, is the very aggressive land use scenario simulated with the experimental land use and travel model in the Sacramento region, which has the greatest level of VKT reduction falling outside the 95% CI. This may be explained by the relative densities and transit quality of the regions: dense European and Washington D.C. regions with high quality transit may limit the relative effectiveness of the additional densification policies compared to the more sprawling and rapidly growing Sacramento region where trend land use patterns do not take full advantage existing transit capacity. Results for Twin Cities, a region similar to Sacramento, also fall the below median between the 68% SI and the 95% SI (*19, 20*). Scenarios simulated with travel models only tend to fall around the median in Philadelphia (*30*), Pee Dee (*31*), San Francisco (*4*), and Orlando (*24*).

Cordon Pricing

Studies of a range of cordon pricing policies are conducted in Washington D.C. as well as in Yorkshire and in six other European cities. In Washington, D.C., Safirova el al. (*13*) evaluate three cordon pricing scenarios: downtown cordon ($4.70); downtown cordon ($2.18) and a beltway cordon around the urban core ($3.43); and a broader beltway cordon ($2.84). Simmonds et al. (*29*) simulate cordon charges around the towns and cities of the Yorkshire region. In the PROPOLIS study, cordon pricing is set at 20% and 60% of the value of commuters' travel time (*25*). Percentage change in VKT for the four time horizons (as illustrated in Figure 1) for these cordon pricing scenarios (N=16) is as follows:

- 10 years: median -2.8%; 68% SI -5.8% to -1.3%; 95% SI -14.5% to -1.1%
- 20 years: median -2.1%; 68% SI -6.1% to -1.3%; 95% SI -11.0% to -0.9%
- 30 years: median -1.8%; 68% SI -6.4% to -0.7%; 95% SI -7.4% to -0.6%
- 40 years: median -1.7%; 68% SI -4.0% to -0.5%; 95% SI -6.9% to -0.4%

All of the cordon pricing policy scenarios are simulated with integrated land use and transport models, which allow for land uses to reallocate in response to the cordon charge and thus the effect of a static policy may be reduced over time. Generally, policies rank with the magnitude of the cordon charge by region. See Figure 2. Below the median at the tail end of the distribution, the Helsinki scenario includes two cordons that appear to affect a significantly larger share of trips than in the other regional cordon pricing scenarios. This result is unlikely to be transferable to regions with multiple employment centers.

Parking Pricing

Parking pricing studies are available for the major California regions and six European cities. Deakin et al. (*8*) simulate two employee parking pricing charges, representing a minimum daily price of $1.00 and another of $3.00 for drive alone work trips. In the PROPOLIS study, parking pricing is set at 20% and 60% of the value of commuters' travel time (*25*). Percentage change in VKT for the four time horizons (as illustrated in Figure 1) for these parking pricing scenarios (N=16) is as follows:

- 10 years: median -2.2%; 68% SI -3.2% to -0.8%; 95% SI -6.9% to 0.1%
- 20 years: median -2.2%; 68% SI -2.9% to -0.8%; 95% SI -7.1% to 0.0%
- 30 years: median -2.2%; 68% SI -2.8% to -0.6%; 95% SI -7.0% to -0.2%
- 40 years: median -2.0%; 68% SI -2.6% to -0.7%; 95% SI -6.1% to -0.0%

FIGURE 1 Box Plots of Single Policy VKT Reductions by Time Horizon

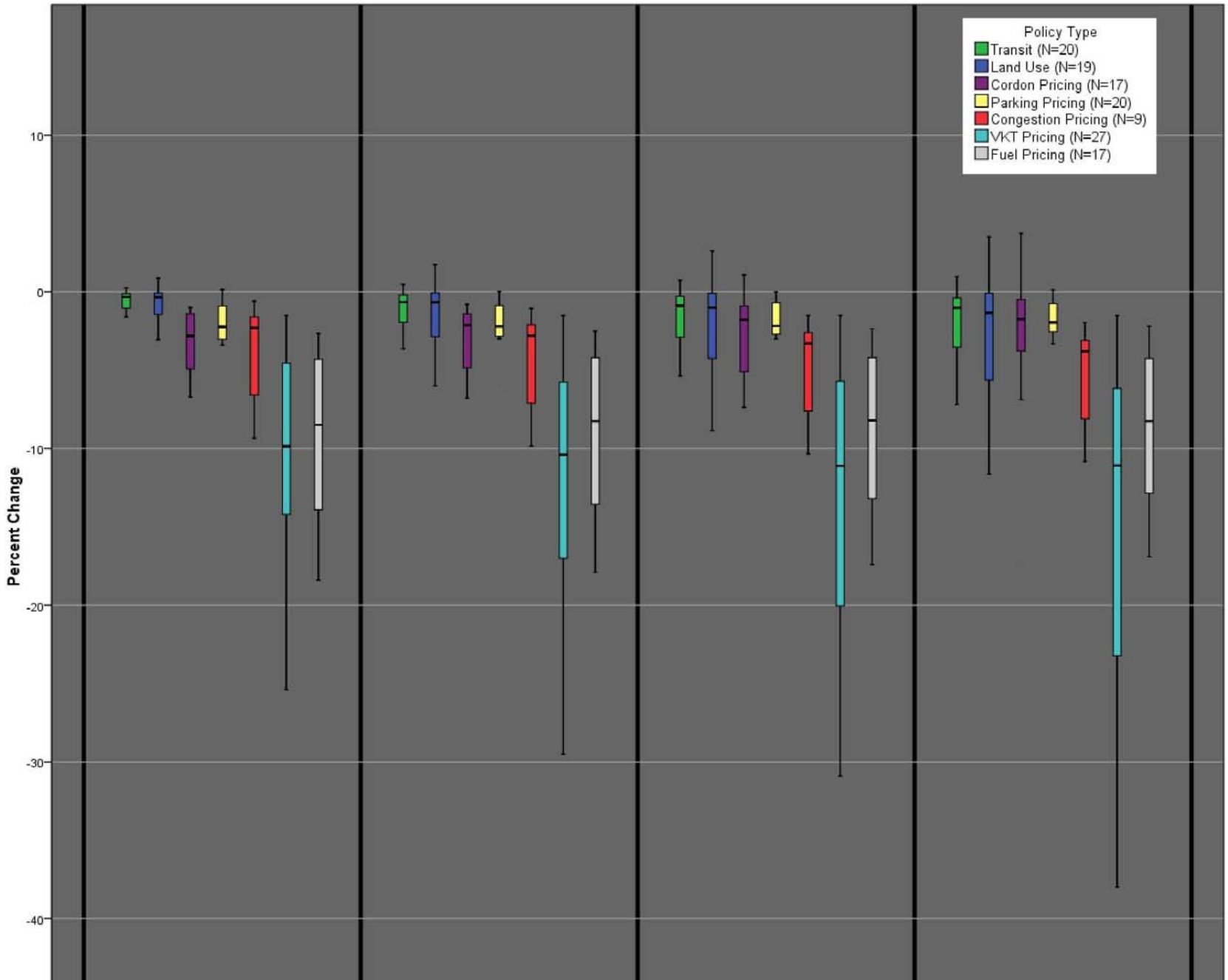
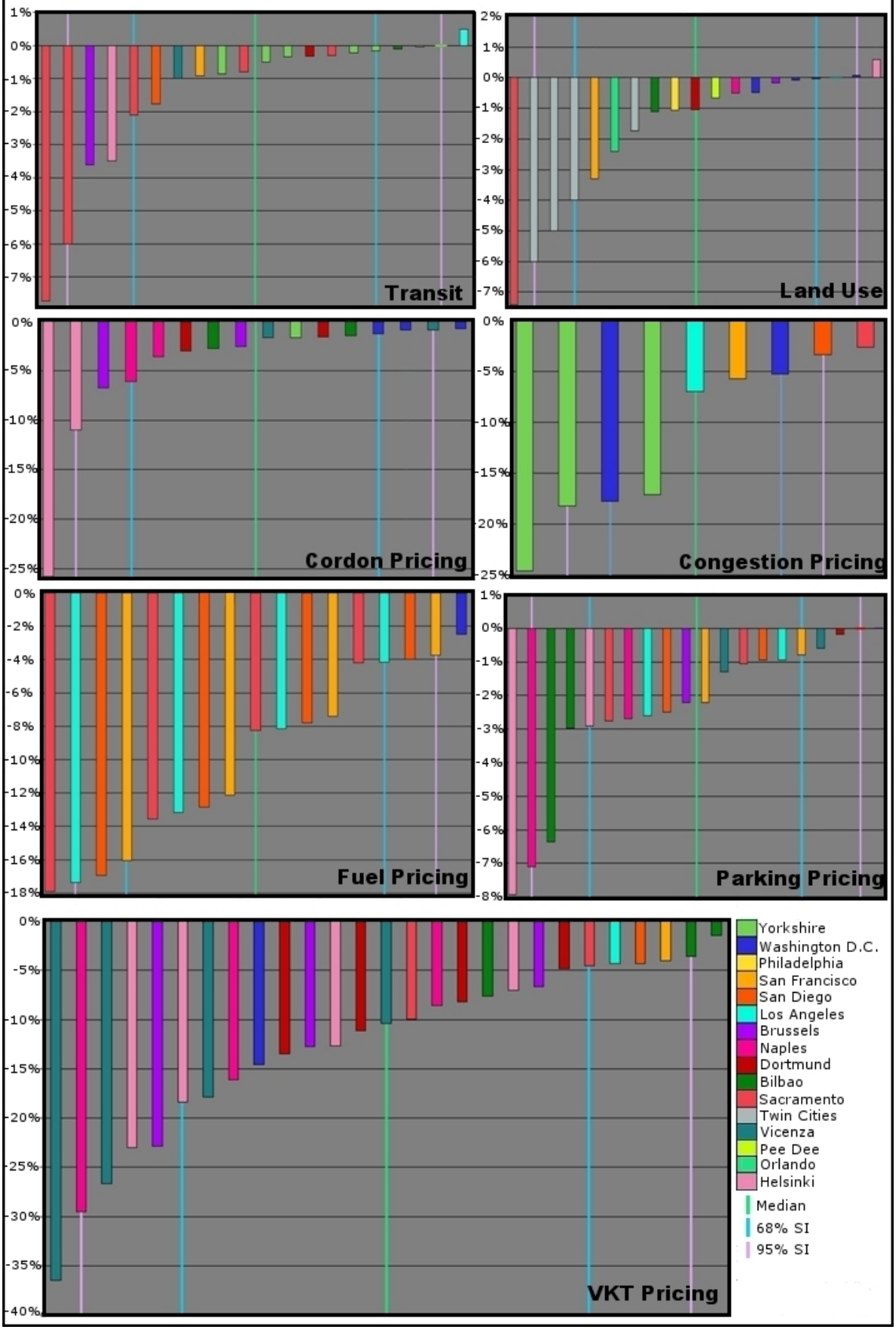


FIGURE 2 Distributions of Single Policy VKT Reductions for 20-Year Time Horizon



The high parking pricing scenarios simulated with an advanced travel model in the California regions fall below the median within the 68% SI, and the low parking pricing scenarios fall above the median within the 68% SI (*8*) with approximately 1% reductions across all time horizons. See Figure 2. In the PROPOLIS study, the scenarios simulated with the integrated land use and travel models tend to rank by policy strength for regions. The regions of Helsinki and Naples tend to be most responsive to the pricing policies, and Dortmund and Brussels tend to be least responsive. The small change in Dortmund is explained by the policy tendency to reduce the auto mode share and to increase average shopping trips lengths (*25*). In Brussels, per capita VKT is increased by 0.02% in one scenario because of housing and employment shifts from the city center and inner urban areas to outer areas of the regions (*25*). As households and employers are able to adjust to the parking pricing policies in scenarios simulated by the land use and transport models, and some results are slightly dampened, and some are increased over-time.

Congestion Pricing

Congestion pricing charges are imposed on all regional roadways to reduce volume to capacity ratios to the 0.9 level in the major California regions (*8*). In the Washington, D.C., area, different congestion tolling schemes are simulated, including a variable comprehensive toll (similar to the Deakin et al., 1996, scenario) and a variable freeway toll (a more limited application) (*13*). In the Yorkshire region, the marginal external cost of pricing is imposed on roadways. Percentage change in VKT for the four time horizons (as illustrated in Figure 1) for these congestion pricing scenarios (N=9) is as follows:

- 10 years: median -2.3%; 68% SI -6.6% to -1.6%; 95% SI -6.8% to -1.0%
- 20 years: median -2.8%; 68% SI -7.1% to -2.1%; 95% SI -7.3% to -1.4%
- 30 years: median -3.3%; 68% SI -7.6% to -2.6%; 95% SI -7.8% to -1.7%
- 40 years: median -3.8%; 68% SI -8.1% to -3.1%; 95% SI -8.3% to -2.1%

As population grows over time, so does congestion, and thus these policies are more effective over time. In general, the stronger congestion pricing policies simulated in the California regions fall at or above the median, and congestion pricing policies of similar strength in Yorkshire and Washington, D.C., fall below. See Figure 2. This result is likely explained by relative congestion levels in these studies. The California region scenarios were simulated with 1990 and 2010 time horizons and thus tend to have lower relative congestion latter studies with a 2020 time horizon. However, it is also possible that the interaction between land use and transport contribute to the larger effects.

VKT Pricing

VKT pricing scenarios are evaluated in the California regions (*8, 10*), Washington, D.C., (*13*), and six European regions (*25*). Deakin et al. (*8*) simulate a VKT fee (two cents per mile/1.6 kilometer increase in auto operating costs) in the four major California regions, which may represent an aggressive but feasible policy strategy in the form of pay-as-you-drive insurance. Rodier (*10*) simulates a higher VKT pricing fee (five cents per mile/1.6 kilometer increase in auto operating costs) in the Sacramento region. Safirova et al. (*13*) simulate an even more aggressive VKT fee (a 10 cent per mile/1.6 kilometer increase in auto operating costs) in the Washington, D.C., area. The PROPOLIS study includes VKT pricing

scenarios that increase per-kilometer auto operating cost by 25%, 50%, and 100% over existing levels (*25*). Percentage change in VKT for the four time horizons (as illustrated in Figure 1) for these VKT pricing scenarios (N=27) is as follows:

- 10 years: median -9.86%; 68% SI -14.2% to -4.4%; 95% SI -22.7% to -2.2%
- 20 years: median -10.4%; 68% SI -18.4% to -4.6%; 95% SI -29.5% to -3.6%
- 30 years: median -11.2%; 68% SI -22.4% to -5.0%; 95% SI -43.2% to -3.9%
- 40 years: median -11.1%; 68% SI -24.4% to -5.0%; 95% SI -54.2% to -3.8%

The moderate VKT pricing policies fall above the median within the 68% SI, and the higher VKT pricing policies in Sacramento and Washington D.C. fall below the median within the 68% SI. See Figure 2. In the PROPOLIS study, the scenarios simulated with the integrated land use and travel model tend to rank by region by policy strength. The regions of Vicenza and Naples tend to be most responsive to the pricing policies, and Dortmund and Bilbao tend to be least responsive. In the PROPOLIS study, over time, as the regional urban economies adjust to the policy, there is a slight dampening of the VKT reductions at the lower VKT price levels and a heightening of the reductions at the highest VKT price levels. The low VKT scenarios in Deakin et al. (*8*) scenarios could represent a pay-as-you-drive insurance scenario in California regions, and these results suggest a 4% to 5% reduction over the four time horizons.

Fuel Tax

Fuel tax studies are examined in the major California regions (*8*) and in Washington, D.C., (*14*) for the 20-year time horizon. In California, the following scenarios are simulated: $0.50 per gallon/3.8 liters (-0.13 fuel elasticity); $2.00 per gallon/3.8 liters (-0.13 fuel elasticity); $2.00 per gallon/3.8 liters (-0.05 fuel elasticity); and $2.00 per gallon/3.8 liters (-0.22 fuel elasticity). In Washington, D.C., Nelson et al. (*14*) simulate a lower fuel tax ($0.25 cents per gallon/3.8 liters). The results of these fuel tax studies show that the policies rank above and below the median by policy strength. Not surprisingly, within these rankings regions with lower quality transit and sprawling land uses (i.e., Sacramento and Los Angeles) are more sensitive to fuel tax increases than more dense urban areas with high quality transit (i.e., San Francisco and Washington, D.C.) because they lack alternatives to the auto for essential travel destinations. See Figure 2. Percentage change in VKT for the four time horizons (as illustrated in Figure 1) for these fuel tax scenarios (N=17) is as follows:

- 10 years: median -8.4%; 68% SI -16.6% to -4.1%; 95% SI -17.6% to -3.9%
- 20 years: median -8.2%; 68% SI -16.1% to -4.2%; 95% SI -17.4% to -3.8%
- 30 years: median -8.2%; 68% SI -15.5% to -4.1%; 95% SI -17.1% to -3.6%
- 40 years: median -12.9%; 68% SI -14.9% to -4.0%; 95% SI -16.9% to -3.5%

Combined Scenarios

Land Use and Transit

Analyses of the VKT effects of land use and transit scenarios are available from a series of official planning and visioning studies in the U.S. Aggressive but feasible land use plans are included in official planning documents for the following regions: San Francisco (*4*), San

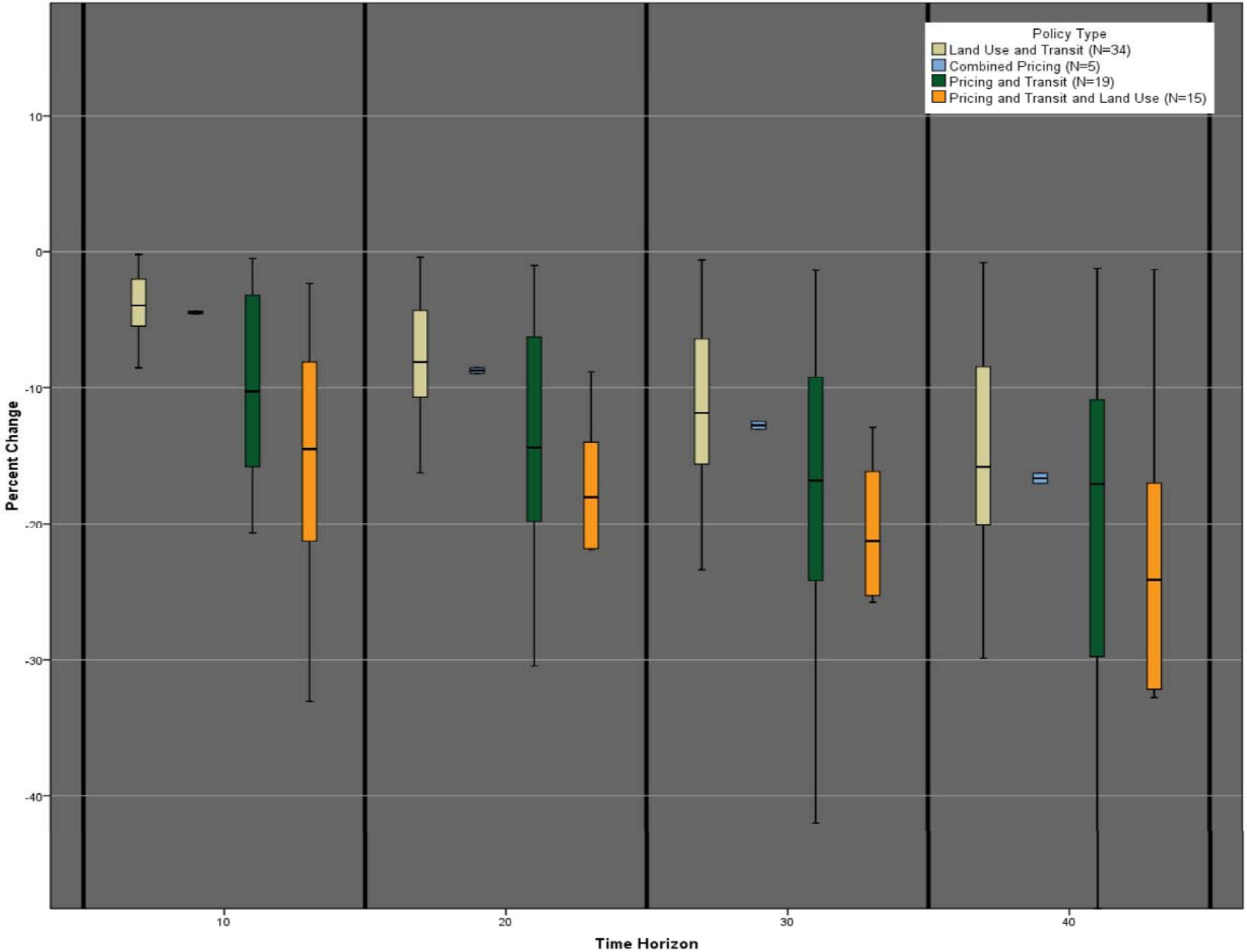
Diego (*2*), Los Angeles (*6, 28*), Sacramento (*2, 5*), Baltimore (*32*), Seattle (*23*), Portland (*16*), and Salt Lake City (*18*). More aggressive visioning studies are conducted in Chicago (*32*), Salt Lake City (*17*), Portland (*15*), Austin (*21*), San Diego (*7*), and the Twin Cities (*19*). More aggressive studies are also included in experimental studies in Sacramento (*9, 10, 11*) and the San Joaquin Valley (*12*). Percentage change in VKT for the four time horizons (as illustrated in Figure 3) for these land use and transit scenarios (N=34) is as follows:

- 10 years: median -3.9%; 68% SI -5.7% to -1.5%; 95% SI -7.7% to -0.4%
- 20 years: median -8.1%; 68% SI -11.4% to -3.4%; 95% SI -14.9% to -1.4%
- 30 years: median -11.9%; 68% SI -16.5% to -5.1%; 95% SI -21.4% to -2.0%
- 40 years: median -15.8%; 68% SI -20.7% to -6.7%; 95% SI -27.5% to -2.7%

In general, the results of the very aggressive visioning studies (*7, 17. 19, 21, 34*) and the experimental academic studies *(10, 11, 12)* fall below the median. See Figure 4. These studies tend to rank by the relative aggressiveness of plan, and those that employ land use and travel models (i.e., Chicago, San Joaquin Valley, and Sacramento) are more likely to fall below the median at the tail end of the distribution. Most of the studies above the median are official planning documents or more conservative plans in visioning studies. The studies above the median and at the tail end of the distribution tend to be less aggressive and use weaker travel models (*6, 15, 23, 28*).

A closer look at the comparison between the extrapolation results for the shorter and longer time horizons in the Sacramento region studies highlights the potential bias against land use and transit policies in a regulatory framework that emphasizes near-term compliance demonstration. SACOG's blueprint land use and transportation plan was simulated over a 50-year time horizon; the extrapolated results show a 4.2% reduction in VKT in the 10-year time horizon (*5*). As mentioned previously, extrapolation will over-estimate near-term effects, and, over a longer time horizon, this over estimate will be more exaggerated. For example, the improved calibrated Sacramento travel model was also used to simulate a very aggressive transit-oriented development scenario in which all new household and employment growth was located within one mile of the new high-quality transit stations, and the results showed only a 0.4% reduction in VKT (*9*).

FIGURE 3 Box Plots of Combined Policy VKT Reductions by Time Horizon



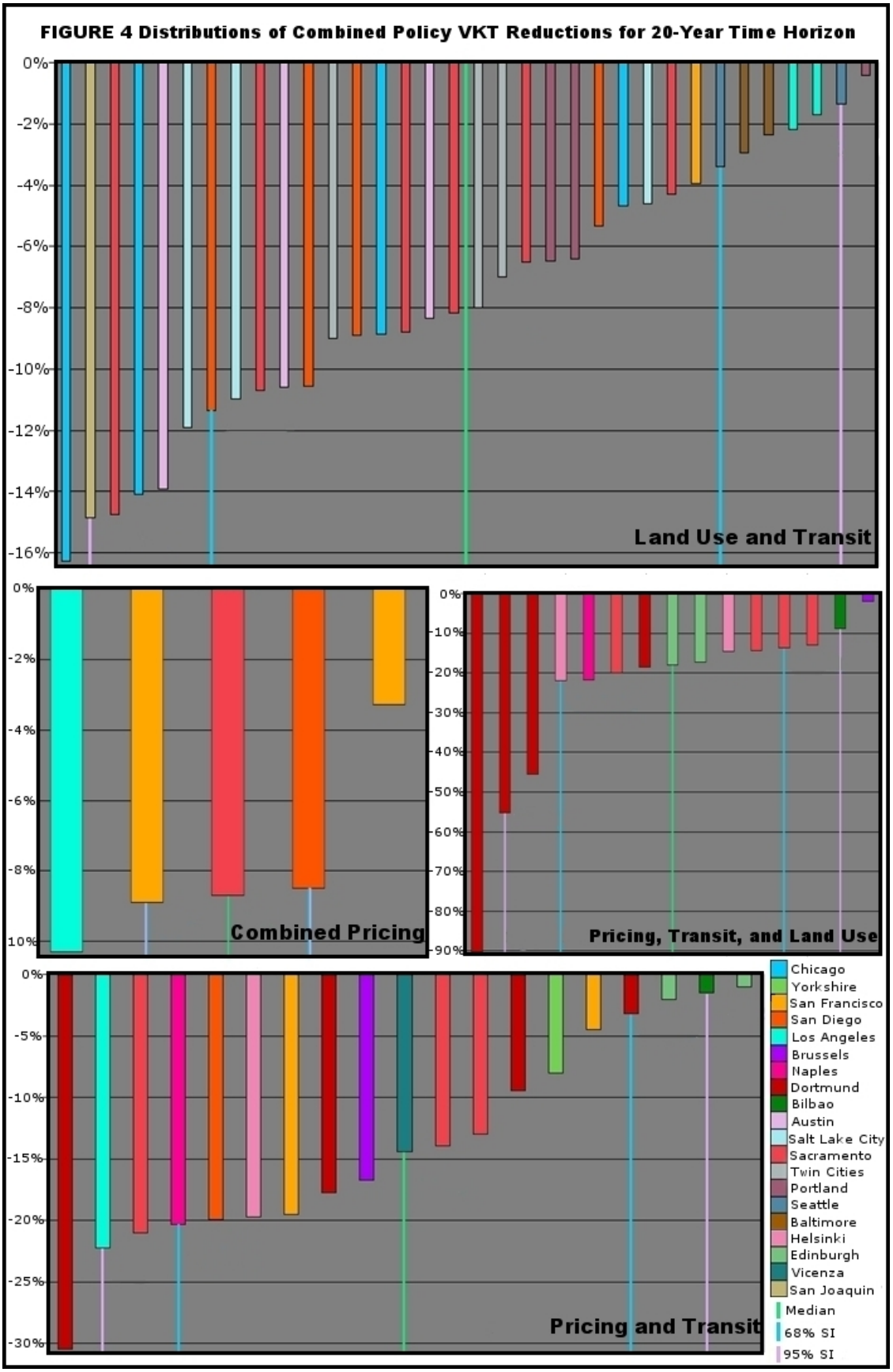


FIGURE 4 Distributions of Combined Policy VKT Reductions for 20-Year Time Horizon
0%
-2%
-4%
-6%
-8%
-10%
-12%
-14%
-16%
Land Use and Transit
0%
-2%
-4%
-6%
-8%
10%
Combined Pricing
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
Pricing, Transit, and Land Use
0%
-5%
-10%
-15%
-20%
-25%
-30%
Pricing and Transit
Chicago
Yorkshire
San Francisco
San Diego
Los Angeles
Brussels
Naples
Dortmund
Bilbao
Austin
Salt Lake City
Sacramento
Twin Cities
Portland
Seattle
Baltimore
Helsinki
Edinburgh
Vicenza
San Joaquin
Median
68% SI
95% SI

Combined Pricing

Combined pricing scenarios are available for the four major regions in California. A comprehensive auto pricing policy scenario is simulated by MTC (*4*) in the San Francisco region that includes a 100% increase in per-mile/1.6 kilometer auto operating costs, 4.9% increase in the average parking cost for work trips, and a congestion pricing charge of $0.25-per mile/1.6 kilometer on all roads when volume to capacity ratios exceed 0.9. Deakin et al. (*8*) also explore combined pricing policies, which include a region-wide congestion pricing policy with an average cost of $0.13 per mile; a region-wide employee parking pricing policy with a minimum charge of $1.00 per day; a fuel tax of $0.05 per gallon/3.8 liters; and VKT/emissions-based fees of approximately $0.01 per mile/1.6 liters. Despite the aggressive pricing measures included in the MTC scenario, the results are the lowest of all scenarios and low compared to the results of the single pricing policies, described above, which illustrates improved travel models lack of sensitivity to pricing policies relative advance models (such at the STEP model). Percentage change in VKT for the four time horizons (as illustrated in Figure 3) for these land use and transit scenarios (N=5) is as follows (SI is high to low only because of sample size):

- 10 years: median -4.5%; 68% SI -4.6% to -4.3%
- 20 years: median -8.7%; 68% SI -8.9% to -8.5%
- 30 years: median -12.8%; 68% SI -13.1% to -12.5%
- 40 years: median -16.6%; SI -17.0% to -16.3%

Transit and Pricing

In California, the comprehensive auto pricing policy scenario (described above) is added to the transit scenario for the San Francisco region (*4*). Deakin et al. (*8*) also add expanded transit to more aggressive pricing policies, including a region-wide congestion pricing policy with an average charge of $0.13 per mile/1.6 kilometers; a region-wide employee parking with a minimum charge of $3.00 per day; a fuel tax of $2.00 per gallon/3.8 liters; and VKT/emissions based fees of approximately $0.01 per mile/1.6 kilometers. In the Sacramento region, experimental studies examine a $0.05 VKT pricing policy with an aggressive transit scenario (*10*) and a more aggressive transit scenario with a gas tax ($1.00 per gallon/3.8 liters) and parking pricing ($6.00 downtown and $1.00 elsewhere) (*11*).

Outside the U.S. in Yorkshire, the congestion pricing policy (described above) is combined with increased transit frequencies and reduced transit fares (*27*). In Dortmund and Edinburgh (*26*), the combined pricing policy (fuel tax, VKT pricing, and congestion pricing), transit enhancements (increased speeds and reduced fares), and traffic auto calming scenarios is simulated with low, high, and/or extreme fuel price levels. In the PROPOLIS study, 75% increase in per mile/1.6 kilometers auto operating costs is added to a 5% reduction in transit travel times.

Percentage change in VKT for the four time horizons (as illustrated in Figure 3) for these transit and pricing scenarios (N=15) is as follows:

- 10 years: median -10.3%; 68% SI -16.6% to -1.6%; 95% SI -20.0% to -1.0%
- 20 years: median -14.4%; 68% SI -20.3% to -3.2%; 95% SI -22.2% to -1.5%
- 30 years: median -16.8%; 68% SI -28.3% to -4.7%; 95% SI -31.4% to -1.5%
- 40 years: median -17.1%; 68% SI -35.8% to -6.3%; 95% SI -39.5% to -2.0%

All the PROPOLIS and the Deakin et al. (*8*) results fall below the median within the 95% SI. See Figure 4. Again, in Deakin et al. (*8* the regions with relatively fewer modal alternatives to the auto are more strongly affected by the auto pricing policies. The Sacramento scenarios simulated by Rodier (*10*) and Johnston et al. (*11*) tend to be less aggressive than the Deakin et al. (*8*) scenarios and fall just above the median. In the STEPS study (*26*), the extremely high (Dortmund) and low (Edinbugh) fuel price scenarios fall at the ends of the distribution.

Land Use, Transit, and Pricing

Pricing, expanded transit, and land use studies are available from studies in Sacramento as well as European regions (*9, 10, 11, 25, 26*). Scenarios in the Sacramento region include very aggressive land use, transit, and pricing policies (VKT tax and parking) (*9*); VKT pricing policy with an urban reserve, subsidy for infill development, and transit expansion (*10*); a VKT pricing policy with an urban growth boundary and transit expansion scenario (*10*); and a combined pricing and transit scenario (described above) with an urban growth boundary (*11*). In the PROPOLIS study, the transit-oriented development policy is combined with a 75% increase in auto operating costs, a 50% reduction in transit fares, and a 5% increase in transit travel speeds. In Helsinki, the transit-oriented development scenario is also added to a 20% reduction in transit fares, a 5% increase in transit travel speeds, and a distance based congestion pricing charge (*25*). In Dortmund and Edinburgh (*26*), the combined land use, carsharing, telecommuting, fuel tax, congestion pricing, and traffic calming policies scenario is simulated at the low, high, and/or very extreme fuel price levels. Percentage change in VKT for the four time horizons (as illustrated in Figure 3) for these land use, transit, and pricing scenarios (N=15) is as follows:

- 10 years: median -14.5%; 68% SI -22.5% to -7.1%; 95% SI -33.1% to -4.9%
- 20 years: median -18.0%; 68% SI -21.9% to -13.7%; 95% SI -55.2% to -8.8%
- 30 years: median -21.4%; 68% SI -25.8% to -14.6%; 95% SI -70.0% to -12.9%
- 40 years: median -24.1%; 68% SI -32.8% to -16.8%; 95% SI -79.9% to -12.7%

The results below the median at the tail end of the distribution include very extreme fuel price levels and a broader range of travel demand management measures (e.g., carsharing, telecommuting, and traffic calming). See Figure 4. These policies may be considered very aggressive in the U.S. context. In general, policies rank by strength given their geographic context.

CONCLUSIONS

The results of this paper provide some order-of-magnitude estimates for policies that appear to have some promise of near term implementation. Employee parking pricing may result in approximately a 1% reduction in VKT over the four 10-year time horizons. Pay-as-you-drive insurance policy may produce reductions ranging from 4% to 5% reduction over all time horizons. Moderate cordon pricing schemes are likely to reduce VKT by 2% to 3% over time. Increased transit investment may reduce VKT by 0.1% to 1% during a 10-year time horizon, and in future 10-year increments, this may increase by 1 percentage point at the higher reduction level. Land-use-only scenarios may reduce VKT by up to 2% in the 10-year time horizon, which may increase by approximately 2 to 3 percentage points at the higher

reduction level at 10 year increments. Land use and transit scenarios may reduce VKT by 2% to 6% during a 10-year time horizon, and these figures may increase by approximately 2 to 5 percentage points at each future 10-year increments. Combined land use, transit, and pricing policy measures would bring significantly greater reductions both in the shorter and longer term time horizons.

In general, the results confirm that even improved calibrated travel models are likely to underestimate VKT reductions from land use, transit, and pricing policies. These models simply are not suited for the policy analysis demands in the era of global climate change. For example, when similar transit scenarios were simulated with the improved calibrated travel model and the integrated land use and transport model, the latter produced significantly larger results (6.0% versus 0.3%). Considering only results of scenarios representing similar policy strength in similar regions, if they were simulated with a typical or improved calibrated travel model, land use and/or transit policies tended to concentrate around the median. Despite the very aggressive pricing measures simulated by the improved travel model in the San Francisco region, the results are significantly lower than weaker pricing policies simulated in the same region using an advanced travel model.

However, even the advanced models used in the reviewed studies exhibit limitations. Scenarios simulated with integrated land use and travel models of relatively moderate policy strength in regions with high quality transit tended to show very small reductions in VKT distributed widely above the median. These integrated models use relatively large zones and thus have coarse geographic resolutions, which may overestimate the share of vehicle trips relative to walk and bike trips from transit-oriented development policies. On the other hand, the advanced travel model used in the pricing studies may fail to identify possible consequences arising from land use and transport interactions. For example, pricing policies simulated with integrated land use and travel models showed that in some cities these policies may actually increase VKT by shifting housing and employment to outer areas of the regions and increasing average shopping trip lengths. Theoretically advanced land use and travel models are needed that have fine-grained geographic resolutions and represent greater variation in the socio-economic attributes of travelers.

The results of the extrapolation analysis in this study also illustrated the challenge of implementing land use and transit strategies in regulatory framework that emphasizes near-term compliance demonstration. For example, SACOG's blueprint land use and transport plan was simulated over a 50-year time horizon; the extrapolated results, which evenly distribute VMT reduction over time, show a 4.2% reduction in VKT in the 10-year time horizon. However, a much more aggressive scenario, simulated with the improved travel model in the region over a 10-year time horizon, only showed a 0.4% reduction in VKT.

The analysis of consistent policies across different regions also provides insight into how VKT reduction may vary given existing land use densities and transit infrastructure. For example, the analysis of land-use-only policies suggest that these policies may be less effective in denser European and Washington, D.C., regions relative to the more sprawling and rapidly growing regions (e.g., Sacramento) where trend land use patterns do not take full advantage existing transit capacity. On the other hand, the fuel pricing scenarios for the four California regions (*8*) showed that regions with lower quality transit and sprawling land uses (i.e., Sacramento and Los Angeles) are less sensitive to fuel tax increases than more dense urban areas with high quality transit (i.e., San Francisco and Washington, D.C.) because they

lack alternatives to the auto for essential travel destinations. This last result has important equity implications.

ACKNOWLEDGEMENTS

The authors would like to thank the Caltrans and CARB for funding this research. In particular, we would like to thank Caltrans staff, Reza Navai and Nancy Chinlund, as well as California Air Resources staff, Kurt Karparos, Jeff Weir, and Leslie Kimura. I would also like to thank Susan Shaheen, Bob Johnston, Gordon Garry, Dan Sperling, and for their support and advice. A special thanks to Martin Brown for all his dedicated assistance to this project. The contents of this report reflect the views of the author, who is responsible for the facts and the accuracy of the data presented herein.

REFERENCES

1. Sacramento Area Council of Governments (SACOG). (2008). *Metropolitan Transportation Plan 2025*. Sacramento, CA.

2. San Diego Association of Governments (SANDAG). (2007). *2030 Regional Transportation Plan: Pathways for the Future.* San Diego, CA.

3. Southern California Association of Governments (SCAG). (2008). Draft *Regional Transportation Plan.* Los Angeles, CA.

4. Metropolitan Planning Commission (MTC). (2007) *Transportation 2035 in Motion Forecasts for the San Francisco Bay Area 2009 Regional Transportation Plan*. November.

5. Sacramento Area Council of Governments (SACOG). (2004). *Tall order forum 2004: Regional choices for our future.* Sacramento, CA.

6. Southern California Association of Governments (SCAG). (2004). *Southern California Compass. Growth Vision Report.* Los Angeles, CA.

7. San Diego Association of Governments (SANDAG). (1998). *2020 Cities/County Forecast Land Use Alternatives Summary*. San Diego, CA.

8. Deakin, Elizabeth, Greig Harvey, Randall Pozdenza, and Geoffrey Yarema. (1996) *Transportation Pricing Strategies for California: An Assessment of Congestion, Emissions, Energy, and Equity Impacts*. California Air Resources Board. November.

9. Johnston, R. A., C. J. Rodier, M. Choy, and J. E. Abraham (2000). *Air Quality Impacts of Transit and Supporting Land Use and Pricing Policies.* A Report for the U.S. Environmental Protection Agency. February.

10. Rodier, C. J. (2002). *Air Emissions Impacts of Regional Transportation and Land Development Policies*. A Report for the U.S. Environmental Protection Agency. June.

11. Johnston, R. A., S. Gao, and M. J. Clay (2005). Modeling Long-Range Transportation and Land Use Scenarios for the Sacramento Region, Using Citizen-Generated Policies. *Transportation Research Record.*

12. Bai, S., Niemeier, D., Handy, S., Gao, S., Lund J., and Sullivan D. (2007) *Integrated Impacts of Regional Development, Land Use Strategies and Transportation Planning on Future Air Pollution Emissions.* 2007 Transportation Land-use Planning & Air Quality Conference.

13. Elena Safirova, Sébastien Houde, and Winston Harrington. (2007). *Spatial Development and Energy Consumption.* Resources for the Future. Washington, DC.

14. Nelson, Peter, Kenneth Gillingham, and Elena Safirova. (2003). *Revving up the Tax Engine: Gas Taxes and the DC Metro Area's Transportation Dilemma.* Resources for the Future. Washington, DC.

15. Cambridge Systematics Inc. (CSI) et al. (1996). *Analysis of Alternatives. Making the Land Use Transportation Air Quality Connections*. Portland, Oregon. May
1000 Friends of Oregon.

16. Metro. (1998). *Region 2040: Concepts for growth*. Portland, OR.

17. Envision Utah. (1998). *Scenario Analysis: Executive Summary*. Salt Lake City, UT.

18. Governor's Office of Planning and Budget. (2000). *Strategy Analysis: Quality Growth Efficiency Tools*. Salt Lake City, UT.

19. Barnes, G. (2003). *Transportation-Related Impacts of Different Regional Land-Use Scenarios. Final Report*. Humphrey Institute of Public Affairs, University of Minnesota. Minnesota Department of Transportation. September.

20. Center for Energy and Environment (CEE), Minnesotans for An Energy-Efficient Economy, 1000 Friends of Minnesota. (1999). *Two Roads Diverge: Analyzing Growth Scenarios for the Twin Cities Region*. June.

21. ENVISION Central Texas. (2003). *Envision Central Texas Briefing Packet.* Austin, TX.

22. Baltimore Metropolitan Council (BMC) (2002). *Baltimore Vision 2030. Transportation Indicators. Baltimore Regional Partnership.* Smart Mobility, Inc. et al., November

23. Puget Sound Council of Governments (PSCOG). (1990) *Summary and Comparison between Alterantives. Vision 2020. Growth Strategy and Transportation Plan for the Central Puget Sound Region. Final Environmental Impact Statement*. September.

24. HDR (2003) *Community Connections A Transportation Vision for the Next 25 Years: Land Use Experiment Technical Memorandum No.8.* July.

25. Lautso, Kari, Klaus Spiekermann, Michael Wegener, Ian Sheppard, Philip Steadman, Angelo Marino, Roberto Domingo, Sylvie Gayda. (2004). *PROPOLIS: Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability: Final Report*, European Commission, Energy, Environment, and Sustainable Development Thematic Programme. February.

26. BCI, AUEB, ITS, JRC IPTS, KUL-SADL, LT, Novem, Speikermann und Wegener, Stratec, TIS, TRL, TRT, TTR, UPM. (2006) *Scenarios for the Transport system and Energy supply and their Potential Effects: STEPs. Work Package 4 Scenario Impacts: Deliverable 4.2.*

27. Simmonds, David, Andy Skinner, Olga Feldman, James Nicoll, and Caroline Sinclair. (2006). *Wider Economic Impacts of Transport Interventions: Final Report.* London, England.

28. Southern California Association of Governments (SCAG). (2008). *Regional Transportation Plan: Transportation Conformity Report.* Los Angeles, CA.

29. David Simmonds and Mouchel Parkman, MVA Consultancies. (2006). *Wider Economic Impacts of Transport Interventions: Final Report.* London, England: Authors.

30. Delaware Valley Regional Planning Commission (DVRPC). (2003). *Regional analysis of what-if transportation scenarios: Final Report*. Philadelphia, PA.

31. Pee Dee Regional Council of Governments (Pee Dee COG). (2003). *Planning Implications of alternate development patterns on infrastructure and existing planning policies.* Florence, SC.

32. Chicago Metropolis 2020. (2003). *The Metropolis Plan: Choices for the Chicago Region*. Chicago, IL.