EQUITY ANALYSIS OF LAND USE AND TRANSPORT PLANS USING AN INTEGRATED SPATIAL MODEL

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ABSTRACT

This paper describes a study to investigate how a spatial economic model can be used to evaluate the equity effects of land use and transport policies intended to reduce greenhouse gas emissions. The Activity Allocation Module of the PECAS (Production, Exchange, and Consumption Allocation) Model for the Sacramento region is used to simulate two scenarios for the year 2035 arising from a recent planning process, ‘Business-As-Usual’ and ‘Preferred Blueprint.’ Advanced aggregate travel models and activity-based travel models have been applied to evaluate distributions of travel time and cost effects of transport and land use policies across different socio-economic groups. But the PECAS model system, with its representation of the interactions among the transport system and the rest of the spatial economic system, enables an evaluation of the distributions of a wider range of economic impacts, including wages, rents, productivity, and consumer surplus, for segments of households, labor, and industry. In this study, the PECAS model is applied to illustrate the distributional measures that can be obtained from this type of model and to provide insights into the equity effects of different transport and land development patterns. The results show that a more compact urban form designed around transit stations may reduce travel costs, wages, and housing costs by increasing accessibility, which can lead to substantial net benefits for industry categories and lower income households. Higher income households may be net losers, since their incomes are more dependent on reduced wages, they are less willing to switch to higher density dwellings, and they are more likely to own their own home.

Key Words: Equity analysis; smart growth, transit-oriented development, land use modeling, travel demand modeling

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EXECUTIVE SUMMARY

Recent legislation in California seeks dramatic reductions in greenhouse gas (GHG) emissions. The Global Warming Solutions Act, Assembly Bill 32 (AB32) requires the reduction of GHG emissions to 1990 levels by the year 2020. Senate Bill 375 (SB375) – commonly known as 'California's anti-sprawl bill' – mandates regional GHG targets linked to land use plans and transport policies. This implicitly acknowledges the view that GHG reductions from the transport sector can only be met by changing the way communities grow, switching from low-density auto-oriented development to compact transit-oriented development[1]. The scoping plan for AB32 places emphasis on SB375 and tentatively calls for a five million metric ton reduction in CO_2 equivalents annually by 2020 from regional land use and transport plans. Enforceable GHG targets are to be initiated in 2012. However, prior to their implementation, AB32 requires analysis of the economic and equity effects of the mechanisms used to achieve these targets.

Advanced aggregate travel models and activity-based travel models have been applied in equity studies in the U.S. that evaluate the distribution of travel time and cost effects of transport and land use policies among different socio-economic groups[2]. However, newer forms of spatial economic models, which represent the interactions between the transport system and the broader spatial economic system, enable equity evaluations that encompass a wider range of economic impacts, including wages, rents, productivity, and consumer surplus, for segments of households, labor, and industry[3].

This report describes a study to investigate how one such spatial economic model was applied to evaluate the equity effects of land use and transport policies intended to reduce greenhouse gas emissions. The Activity Allocation (AA) Module of the PECAS (Production, Exchange, and Consumption Allocation) Model for the Sacramento region is used to simulate two future scenarios arising from a recent regional visioning planning process, which was conducted to cope with an estimated doubling of the regional population by the year 2050. The 'Preferred Blueprint' plan articulates levels and locations of redevelopment and new transit-oriented development linked to a list of preferred transport projects. The 'Business-As-Usual' plan continues previous land use and transport trends, and leads to a larger area of urban coverage and lower development densities. The U.S. EPA permitted the region to use the 'Preferred Blueprint' land uses in their official regional transport plan alternative and the 'Business-As-Usual' land uses in their base alternative. Similar visioning planning processes have now been conducted in all of the major metropolitan areas in California. The basic participatory planning process has now been codified in SB 375.

The application of the Sacramento PECAS model in this study demonstrates the types of equity and economic measures that can be obtained from spatial economic models. These include:

- Change in transport costs as a share of wage income;
- Change in rent and value of owned homes by income class;
- Change in wage income by labor category;
- Consumer surplus by income class; and
- Producer surplus by industry sector.

The study uses the AA module of PECAS to allocate employment and housing locations using 2035 built form from the ‘Preferred Blueprint’ and the ‘Business-As-Usual’ plans and scenario specific transport costs from the regions’ activity-based travel model. The size of the economy is held constant in the simulations. Thus, the results suggest equity effects possible given the built form and transport projects in each scenario and constant industry and household growth. Such an analysis is a valuable first step in the evaluation of land use and transport plans, because it allows planners to identify potential benefits and costs to household and industry segments. In this study, the results show that a more compact urban form designed around transit stations can reduce travel costs, wages, and housing costs by increasing accessibility, which can lead to substantial net benefits for industry and for lower income households. Higher income households may be net losers, because their incomes are more dependent on reduced wages, they are less willing to switch to higher density dwellings, and they are more likely to own their own home. This study shows how increased accessibility benefits industry directly and indirectly (e.g., through lower wages), but it does not represent how industry may grow faster in the region because of this benefit. If a separate model of region-wide economy size were to respond to the model’s producer surplus measures, then industry would grow faster, and some of the benefit ascribed to industry would be transferred to households through less wage reductions.

Once planners identify a regional plan, like the ‘Preferred Blueprint,’ that holds the promise of benefiting the regional economy and distributing benefits equitably, the next step is to evaluate the mechanisms to achieve the plan. At this point, the full PECAS model, including developer actions and economic development effects, can be used to evaluate the effectiveness of different mechanisms and their relative benefits and costs to industry and household segments. For example, developers may not “win” in the ‘Preferred Blueprint’ scenario and thus may not want to build its built-form without financial incentives, which could be costly to taxpayers, including both households and businesses.

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INTRODUCTION

Recent legislation in California seeks dramatic reductions in greenhouse gas (GHG) emissions. The Global Warming Solutions Act, Assembly Bill 32 (AB32) requires the reduction of GHG emissions to 1990 levels by the year 2020. Senate Bill 375 (SB375) – commonly known as 'California's anti-sprawl bill' – mandates regional GHG targets linked to land use plans and transport policies. This implicitly acknowledges the view that GHG reductions from the transport sector can only be met by changing the way communities grow, switching from low-density auto-oriented development to compact transit-oriented development[4]. The scoping plan for AB32 places emphasis on SB375 and tentatively calls for a five million metric ton reduction in CO_2 equivalents annually by 2020 from regional land use and transport plans. Enforceable GHG targets are to be initiated in 2012. However, prior to their implementation, AB32 requires analysis of the economic and equity effects of the mechanisms used to achieve these targets.

Advanced aggregate travel models and activity-based travel models (ABMs) have been applied in equity studies in the U.S. that evaluate the distribution of travel time and cost effects of transport and land use policies across different socio-economic groups[5]. However, newer forms of spatial economic models, which represent the interactions between the transport system and the broader spatial economic system, enable equity evaluations that encompass a wider range of economic impacts, including wages, rents, productivity, and consumer surplus for segments of households, labor, and industry[6].

This study describes an application of this newer form of spatial economic model, the PECAS (Production, Exchange, and Consumption Allocation) model of the Sacramento region, to demonstrate the range of equity impacts available from such models and to provide insight into possible equity and economic effects of a land use and transport plan designed to reduce GHG emissions. The study begins with an outline of the legislative and administrative requirements for equity analyses of federally funded transport activities and reviews the literature on the state-of-the-practice of equity analyses in regional transport planning in the U.S. This is followed by a description of the scenarios simulated in the study. Next, the PECAS Model of Sacramento and its study application are presented. Finally, the results of equity analysis are discussed and conclusions from the study are drawn.

BACKGROUND

Requirements for Transport Equity Analysis

The U.S. Executive Order 12898 (1994) codified a renewed concern about the effects of the government's activities on minority and low-income populations. It states that "each federal agency shall make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionally high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations." The Order emphasized existing nondiscrimination laws and requirements including Title IV of 1964 Civil Rights Act and the 1969 National Environmental Policy Act. Equity analyses were relatively common in the 1970s, but had largely ceased through the 1980s and into the late 1990s[7].

The renewed concern for the equity impacts of government actions had strong resonance in the transport policy arena. It is a common view that the expansion of the interstate highway system starting in the 1950s exacerbated the sorting of urban America into inner cities dominated by low-income and minority groups, suburbs with more affluent white populations, and increasingly separate housing and employment locations. It is also observed that there has been a disproportionate location of unwelcome transport infrastructure (e.g., highways) through low-income and minority communities since the 1980s[8].

Not surprisingly, the federal surface transport acts of the 1990s both (a) emphasized the importance of citizen participation in regional transport planning and (b) funded programs to improve the mobility of disadvantaged and low-income populations. At the end of the decade, the United States Department of Transportation (USDOT) and the Federal Highway Administration (FHWA) issued Orders (5610.2 and 6640.23, respectively) that articulated three key environmental justice principles to be incorporated into the transport planning and decision-making process:

- To avoid, minimize, or mitigate disproportionately high and adverse human health and environmental effects, including social and economic effects, on minority populations and low-income populations.
- To ensure the full and fair participation by all potentially affected communities in the transport decision-making process.
- To prevent the denial of, reduction in, or significant delay in the receipt of benefits by minority and low-income populations.

State transportation departments and metropolitan planning organizations (MPO) – the functional conduits for significant infusions of federal transport dollars to states, cities, and counties – were then charged with developing data, tools, and measures to evaluate the achievement of these principles in their transport planning processes. For example, USDOT asks state transportation departments to "develop the technical capability to assess the benefits and adverse effects of transportation activities among different population groups and use that capability to develop appropriate procedures, goals, and performance measures in all aspects of their mission[9]." They also urge MPOs to "identify residential, employment, and transport patterns of low-income and minority populations so that their needs can be identified and addressed, and the benefits and burdens of transport investments can be fairly distributed[10]." However, USDOT has generally left it to the states, MPOs, and local jurisdictions to develop specific methods and measures to evaluate the equity effects of transport investments, policies, and plans[11].

Practice of Transport Equity Analyses

Today, 15 years after the issuance of Executive Order 12898, the literature documents MPOs' attempts to evaluate environmental justice and equity effects in transport plans as well as various challenges to such analyses. Sanchez and Wolf[12] conducted a survey of 50 large MPOs and found that several used geographic analysis tools to map the location of transport improvements and the spatial distribution of low-income and minority households to "illustrate the distributional equity of MPO plans" (p.12). Such analyses are a start, but they fail to adequately capture the benefits and costs of new transport projects for low-income or minority populations dispersed geographically, over both the short-and long-term, because of distortions arising from geographic and demographic aggregation, incomplete representation of modal travel time and cost[13], and limited representation of the role and impact of the transport system within the larger spatial economic system[14].

Some current aggregate travel models may be used by MPOs to take their geographic analysis of equity impacts one step further. Models that consider segments of households (e.g., auto ownership and income groups) can be used to calculate the distribution of transport project and policy impacts – including changes in travel times and costs– across household segments[15].

The new generation of activity based travel models (ABMs) that use microsimulation with synthetic populations can be used to calculate the distribution of transport impacts across the full range of characteristics included in the population synthesis[16]. Deakin and Harvey[17] developed an early microsimulation model (STEP) that was used to evaluate the distributional effects of auto pricing policies in the major regions of California. More recent versions of the STEP model have been applied for equity analyses in Baltimore, Maryland and Las Vegas[18]. Most recently, the San Francisco ABM was used to evaluate how the travel time savings arising with a proposed transport plan would be distributed among specific communities of concern[19].

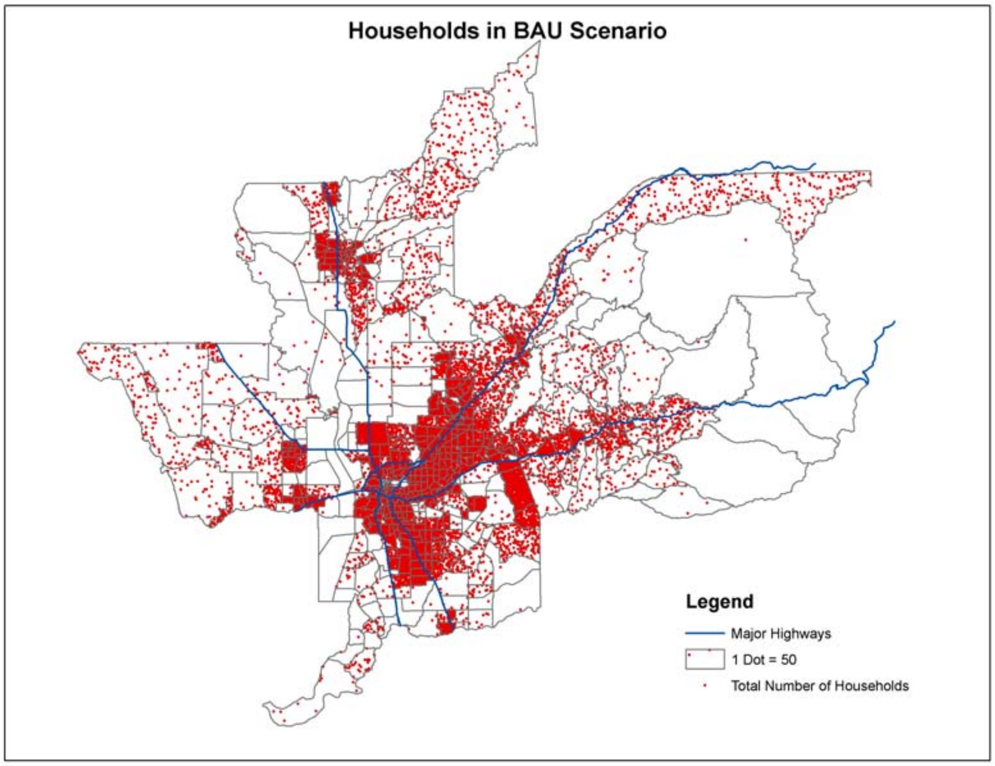
These new ABMs can be used to calculate the distributions of travel time and cost impacts. But calculating the distributions of wider impacts on the economy – including wages, rents, productivity and/or changes in consumer surplus, require models that include explicit representation the transport system and the rest of the spatial economic system[20]. The integration of ABMs and recent generations of land use models, such as PECAS, will allow analysts to answer a broader range of questions about the equity effects of transport and land use plans and policies.

SCENARIOS

The transport and land use scenarios simulated in this study were generated as part of the region's MPO's (Sacramento Area Council of Governments or SACOG) 'Blueprint Project,' which was a public-participation planning process undertaken to develop a common land use and transport vision for the region. A total of over 5,000 residents joined in the effort to develop a plan to cope with the estimated doubling of the regional population by the year 2050. The outcome, the 'Preferred Blueprint (PRB),' articulated levels and locations of redevelopment and new transit-oriented development linked to a list of preferred transport projects. This was contrasted with the 'Business-As-Usual (BAU)' plan that continued previous land use and transport trends, and led to a larger area of urban coverage and lower densities of urban development relative to the PRB. The U.S. EPA permitted SACOG to use land use and transport components of the PRB plan in their official regional transport plan alternative and the BAU in their no-build scenario as part of their air quality conformity process. Similar Blueprint Projects have now been conducted in all of the major metropolitan areas in California. The basic participatory planning process has now been codified in SB 375.

Currently there are approximately one million jobs and 800,000 housing units in the Sacramento Region. This is forecasted to grow by an additional 535,000 jobs and 433,000 housing units. The location and intensity of household and employment location is illustrated in Figure 1 and 2 for the BAU and the PRB scenarios respectively. In the BAU scenario, transport investments continue to focus on highway expansion and land development persists in low-density, auto-dependent patterns. In the PRB scenario, transport investment emphasizes improvement in transit, sidewalks, and bike lanes over highway expansion. Significant housing development is located near existing employment centers in downtown Sacramento, Rancho Cordova, and Roseville to improve the overall jobs to housing balance and concentrate growth near high quality transit service. As documented in Figure 3, there is a relatively large increase in multi-family dwelling units (10.9%) and decrease in luxury single-family dwelling units (6.3%); however, total single-family dwelling units decline by only 1.9%. The PRB scenario assumes that local jurisdictions honor their Blueprint Plan commitments through local land use controls.

Of interest in this study are the distributions of these impacts, and the related further effects on different segments of the economy and among different groups. These distributions are explored with the Activity Allocation module (AA) of the PECAS model of the Sacramento region as described in the next section.



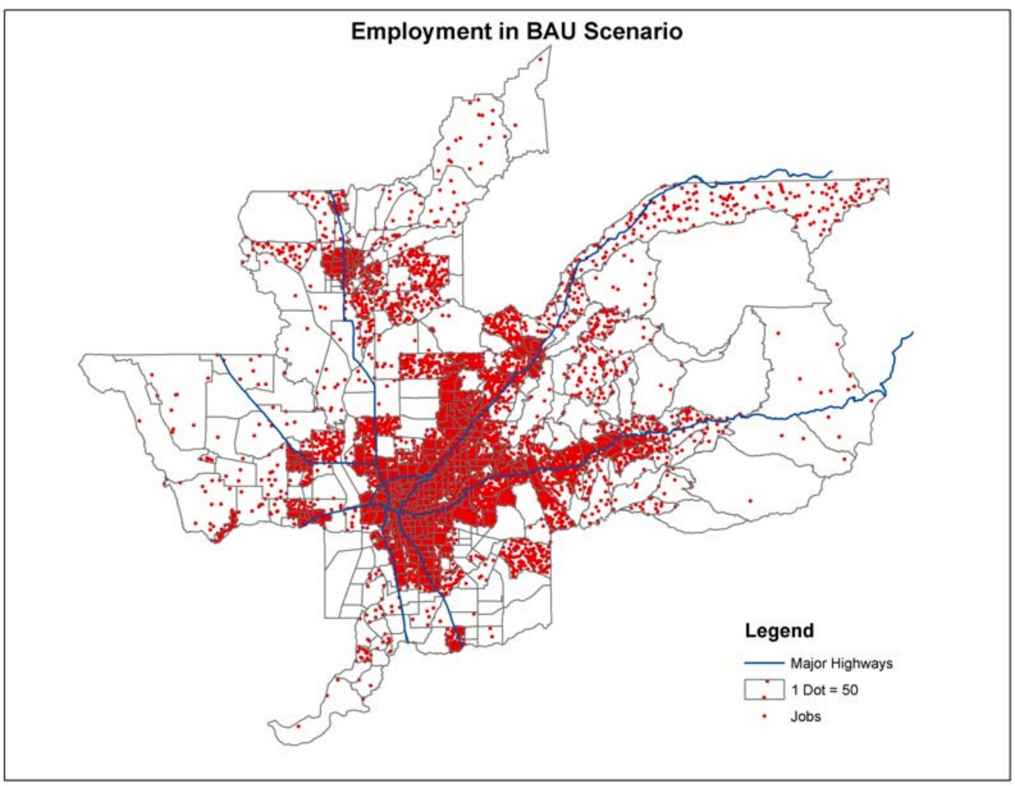


FIGURE 1 Household and employment location in the BAU scenario

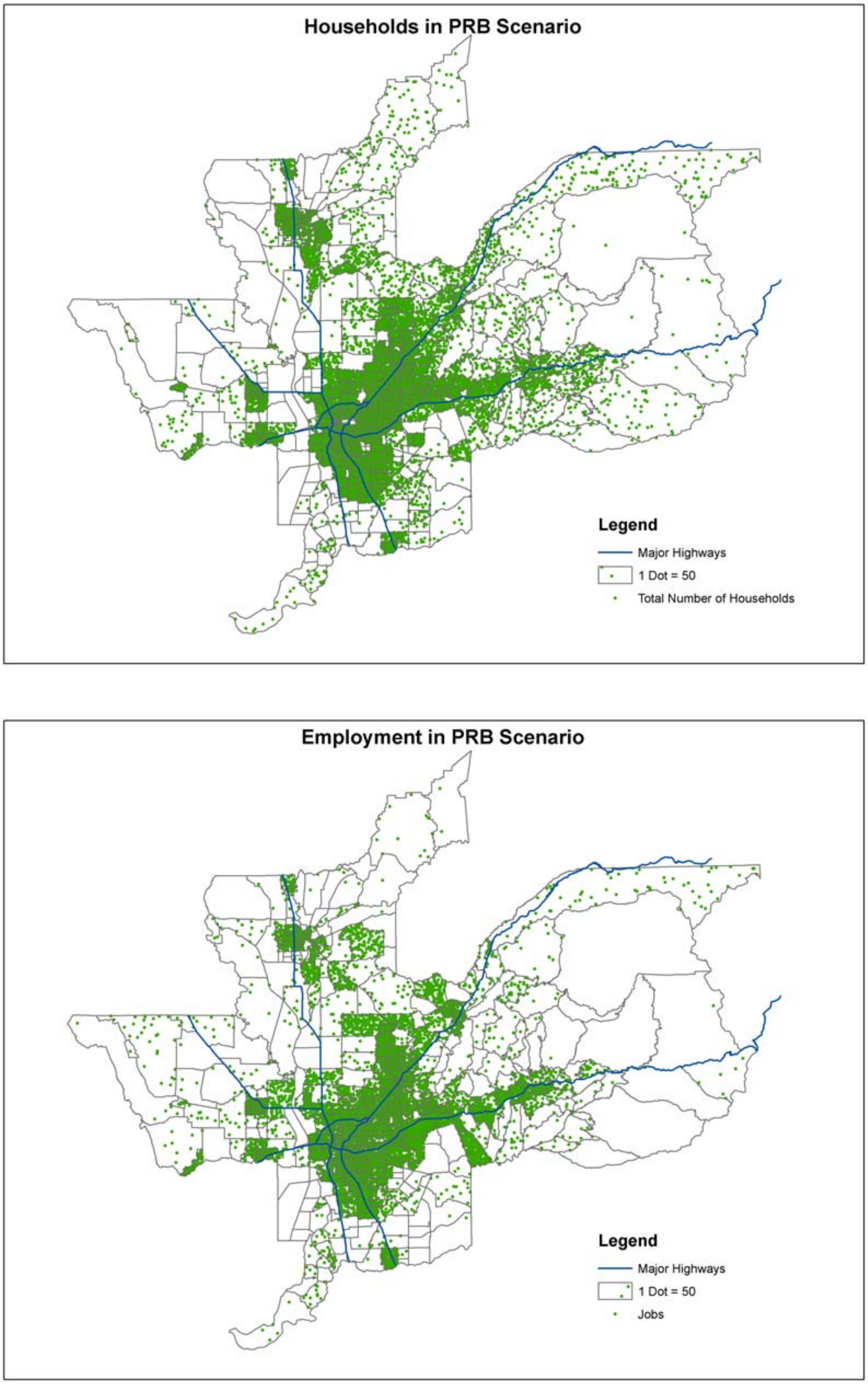
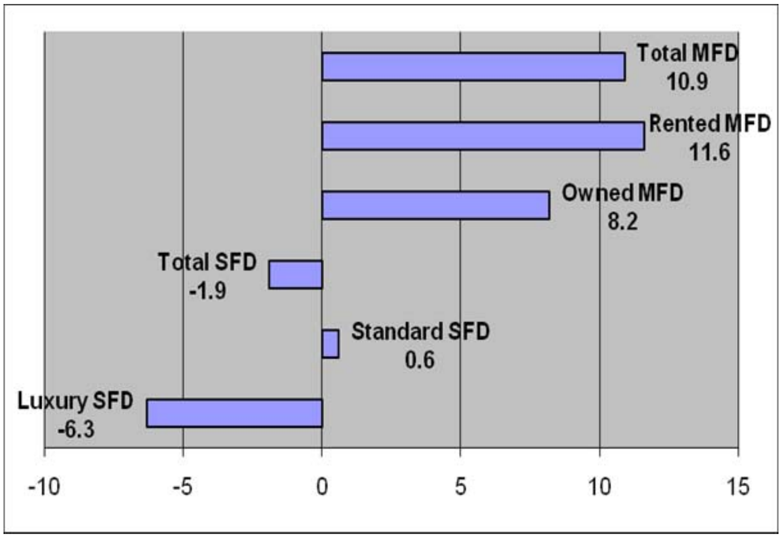


FIGURE 2 Household and employment location in the PRB scenario

FIGURE 3 Percent Change in Dwelling Units by Type Between the BAU and the PRB



SFD=single family dwelling units; MFD=multi family dwelling units

METHODS OF ANALYSIS

The PECAS Model of Sacramento

In this study, the AA module of the PECAS model for the Sacramento region is used to explore the distributions of impacts from the PRB scenario relative to the BAU scenario for the year 2035. PECAS is a generalized approach for simulating spatial economic systems. It is designed to provide a simulation of the land use component of land use transport interactive modeling systems.

PECAS stands for Production, Exchange, and Consumption Allocation System. Overall, it uses an aggregate, equilibrium structure with separate flows of exchanges (including goods, services, labor, and space) going from production to consumption based on variable technical coefficients and market clearing with exchange prices. It provides an integrated representation of spatially distinct markets for the full range of exchanges, with the transport system and the development of space represented in more detail with specific treatments.

Flows of exchanges from production to exchange zones and from exchange zones to consumption are allocated using nested logit models according to exchange prices and transport generalized costs (expressed as transport utilities with negative signs). These flows are converted to transport demands that are loaded to transport networks in order to determine congested travel utilities. Exchange prices determined for space types inform the calculation of changes in space attractiveness thereby simulating developer actions. Developer actions are represented at the level of individual land parcels or grid cells using a microsimulation treatment. The system is run for each year being simulated, with the travel utilities and changes in space for one year influencing the flows of exchanges in the next year.

Basic Model System Modules

PECAS includes two basic modules that are linked together with two other basic modules to provide a representation of the complete spatial economic system. The set of four basic modules includes:

- Space Development module (SD module): This is one of the two PECAS modules. It represents the actions of developers in the provision of different types of developed space where activities can locate, including the new development, demolition, and re-development that occurs from one point in time to the next. This developed space is typically floor space of various types and is called “space” in the PECAS framework.
- Activity Allocation module (AA module): This is the other of the two PECAS modules. It represents how activities locate within the space provided by developers and how these activities interact with each other at a given point in time.
- Transport Model (TR module): This is one of the “non-PECAS” modules. It represents the transport system connecting locations, including at a minimum a transport network, the transport demands that load onto this network (as a result of the economic interactions

represented in the AA module) and the congested times and costs for interactions between locations arising from the loading of these demands.

- Economic Demographic Aggregate Forecasting Model (ED module): This is the other of the "non-PECAS" modules. It is some form of model or approach used to develop aggregate economic forecasts for the study area being modeled. Typically, these forecasts include projected numbers of households or population by category and employment by type (as indications of expected economic activity) for specific points of time in the future. This model or approach may be able to adjust its forecasts in response to information from the AA and SD modules – as is represented in the descriptions included here – or it may provide a static set of forecasts. It may even be the case that there is no model per se that is available, merely the forecast values for the study area. It is also possible to use an extended form of the PECAS AA module to develop such aggregate forecasts – by making some specific assumptions about the relative contributions to the study-area economy from inside and outside the study area. For the descriptions included here, all of these possibilities are included in the single "ED module" designation that is used.

The four basic modules listed above are linked together with information flows as shown in Figure 4. This linked system works through time in a series of discrete, fixed steps from one point in time to the next, with the AA module running at each point in time and the SD module considering the period from each point in time to the next. In general, the fixed steps can be of any duration, but one-year time steps are recommended since they allow an appropriately quick response of land developers in the SD module to the space prices established in the AA module.

Ideally, the transport model (TR module) used to calculate the congested travel times and associated transport utilities is run for each year, after the AA module has been run for that year. If the overall model run times are too long and travel conditions are relatively stable, the TR module can be run less often to save computation time.

FIGURE 4 Modules and Information Flows Simulating Temporal Dynamics

The study area is organized into a set of land use zones (LUZs). In the AA module activities locate in these zones and commodities flow between them. Ideally these zones match the transport zones (TAZs) used in the TR module or are aggregations of whole numbers of adjacent TAZs. The connectivity among the LUZs is based on the representation provided by the TR module, where the TR module establishes congested network times and costs and associated transport utilities that the AA module uses in its consideration of the interactions between the LUZs in the next time period.

The land in each LUZ is further partitioned into smaller cells or parcels. The parcels can correspond to actual legal parcels or portions of legal parcels. The cells can be formed by superimposing a grid pattern over the land. The term "parcel" is used to refer to both cells and parcels in the descriptions below. In the microsimulation version of the SD module, developed space (called "space") is located on these parcels, with only one type of space on a given parcel, and the total quantity of each type of space in the LUZs is the sum of the quantities on the parcels in the LUZs.

When an activity in the AA module is located in a zone, it consumes space in the zone, at rates consistent with the production technology or technologies it is using in the zone. Land is used in the provision of the space in the zone as an input to the development process, as represented in the SD module.

Activity Allocation Module

The AA module is an aggregate representation. It concerns quantities of activities, flows of commodities and markets with aggregate demands and supplies and exchange prices. Activities are located in LUZs. Activities produce commodities and then transport and sell these commodities; they also consume commodities after buying them and transporting them. There are different types of activities, including industrial sectors, government and households. Activity quantities can be measured in values (e.g., dollars of business repair industrial activity) or numbers (e.g., number of households with high income and two or less persons). The AA module allocates the study-area wide quantity of each activity among the LUZs as part of its allocation process.

Commodities flow at specific rates from where they are produced to where they are exchanged (from seller to buyer), and then from where they are exchanged to where they are consumed. Commodities are grouped into categories, including different types of goods and services, labor, and space. Commodities other than space in general flow across zone boundaries. Space is restricted in that it is "non-transportable" and must be exchanged and consumed in the LUZ where it is produced – which means that the space commodity categories receive some special additional treatments in PECAS as described further below. Commodity flows are measured in values per unit time (e.g., dollars of management services per year) or numbers per unit time (e.g., tons of coal per month). The movement of these flows of commodities from where they are produced to where they are consumed is the economic basis for travel and transport in the modeling system. It is the travel conditions – the distances, costs, times and associated (dis)utilities by mode – for the movement of these commodities that results in the influence of the transport system on the interactions among activities and the attractiveness of locations for activities. The AA module allocates the flows of commodities from production location LUZ to exchange location LUZ and from exchange location LUZ to consumption location LUZ, and finds the corresponding set of prices at the exchange location LUZ that clears all markets, as part of its allocation process.

Activities produce commodities and consume commodities in the production process according to the technology they use. More specifically, an activity quantity in a given LUZ produces commodities at specific rates per unit of activity and consumes commodities at specific rates per unit of activity according to the technology being used by the activity. One or more "technology option" alternatives are defined for a given activity. Each of these technology options is a specific vector of production and consumption rates for different commodities per unit of the activity, representing a particular technology option for the production process available to the activity. The AA module allocates the quantity of the activity in each LUZ among these "technology options" as part of its allocation process.

The allocation process in the AA module uses a three-level nested logit model with a nesting structure as shown in Figure 5.

FIGURE 5 Three-Level Nesting Structure Used in AA Module Allocations

At the highest level of the nesting structure, the study-area total quantity of each activity is allocated among the LUZs. At the middle level, the quantity of each activity in each LUZ is allocated among the available technology options. At the lowest level, there are two logit allocations for each commodity in each LUZ. The first is an allocation of the produced quantities among the various exchange locations where they are sold to other activities. The second is an allocation of the consumed quantities among the various exchange locations where they are bought by other activities.

At the lowest level, the utility of each exchange location alternative is influenced by the price at the exchange location and the characteristics for transporting the commodity to or from the exchange location. The composite utility values from these two lowest-level logit models are called the “buying utility” and the ”selling utility” for the commodity in the LUZs. They are used as the transport-related inputs in the middle-level for allocating the activities in the LUZs among the relevant technology options. The composite utility value for the range of technology options considered at the middle-level for an activity in a LUZ is part of the location utilities used at the highest-level.

The spatial aspects of the AA module allocation process are illustrated in Figure 6. Buying and selling allocations link through the exchange locations to establish commodity flows from production to consumption locations in the LUZs.

The exchange locations are location-specific markets for commodities, where sellers sell commodities to buyers. Prices are established at exchange locations so that the quantity bought equals the quantity sold – thus the spatial allocation procedure in the AA module assumes a short-run market equilibrium in commodities.

AA Utility Equation

Since AA is based on random utility theory, it is based on a "utility function" describing the attractiveness of each option implied in Figure 5. For one unit of activity type $a \in$A, where A consists of the full set of types of activity under consideration, including households, business establishments, and other institutions, consider the joint choice of:

- Location, $l \in$L , that is the home location for the unit; being residential location for households, or establishment location for business establishments and other institutions (the top level of Figure 5);
- Technology Option, $p \in P^a$, described by a set of technical coefficients $\alpha_p = \{\alpha_{p1}, \alpha_{p2}, ... \alpha_{pn}, ..., \alpha_{pN_p}\}$ and a corresponding list of commodities $c_p = \{c_{p1}, c_{p2}, ..., c_{pn}, ..., c_{pN_p}\}$, each $c_{pn} \in$C. Each α_{pn} describes how much of commodity c_{pn} is produced (or consumed, if α_{pn} is negative) per unit of activity a, with indices n from 1 through N_p. P^a is the set of allowed Technology Option alternatives for activity a (the middle level of Figure 5); and
- Exchange location, $e_n \in E_c$, for each commodity c_{pn} produced or consumed, being the choice of where to purchase, sell (or otherwise exchange as is the case for unpriced commodities) the quantity $|\alpha_{pn}|$ (the bottom level of Figure 5).

The utility of this joint choice is given by:

$$U^a_{lpe_1e_2 \dots e_n} = V_l^a + \varepsilon_l^a + V_p + \varepsilon_{lp} + \sum_{n=1 \cdots N} |\alpha_{pn}| s_{pn} \left(V_{e_n l} + \varepsilon_{e_n lp} \right) \quad (1)$$

where:

V_l^a	=	the measurable component of utility associated with the location l and activity a
ε_l^a	=	a random component of utility associated with location l and activity a
V_p	=	the measurable component of utility associated with the technology option p
ε_{lp}	=	a random component of utility associated with the technology option p and location l
α_{pn}	=	the technical coefficients associated with technology option p as described above
s_{pn}	=	scaling adjusting associated with technical coefficient α_{pn} (non-negative and usually 1.0)

$V_{e_n l}$ = the measurable component of utility associated with exchanging the commodity c_{pn} associated with α_{pn} in exchange location e_n given location l and technology option p

$\varepsilon_{e_n lp}$ = a random component of utility associated with exchanging the commodity c_{pn} at exchange location e_n given activity location l and technology option p.

The terms V_p and V_l^a are normally established in calibration, and do not change between years or between scenarios. Thus core policy-sensitivity of the model is in the $V_{e_n l}$ terms. Each of the $V_{e_n l}$ terms contains three subterms:

- the cost of transporting commodities to or from the exchange zone,
- the prices of commodities in the exchange zone, and
- the relative size of the exchange zone.

Since prices are determined endogenously to clear the spatial markets, the dominant policy-related inputs to AA involve transport costs and measures of zone size (normally quantities of space from SD), and the total quantity of each activity specified as a policy control total to be allocated according to equation 1 and Figure 5.

See Hunt and Abraham[21] and Abraham and Hunt[22] for complete documentation of the theoretical formation and calibration methods of the PECAS model.

Implications

The intention of this study was not to forecast built form and land use patterns, but rather to use the AA module of PECAS to evaluate patterns of built form. Since AA is based on rigorous application of nested and additive logit theory[23] the top level expected maximum utility measure (the "logsum") at the top of Figure 5 is a representation of the full composite utility (the Consumer Surplus in the case of household activities) of all the choices of where to locate, the quantity of interactions to undertake, and the transport costs, prices, and opportunities for each of these interactions. Equation 1 is the utility of one particular option in the model regarding the choice of location, technology, and exchange locations. The expected maximum utility of choosing from amongst all the options of location, technology, and exchange location options provided by the built form and transport system is calculated by the AA module and is available as an output benefit measure for each activity in the model.

In particular, for households in the Sacramento model, the top level expected maximum utility takes into account the transport costs for all of the households' interactions, the relative prices for every category of good, service, labor, and housing, as well as the willingness and ability of households to shift their location, their housing type, their occupation, and the destination of all of their trips.

Benefits of increased opportunities are considered and weighted against transport costs and other costs in this output measure from PECAS: if a policy or scenario reduces opportunities at any level of Figure 5, costs may be reduced (because opportunities to spend money or travel time have been reduced) but benefits will also be reduced. Benefit calculation with transport models alone, or with transport models with land use models which are less rigorously consistent, can fail in this aspect: for instance closing down congested roads.

The PECAS model allows this type of consistent rigorous analysis using random utility theory applied consistently to spatial choices for both supply and demand of goods, services, labor, and space in a complex economy.

This study uses the PECAS AA module to evaluate built form scenarios and transport scenarios. A transport demand model was used to forecast transport level of service. The SD model was not used in this study – as a result the input to the scenario is not a set of policies designed to shape future built form and land use, but rather a specific future configuration of built form. AA was used to allocate quantities of industry and households into the assumed space, with AA generating prices for space in each land use zone along with prices for every other commodity in each land use zone.

Calibration of the PECAS AA Module

Calibration of the PECAS model has been ongoing as part of SACOG's model improvement program[24.] However further calibration is always possible given additional data and additional resources, especially in the case of PECAS because its scope is very deep, covering the whole of the spatial economy.

Additional calibration efforts were performed that were specific to the benefit analysis. Transport cost functions, which translate travel model zone-pair travel attributes into disutility measures for each commodity in PECAS, were refined using improved data from the travel models, wage data by occupation, and from goods movement studies. The commodity flow distances were calibrated to trip length information, to establish the logit dispersion parameter in the models of buying or selling for each commodity. These dispersion parameters control the random term in the flow allocation (they are inversely related to the standard deviations of the $\varepsilon_{e_n lp}$ terms in equation 1). It is important to establish these parameters before undertaking benefit analysis, because they establish the value associated with variety in each commodity (recall that the other terms at this level of the model reflect price, transport cost/disutility, and zone size). In the case of commodities with low dispersion parameters, additional opportunities for interaction are very valuable, even if they are poorly priced or a long distance away.

The choice model of household lifestyle (the middle level of Figure 5, for household activities) was calibrated based on observed patterns of behavior from the US Census Public Use Microsample (PUMS). This established the tendency of certain types of household to use certain types of housing and make certain types of labor, and the willingness (and/or the ability) to shift occupation and housing depending on conditions. Dispersion parameters for the higher level choices in Figure 5 were refined with the help of the additive logit theory in Abraham and Hunt[25] which was not available when the Sacramento PECAS model was first developed.

Other elements of the model that were further calibrated include the treatment of imports and exports (more explicit in quantity and direction than in Abraham et al.[26]), and the floorspace short term supply function (which allow large vacancy rates if space demand in any zone is uncharacteristically low).

See Abraham et al.[27] for a description of the Sacramento PECAS model, its initial calibration and its planned ongoing calibration. It describes how the make and use coefficients (the α_{pn} in equation 1) were established for the various activity-commodity combinations from economic "input-output" relationships and Census data, the classification systems applied to determine the categories of activities, commodities, and land use zones (LUZs), the strategies for establishing both alternative specific constants for particular production options (p in equation 1) and location options (l in equation 1), and strategies for calibrating the parameters controlling the size of the random components in equation 1.

Abraham et al.[28] also describes the development and calibration of the SD module, which would be used if land use policy over time were being used as an input to the model. (In this study land use patterns were being evaluated, not land use policy.)

2035 Input Data

SACOG provided employment, household, and land inputs for the BAU and PRB scenarios in the year 2035 that were used in their ABM (SACSIM) simulations. Employment and household location were not used directly by PECAS – since one of PECAS's functions is to allocate employment and households. Rather, the expectations regarding employment and household locations from the two scenarios were used to develop the inputs on built form (or floorspace) that would normally be provided by PECAS's SD module. A full version of PECAS, with both SD and AA, would predict both the location of employment and households, and the location of built-form, with policy variables (such as zoning regulations) as inputs. A travel model, on the other hand, requires employment locations, household locations and built-form as inputs. In this work, a middle road was taken, with built-form as an input, while employment and household locations are determined by AA and thus output floor space varied from input floor space.

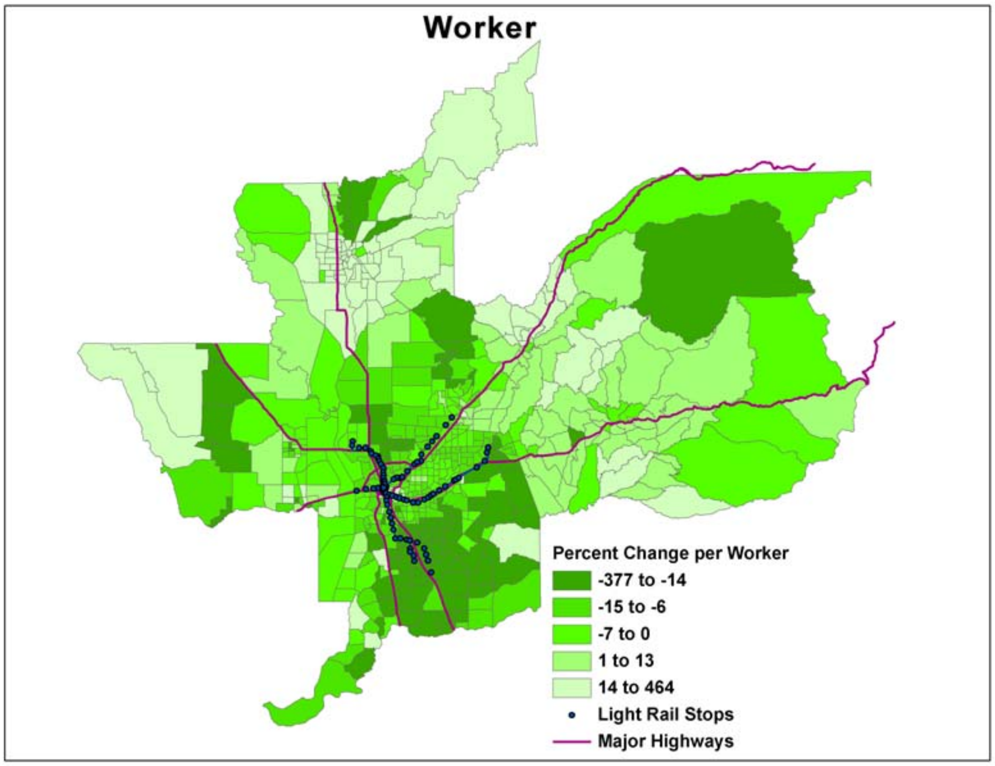
Zone-to-zone travel times and costs (generalized transport costs or logsums) for all modes by trip purpose were obtained from SACSIM and were consistent with input floorspace for each scenario. Zone-to-zone travel times and costs were aggregated to PECAS zones using an approach that weighted values by trip frequency. Total economic growth by activity category was assumed to remain constant for both scenarios simulated with the PECAS AA model. Output zonal floorspace for industry and households both varied by less than 5% of input floorspace, and thus subsequent iterations of SACSIM and the AA module were deemed unnecessary.

The analysis of dwelling unit rents and values as well as the consumer surplus measure include changes in imputed rents for owner-occupied dwellings based the 2001 Current Population Study, which provides percentages of owner occupied, rented, and occupier paid no cash rent by income quintile.

RESULTS

The change in average transport cost from the BAU to the PRB scenario is illustrated in Figure 7. The worker transport map shows the change in transport costs for commuting to work from a home zone. The industry transport map shows the change in conducting business from the zone in which a business is located. The PRB scenario provides relatively large reductions in transport costs compared to the BAU scenario, but not all zones have reduced costs. In general, transport costs tend to be reduced along major highway and transit corridors. Industry transport costs increase in the outlying eastern, northwest, and southwest areas of the region. Worker transport costs are reduced in the central urban area of the region as well as in suburban areas linked to major business centers.

The distribution of the change in transport costs across worker categories is presented in Table 1. Each worker group experiences a reduction in average annual transport costs ranging from 6.6% to 15.9%. Transport cost as a share of income across worker groups is reduced by a half a percentage point from the BAU to the PRB scenario. In general, the size of the benefit is determined by the work groups' value of travel time as well as travel distance and time savings. For example, education workers benefit least from the PRB scenario ($170 reduction in average annual transport costs) and non-retail sales workers benefit most ($426 reduction in average annual transport costs). Education workers have relatively low wages and values of times. In addition, schools tend to be located near residential areas and not in major business centers where much of the improvement in accessibility is focused in the PRB. As a result, education workers experience comparatively fewer transport benefits and these are valued at a relatively low level. On the other hand, non-retail sales workers tend to have high salaries and values of time, and travel extensively as part of their job. As a result, non-retail sales workers experience relatively more reductions in transport costs and value it highly.


Worker
Percent Change per Worker
-377 to -14
-15 to -6
-7 to 0
1 to 13
14 to 464
Light Rail Stops
Major Highways

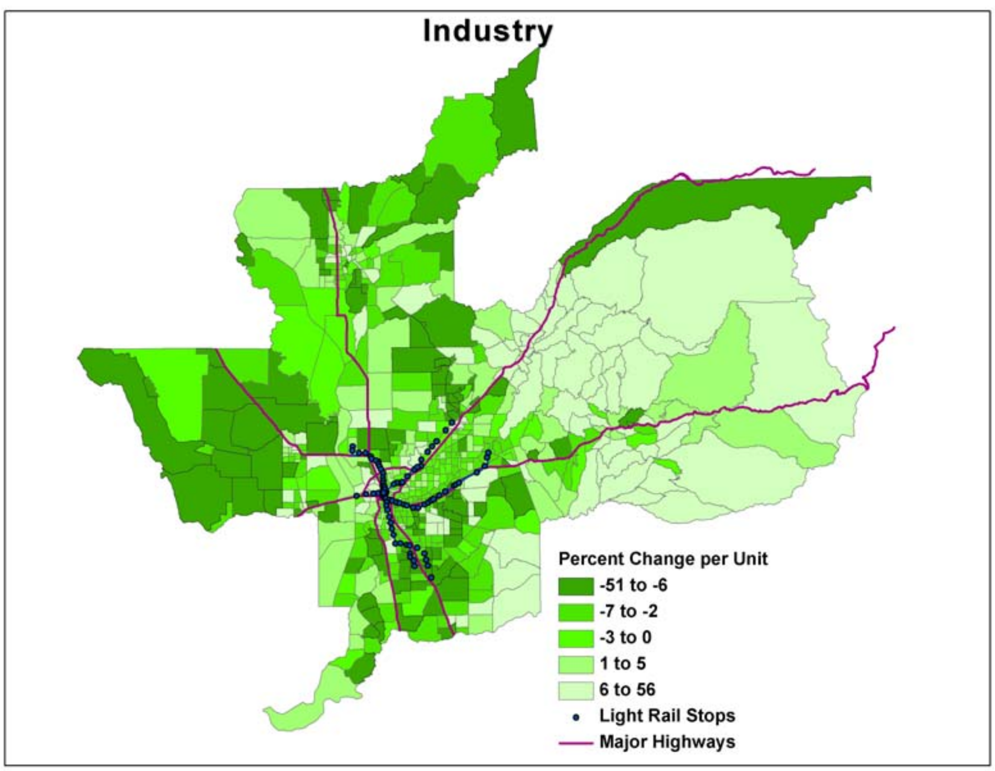

Industry
Percent Change per Unit
-51 to -6
-7 to -2
-3 to 0
1 to 5
6 to 56
Light Rail Stops
Major Highways

FIGURE 7 Percentage change in annual worker and industry transport cost from the BAU to the PRB scenario

TABLE 1 Average Annual Transport Cost (TC) by and across Labor Group(s) (2000 U.S. nominal dollars)

Labor Group	Change in TC (dollars)	Percentage Change in TC	BAU: TC as Income Share	PRB: TC as Income Share
Agriculture	-326	-11.8	6.0	5.2
Construction	-303	-11.1	5.8	5.2
Educators	-170	-6.6	5.8	5.6
Entertainers	-372	-14.2	5.7	5.0
Food	-250	-9.9	5.5	5.0
Health	-306	-11.9	5.3	4.8
Maintenance & repair	-300	-11.1	5.9	5.3
Managers	-339	-13.0	5.5	4.8
Non-retail sales	-426	-15.9	5.7	4.9
Office & administrative	-323	-12.7	5.4	4.8
Production	-293	-10.9	5.9	5.3
Professionals	-351	-13.4	5.4	4.8
Retail sales	-256	-9.9	5.5	5.0
Service	-306	-12.0	5.4	4.9
Transport	-281	-10.6	5.9	5.4
Total	**-307**	**-11.8**	**5.5**	**5.0**

Average annual rents also decline in the region in the PRB scenario relative to the BAU (see Table 2). As described above, the total distribution of housing units by type in the PRB scenario represents a 10.9% increase in the number of multi-family units and 6.3% reduction in luxury single family dwelling units. Because of the greater supply of multi-family housing units, which are typically less expensive, average annual rents, for all but the highest income classes, are reduced in the PRB scenario. On average, rents are reduced by $1,526, which is a 6.1% reduction. The three lowest household income classes experience reductions in annual rent ranging from $1,248 to $1,702 (percentage reductions from 6.4% to 8%). Note that according to federal government standards, the lowest household income class (less than $10,000 a year) is considered to be extremely low income (or approximately 30% of the Sacramento area median income or AMI), $10,000 to $19,000 is very low income (or approximately 50% of AMI), and $20,000 to $39,000 is low income (or approximately 80% of AMI). The middle income classes ($20,000 to $99,000) see the greatest total reduction in rent. The highest income class ($200,000 and above) experiences an increase in rent ($505), which is a 1.0% increase. The second highest income class experiences the lowest reduction in rent ($309 and 0.7%).

In sum, it appears that the preference among the highest income households for larger homes and lots, the relatively diminished supply, and higher transport costs in the outer suburban areas where such homes are typically located have driven up average rents for the highest income class and mitigated declines relative to the regional mean. It also appears that the low and middle income household categories have benefited from the significantly increased supply of multi-family housing and lower transport costs in the areas in which they are located (i.e., the inner suburbs and central business areas). Upper income households are also more likely to be owner-occupied, and thus receive less benefit from reductions in rent than do lower income households. Note that this sort of reduction in rents will not necessarily lead to an increase in consumer surplus in AA, since AA also represents the greater preference for single family dwelling units. The PRB scenario reduces opportunities for housing, which reduces consumer surplus, but also reduces rents for housing, which increases consumer surplus. AA represents both of these and weighs them against each other.

TABLE 2 Change in Average Annual Rent by and across Household Class(es) (2000 U.S. nominal dollars)

Income Class ($1,000)	Total Change (dollars)	Percentage change
less than 10	-1,248	-6.4
10 to 19	-1,299	-6.0
20 to 39	-1,702	-8.0
40 to 49	-1,833	-7.9
50 to 99	-1,933	-6.7
100 to 199	-309	-0.7
200+	505	1.0
Total	**-1,526**	**-6.1**

Table 3 shows that the total annual value of owned homes decreases across all income brackets with the exception of the highest income category. This is consistent with the general decreases and increases in rental values by income class and indicates a change in residential property value.

TABLE 3 Total Annual Value of Owned Homes (2000 U.S. nominal dollars)

Household Income ($1,000)	BAU ($100,000)	PRB ($100,000)	Percentage Change
less than 10	7,840	7,788	-0.7
10 to 19	13,384	13,201	-1.4
20 to 39	38,520	37,578	-2.4
40 to 49	20,868	20,258	-2.9
50 to 99	124,620	121,462	-2.5
100 to 199	78,739	78,122	-0.8
200 or more	15,298	15,415	0.8
Total	**299,268**	**293,823**	**-1.8**

The results suggest that lower transport and housing costs in the PRB scenario have driven down the region's cost of living, and thus average annual wages (see Table 4). Average wage income is reduced by $783 (a percentage reduction of 1.6%). By labor occupation category, average reduction ranges from a low of $50 to a high of approximately $1,000 (percentage reductions of 0.1% to 2.0%, respectively). Agricultural and construction workers, typically lower income jobs, experience some of the lowest reductions and professional, sales, and administrative labor groups, typically higher income, experience some of the highest reductions.

TABLE 4 Change in Average Annual Wage Income by and across Labor Group(s) (2000 U.S. nominal dollars)

Labor Group	Total Change (dollars)	Percentage Change
Agriculture	-50	-0.1
Construction	-282	-0.6
Educators	-802	-1.8
Entertainers	-925	-1.9
Food workers	-752	-1.6
Health workers	-847	-1.7
Maintenance & repair	-731	-1.6
Managers	-922	-1.9
Non-retail sales	-951	-2.0
Office & administrative	-892	-1.9
Production	-670	-1.4
Professionals	-980	-2.0
Retail sales	-759	-1.6
Service	-749	-1.5
Transport	-719	-1.6
Total	**-783**	**-1.6**

Total consumer surplus results for the PRB scenario relative to the BAU scenario in 2035 are presented in Table 5. There is a net increase in total consumer surplus for the region as a result of the changes in land use planning and transport investment in the PRB scenario relative to the BAU. Lower transport and labor costs produced a surplus for each industrial activity. Total industry surplus is approximately two billion dollars and the average per million dollars of production is 15 thousand dollars. Across all households, consumer surplus is 32 million dollars and the average consumer surplus per household is 27 dollars. In general, household benefits are inversely related to income levels. Average consumer surplus for the low income groups range from approximately $1,074 to $647 dollars. The median income range ($40,000 to $49,000) sees an average benefit of $229. However, the higher income classes all experience a loss in consumer surplus that ranges from $442 to $668. The higher income households have reduced utility for three readily observable reasons: 1) they produce more labor, and hence are affected more by the reduction in wages, 2) they have a larger preference (higher willingness-to-pay) for larger houses which are less available and likely have reduced accessibility in the PRB scenario, and 3) they are more likely to own their own houses, and hence do not benefit as much from the reductions in rent. Conversely, the lower income households likely have increased utility because: 1) they produce less labor, and hence are less affected by wage reductions, 2) they have a larger preference for multi-family houses which are more available and likely have improved accessibility in the PRB scenario, and 3) they are less likely to own their own houses, and hence benefit more from the reductions in rent.

Note that the two scenarios had equal exogenously specified control totals for industry size. In reality, the gains in producer surplus in the industrial categories shown in the top section of Table 6 would attract more industry to the region. This would lead to reduced benefits (per unit) for industry because of the increased competition for space, labor, and other commodities. This can already be seen based on the increases in the annual value of industrial space in the PRB scenario (see Table 6), which would increase at an accelerated rate if additional industry was allowed to move into the region. However, this increased competitiveness would also lead to more jobs in the region and hence increased benefits for households. As discussed above, it is common in PECAS modeling to also have an economic growth model that responds to PECAS's measures of consumer surplus and can adjust economic growth over the years of a multi-year simulation. It is also common, however, to purposely **not** have growth forecasts change in response to consumer or producer surplus in order to better isolate the cause of differences between scenarios.

Some of these results may seem counterintuitive to some for very specific reasons. First, higher density commonly occurs in larger cities, which have higher prices because of their size. In this study, city size was fixed, as discussed above. Second, developers tend to want to build at higher densities where prices are higher, leading to higher prices on higher density housing because of the location where it gets built. In this study, there was no forecasting of the actions of developers (the SD module was not running); instead, the published plans dictated the type and location of housing and housing prices adjusted until the markets cleared. Third, productivity gains in reality may lead to more production and more consumption and hence wider benefits overall. In this model final demand for goods and services was fixed between the scenarios, consistent with the exogenously specified control totals for industry described above.

TABLE 5 Total and Average Consumer or Producer Surplus for PRB Scenario Relative to the BAU Scenario (2000 U.S. nominal dollars)

Industry Activities	**Total ($100,000)**	**Average (per million dollars of production)**
Agriculture	254	13,819
Construction	944	8,783
Manufacturing	962	5,588
Transport	249	12,336
Communication	483	9,630
Wholesale trade	996	8,532
Retail	5,354	20,345
Restaurants	2,281	51,192
Financial	1,961	18,934
Real estate	1,330	6,804
Business services	1,200	15,477
Automotive services	308	13,994
Amusement services	197	46,647
Education	717	36,163
Personal services	697	35,366
Non-profit organizations	565	48,809
Professional services	1,213	17,099
Government	2,916	15,501
Total	**22,626**	**15,028**
Household Income Class ($1,000)	**Total ($100,000)**	**Average per Household**
less than 10	731	1,008
10 to 19	1,226	1,074
20 to 39	1,617	647
40 to 49	254	229
50 to 99	-1,966	-442
100 to 199	-1,384	-668
200+	-151	-454
Total	**327**	**27**

TABLE 6 Total and Change in Annual Values of Space Categories (2000 U.S. nominal dollars)

	BAU Total ($100,000)	**PRB Total ($100,000)**	**Total Change ($100,000)**	**Average Change**
Industry Space				
Agriculture & Mining	43	48	5	0.3
Industrial	3,424	3,504	79	0.1
Office	22,561	22,729	169	0.1
Retail	24,205	24,240	35	0.0
Medical	26,152	26,200	48	0.1
Primary School	7,434	7,436	1	0.0
Colleges & Education	2,653	2,655	1	0.0
Government Office	31,015	31,002	-13	0.0
Total	**117,488**	**117,813**	**325**	**0.0**
Residential Space				
Luxury SFD	195,707	185,408	-10,299	549.0
Standard SFD	153,245	152,531	-714	-243.0
Owned MFD	8,976	9,322	345	-1017.0
Rented MFD	26,510	27,069	559	-1537.0
Total	**384,438**	**374,330**	**-10,108**	**-820.0**

SFD=single-family development; MFD=multi-family development

CONCLUSIONS

This study described an application of a newer form of spatial economic model, the PECAS model of the Sacramento region, to demonstrate the range of equity impacts available from such models and to provide insight into possible equity and economic effects of a land use and transport plan for the region. The study shows that a more compact urban form designed around transit stations can reduce travel costs, wages, and housing costs by increasing accessibility. These can lead to substantial net benefits for industry categories and for lower income households. Higher income households may be net losers, since their incomes are more dependent on reduced wages, they are less willing to switch to higher density dwellings, and they are more likely to own their own home.

Maintaining fixed total industry size between scenarios impacts the consumer surplus measures. The PECAS AA model represents how increased accessibility benefits industry directly and indirectly (for example through lower wages), but it does not represent how industry may grow faster in the region because of this benefit. If a separate model of region-wide economy size were to respond to AA's producer surplus measures, industry would grow faster, and some of the benefit currently ascribed to industry would be transferred to households through less wage reductions.

Reductions in rent values for floorspace will lead to an increase in the basic consumer surplus calculated in PECAS AA. But every unit of floorspace is owned by someone, and when rents go down landlords suffer. For local policy analysis, it is difficult to decide how to weight this disbenefit experienced by landlords due to a reduction in rent. Certainly it is essential to account for the changes in the imputed rents for owner-occupied dwellings, since these households are clearly within the local policy system. Non-residential space, and non owner-occupied dwellings, may be owned by investors outside of the local policy system. Local policy makers may not want to count the full disbenefit of reduced rents on the landlord side because only a portion of these disbenefits directly affect their citizenry. In this study, we have reported non-residential and non-owner-occupied residential rent revenue reductions completely but also separately.

Another actor that is outside of the consistent AA evaluation system is the land developer. The SD module of PECAS could be used to calculate a measure of developer profits, but since this study did not use the SD module it is important to point out that developers may not win in the PRB scenario. Hence developers may not want to build the built-form assumed in the PRB scenario without additional incentives, which could be costly to taxpayers and hence households.

Recommendations for Future Research

This study shows how a specific more compact urban growth land use scenario can lead to positive benefits, at least for industry and poorer households. However patterns of land use are not policy, they are the outcome of developers working within policy. To test policy, the full PECAS model should be run with policies designed to encourage more compact and more cohesive growth. This would allow an understanding of the types and size of policies needed to encourage and nurture a certain land use pattern.

It is valuable to show planners that certain visionary built form patterns can cause improved equity and an improved economy. This study should help to show planners that their visions and ideas can be analyzed to determine if they are "good" in very specific dimensions using appropriate economic metrics that holistically account for the entire spatial economy. Once planners' visions are shown to have potential value, a logical next step would be to evaluate policies designed to implement the vision – and that is where the full PECAS system, including the SD module, the ED module, and running through time with the TR model, should be used to evaluate policy options. Future research should compare and contrast an analysis of future built form patterns with an analysis of spatial policy.

Integrating with an ED module in the direction where AA's measures influence ED would also allow a different kind of study. In this study the size of industry was fixed region wide as a control total. This allowed a direct investigation of the impact of a specific transport and built form scenario on each industry and household individually. However in reality a more productive and efficient economy would attract more growth to the region, leading to a larger economy, with the associated economic benefits, partially tempered by increased congestion and externalities.

On the other hand understanding how a region's economy grows and shrinks with its efficiency requires assuming something about the changing efficiency of the rest of the world; thus such scenario analysis will have a higher assumption load than the type of analysis performed here. The scenarios with ED integration will be more realistic, but also more subject to challenges on their assumptions.

The calibration on the model that was performed for this study focused on the transport cost parameters, certain random terms related to commodity exchange location choice decisions, and the parameters related to households choice of occupation and type of residence. Calibration of a complex, holistic model should be ongoing – such a model can always be improved. The PECAS model should be further calibrated if budget and data are available. The parameters in AA that could most benefit from further calibration are probably the other parameters that were *not* addressed in this study, including parameters controlling the choice of technology and location for non-household activities (primarily employment locations).

ENDNOTES

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John Abraham has been involved in computer simulations of transportation systems since 1989, when he developed commercial software for pipeline simulations. In 1992 he began to study urban systems, emphasizing models of the interaction between land use and transportation. John's 1994 M.Sc. thesis explored the locational choices of multi-worker households in an urban setting by extending the state-of-the-art in behavioural modelling techniques. His 2000 Ph.D. thesis investigated calibration and validation processes for urban models.

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