POLICY ANALYSIS USING THE PECAS FRAMEWORK

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Submitted for TRB 92nd Annual Meeting, January 2013  
Submission date: August 1, 2012  
Word count: 4,491 words (including 129 words abstract) + 12 figures or tables  
7,491 words total
Abstract

The PECAS land use and transportation interaction model of Baltimore MD has been simplified and modified for demonstration purposes. The resulting Demo Model was run to analyze four policies: 1) provision of new crosstown inner city road infrastructure, 2) increase in government activity and employment, 3) public housing development, and 4) mobile source carbon tax. Different types of model outputs are shown and compared between scenarios, including calculation of consumer surplus benefits (for comparison against costs), industrial and household location, space development and rents, wages, labor production and consumption, travel cost and travel composite utilities. The examples show some of the diverse types of analysis possible with a PECAS model and the ways that a land use and transportation interaction model can promote complete policy discussion and holistic planning.

Keywords: spatial economic models, PECAS, policy analysis, consumer surplus, location choice, household benefits, land use and transportation interaction modeling
1. BACKGROUND

1.1. Modeling Framework

PECAS is a land use forecasting and policy analysis framework. PECAS stands for “Production, Exchange, Consumption Allocation System”, since a focus is on the representation of economic agents and how they interact with each other through their interdependencies in the exchange of the things they produce and consume.

PECAS consists of two modules, the Activity Allocation (AA) module and the Space Development (SD) Module. The AA module allocates the economic agents into zones and solves the economic system with businesses and households choosing to live in buildings that are well-placed with regard to their interactions (exchanges) with other businesses and households. Transportation costs and disutilities are represented, which would encourage everyone to locate close to each other, but since everybody cannot all live and produce in the same building, competition for location leads to rents (in what’s called a “bid rent” allocation) and households and businesses trade off the travel costs for their interactions against favorable locations and advantageous rents.

The SD module is responsible for evolving the building stock (the supply of “space”) over time by representing the choices made by developers regarding construction (including renovation and demolition). Developers would like to construct buildings for tenants where the rents are high and the construction costs are low. The SD module is a microsimulation of individual parcels, allowing it to consider site-specific variables, including zoning regulations, physical geography affecting construction costs (slope, soil, servicing), and site attractiveness for different uses.

PECAS is connected to a travel demand model, so that the travel conditions between locations can be forecast. In particular, congestion can arise if the AA module forecasts many interactions between places with limited transportation service and infrastructure. The AA and SD module are run each year, with AA determining rents for SD and SD determining quantities of space for next year’s AA module. The travel demand model is run less often (every three years in the Baltimore and Demonstration PECAS models), determining transportation demands from the locations in the most recent run of the AA module and calculating equilibrium transportation conditions which feedback into the next years of AA.

PECAS has been operationalized in open-source software, and has been further described in various papers and reports (1) (2).
1.2. Demonstration Model

1.2.1. Purpose and Pedigree

The Baltimore Metropolitan Council have developed and calibrated a PECAS model of the Baltimore, MD region. The council generously allowed their model to be a foundation for the Demonstration PECAS Model (the “Demo Model”). The Demo Model is designed to show the different types of forecasting and policy analysis possible with the PECAS framework.

To simplify the Baltimore model, BMC’s transportation model was discarded and replaced with an open-source assignment procedure originally developed by Jim Hicks for the Oregon Statewide Integrated Model. The entire system is thus freely distributable to researchers and students and runs on most current laptop computers. The model still uses various server-class software (databases, web servers and map servers) that make it somewhat difficult to install, but it was successfully used by all the students in an undergraduate level course at the University of Calgary in 2011. The open-source assignment procedure does not represent non-auto trips, so the PECAS model had to be adjusted to properly respond to road network travel times and distances. The model was modified to use some of the newest features in the PECAS software implementation; these were added with minimal calibration.

1.2.2. Study Area and Demo Model zone system

The study area for the demonstration model covers the Baltimore Metropolitan Council area (FIGURE 1). This area has been divided into 185 LUZ (land use zones) used in the PECAS model; and 1,151 TAZ (transportation analysis zones), used in both, the PECAS and the transportation model. The LUZ boundary lines follow TAZ boundaries, so groups of TAZs are fully contained in one LUZ. The SD model contains 2.17 million parcels (in the base year of 2000; as the model runs SD increases the parcels while it represents parcel subdivision). FIGURE 1 shows a map with a zoom of the Baltimore city, while the LUZs are shown in FIGURE 2.

1.2.3. Overview of transportation network, current, planned

The road network for the Demo Model in the base scenario has 30,745 links, 10,978 nodes and 1,151 centroids. The network spatial configuration and density can be seen in FIGURE 1.
FIGURE 1 Study area network and changes in network for S01 scenario.

The link attributes are organized based on the road type, and the network for this Demo Model contains 21 types of roads. The average values for road capacity, speed, volume-delay functions and other attributes were provided by BMC for each type.

1.2.4. Overview of zoning map and current space types

The primary land-use inputs to the model are presented in FIGURE 2: the zoning rules controlling the development that is allowed for the future (which constrains the SD module) and the base year location of built space. The area of the pie charts in each LUZ is proportional to the quantity of land or space, showing the larger amounts of existing development in Baltimore City and in the SW to NE corridor following Interstate 95. A concentric ring spatial pattern can be visually identified in the zoning rules of Baltimore city, with more commercial zoning in the core, surrounded by other zoning and high density residential zoning, followed by a more dispersed and mixed pattern of industrial, commercial, high density and medium density residential, with much of the outer area protected from development except in many places along the Interstate 95 corridor where mixed use and industrial uses are allowed. Existing development in the base year is prominent outside of the Baltimore City boundaries, but tails off in the more distant LUZs. The inputs in FIGURE 2 are provided to the model in detailed spatial layers at the parcel level, they are summarized here by LUZ for simplicity.
FIGURE 2 Percentage distributions of land by zoning rules (top) versus space type quantities (bottom) in 2000.
2. SCENARIO DESCRIPTION

The base case scenario used as a reference is called “W00”. Four scenarios were defined to analyze policy:

- S01: New crosstown interstate
- S02: Government stimulus
- S03: Public housing
- S04: Carbon tax on vehicles

2.1.1. S01 – New crosstown interstate

A new E-W interstate could be built in central Baltimore in 2014. This policy test was to study the effects of new roads (improvement in accessibility). Two new high capacity and high speed road sections were coded into the transportation network; these are shown in green in FIGURE 1.

2.1.2. S02 – Government stimulus

This scenario simulates the impact of a 20% increment in the government activity in the region as compared to the W00 scenario, with the first increase in 2012 being 5.85 billions of dollars. The spending patterns of government activity were kept fixed, so this led to a secondary increase in labor demand, the demand for construction services and all other goods and services. The amounts of the industries and households that provided to government were not increased, so the additional demand had to be fulfilled by further imports into the region. For labor, the additional demand could be partially fulfilled through additional production, because the production of labor by households is elastic in the model design. (Households can produce more labor through a combination of higher employment, labor force participation, more hours worked, or higher efficiencies, all of which are represented implicitly in the elasticity coefficients.) Note that this isn’t an economic multiplier analysis, which would involve keeping regional purchase coefficients constant, although that type of analysis is also possible with PECAS.

2.1.3. S03 – Public housing

In this scenario a new public housing project is built in an older area of Baltimore City located in the NE of downtown. The project involves the construction of 8 buildings of 20 stories each and 16 units per story for a total of 2,560 new apartment dwellings. This totals 3 million ft$^2$ of high density residential space added in the year 2012. A set of 318 parcels were identified on 8.02 acres of land, these were cleared of their existing space (209,094 ft$^2$) before being modified.
2.1.4. *S04 – Carbon tax on vehicle*

This scenario tests how an increase of 100% of the cost for all vehicle operation beginning in 2014 impacts the region. The scenario was called a “carbon tax” scenario, rather than a “high fuel price” scenario, so that the additional tax revenues could be calculated and compared with accessibility disbenefits, and to cast the scenario as a policy scenario rather than a change in external economic conditions beyond policy makers’ control.

3. ANALYSIS

3.1. Consumer Surplus

3.1.1. Top level logit consumer surplus measure

A major feature of the PECAS framework is that it represents the full spatial allocation, including all prices and all flows on the transportation network, within a consistent random utility framework. This allows a simple and consistent calculation of Consumer Surplus for households and industry (perhaps better called “Producer Surplus” in the case of industry) by subtracting the base scenario (W00) top level *logsum* calculation of the AA module from the *logsum* calculation for the policy scenario (1).

FIGURE 3 shows this calculation for each industry and each scenario. The scenario S02 is the one that produces the highest benefits. It has a large positive impact on the certain activities such as construction blue collar and government. It also produces positive benefits for all the household categories.
FIGURE 3 Changes in consumer surplus by scenario.

3.1.2. Consumer Surplus versus Costs

The AA module consumer surplus values should be compared with various other aspects of the scenario, such as the direct costs of the policy. TABLE 1 tabulates the overall benefits against an estimate of the cost of constructing new infrastructure for S01 (a simple estimate based on lane miles and prior construction costs for similar infrastructure in the Baltimore region, amortized over 35 years at 4% for comparison against AA’s annual benefit measures) (3), the amount of additional government activity transferred to the region in S02 in 2020, the amortized costs of the additional housing for S03 (based on $80/ ft$^2$ construction costs and a 50 year life at 4%) and the carbon tax revenue collected in 2020 for S04. These other monetary elements of the scenario...
are not meant to be accurate, but show how the PECAS consumer surplus benefit measures can be used to determine whether a policy has a net benefit or not.

The net negative change in consumer surplus in scenario S01 is unusual for PECAS. Usually in PECAS modeling an increase in transportation infrastructure leads to an increase in the AA Consumer Surplus measure. A partial explanation is evident later in this paper. Further research could use the model to determine all the reasons for the negative impact.

**TABLE 1 Consumer surplus versus other elements of scenarios, in millions of dollars**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>S01</th>
<th>S02</th>
<th>S03</th>
<th>S04</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AA Total Consumer Surplus for 2020</strong></td>
<td>$ (27)</td>
<td>$ 949</td>
<td>$ 36</td>
<td>$ (1,415)</td>
</tr>
<tr>
<td>Households</td>
<td>$ 50</td>
<td>$ 387</td>
<td>$ 57</td>
<td>$ (1,266)</td>
</tr>
<tr>
<td>Industry</td>
<td>$ (77)</td>
<td>$ 563</td>
<td>$ (22)</td>
<td>$ (149)</td>
</tr>
<tr>
<td><strong>Other aspects of scenario for comparison</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tax Revenue 2020</td>
<td></td>
<td></td>
<td></td>
<td>$ 1,662</td>
</tr>
<tr>
<td>Additional Government Activity in Region 2020</td>
<td></td>
<td></td>
<td></td>
<td>$ (6,157)</td>
</tr>
<tr>
<td>Amortized cost of Infrastructure at $23.8 million per lane mile 35 years 4%</td>
<td>$ (76)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amortized cost of housing @ $80/ft² 50 years 4%</td>
<td></td>
<td></td>
<td>$ (11)</td>
<td></td>
</tr>
<tr>
<td>Change in total rent paid by all the space types</td>
<td>$ 4</td>
<td>$ 509</td>
<td>$ 4</td>
<td>$ 3</td>
</tr>
</tbody>
</table>

The AA module’s consumer surplus measure represents the disutility of paying rents, but not the corresponding benefit of the receipt of rents by landlords (and homeowners, who are modeled as if they “rented from themselves”). For comparison, the change in total rents is shown in the last row in TABLE 1, and in the S01, S03 and S04 scenarios the change is small compared to the other benefits, while in S02 it adds substantially to the other benefits. It is important to consider that much real estate is owned by entities from outside the region, so the entire increase in rent in the last row should not be counted as a benefit (the proportion counted could vary by type of space; for instance most low density residential space is owner-occupied) if a full cost/benefit analysis is being performed based on the region’s boundaries.

**3.1.3. Rule-of-a-half benefit approximations by location**

The total benefit by LUZ can be estimated using a rule-of-one-half approximation, where the change in the utility of a zone between the scenarios is multiplied by the average of the quantity in each scenario. Although this is algebraically similar to the rule-of-one-half often done in transportation policy analysis (e.g. 4), the utility measures used here include all of the decisions, costs and prices up to but not including the location decision. So for instance if travel increases because of increased opportunities the PECAS rule-of-a-half will show a benefit, while a simple transportation cost rule-of-a-half will show a misleading disbenefit. FIGURE 4 shows the
aggregated change in consumer surplus for households and for industries for S02 in 2020. The additional government activity locates primarily in the dark green zone (the building icon on FIGURE 4 indicates 6.15 billion dollars of extra government production) and almost all of the benefit for all industries occurs in that zone. The benefits for households are more dispersed, spreading out within commuting distance of the zone where the additional industry locates.
FIGURE 4 Changes in Consumer Surplus for households (top) and industries (bottom) between S02 and W00 in 2020.
3.2. Locations

3.2.1. Industry

The infrastructure in S01 causes a strong rearrangement of production in the central area, with some zones gaining and others losing, as industries adapt to the new infrastructure and the change in local access and congestion. In more distant areas, there is some attraction to the I95 corridor that runs NW and SE through the region.

FIGURE 5 shows the change in industrial production of S04 in comparison with W00. (Industrial production refers to the total production by business and government enterprises in all sectors of the economy; not just the types of production activity that land use planners might classify as “industrial” based on noise, emissions and space type requirements.) In this scenario, the additional transportation costs from the carbon tax do not cause an overall centralization of industrial production (nor of jobs, the topic of section 3.3.1, although results for S04 are not mapped in section 3.3.1. due to space limitations). According to urban economic theory (5), increased transportation costs is a centralizing force. The Demo Model result shows that centralization of industry is not towards the center of the entire region, but perhaps towards certain sub-centers. One reason for this is the zoning regulations. There is a large capacity for additional development of non-residential space in specific zones outside of Baltimore City (FIGURE 2), whereas the capacity in the central areas of Baltimore City is limited. (In the next section, FIGURE 5 shows that households do centralize overall in the scenario S04).
3.2.2. **Households**

One particularly important purpose of a land use model is to predict the location of households and residences, and the impact of policy on household location. The S01 scenario showed very little change in household location versus W00; the new infrastructure caused a rearrangement of industrial activity, but households largely stayed in the same location.

In the S02 scenario, a movement of households to the southwest area was observed, to locate closer to the new center of government activity that emerges, consistent with the change in benefits in FIGURE 4.

In the S03 scenario, an additional 2,560 households located in the zone where the public housing was constructed as a policy, leading to 1,226 additional households in Baltimore city in 2020.

FIGURE 6 shows the change in households in the carbon tax scenario (S04) versus W00. Here the centralizing pattern of higher transportation costs is seen, as predicted by the urban economic theory.
3.3. Employment

3.3.1. Changes in labor production by location

One of the features of a PECAS model is that industry and households are connected with jobs, which are classified by occupation. Households produce labor in different occupations, while industry consumes labor, and there is a benefit in terms of transportation disutility if the demand for labor is spatially located near (within commuting distance and/or time) of the supply of labor.

Changes in the production of labor by households in the S02 scenario versus the W00 scenario are shown in FIGURE 7. The production of labor has increased in the west part of the region as households produce more labor if they are close to the new government center and households also move to be located closer to the new activity center.
3.3.2. Changes in jobs by location

The other side of the exchange of labor is the purchase of labor by industry, representing job locations. In the S02 scenario, almost all of the increase of the demand for labor is in the zone indicated by the building icon in FIGURE 7. Many other zones show small reductions in labor demand as supporting industries shift towards the new government subcentre.

3.3.3. Changes in wages for the whole region

Wages are defined as the demand for labor (quantity) multiplied by the price (salary). This can be estimated by LUZ or for the whole model area. Changes in average wage by zone can be seen on the left of FIGURE 8 and the change in total wage by zone can be observed on the right of the same figure. The change in average wage by zone is calculated with Equation 1, while the change in total wage by LUZ is calculated with Equation 2.

$$\text{avg(wage)}_z = \frac{\sum_{o \in \text{Occupations}} (Q_{o,z,s_1} \times P_{o,z,s_1})}{\sum_{o \in \text{Occupations}} (Q_{o,z,s_1})}$$ (1)
\[
\text{total wage}_z = \sum_{o \in \text{occupations}} (Q_{o,z,s_1} \times P_{o,z,s_1}) \quad (2)
\]

Where:

1. \( Q \) = quantities of labor (usually measured as nominal revenue amounts if prices had remained constant.)
2. \( P \) = price of labor (usually expressed as a ratio to the average base-year price)
3. \( Z \) = land use zone
4. \( S_1 \) = scenario being analyzed

Averages wages increased everywhere in S02, but since households moved to the new activity center the total wages increased more dramatically in the southwest areas of the region.

**FIGURE 8** Changes in average wages per household of medium income households (on the left) and changes in total wages of for all medium income households (on the right) for S02 versus W00.

For the whole model area the changes in demand and wages can be seen in TABLE 2. Jobs increased in 1.19\% for blue collar and 1.48\% for white collar in S02, while total wages went up in 3\% for the whole region. This represents a 1.62\% increase in wage rate (weighted average).
TABLE 2 Changes in jobs and wages for the full model area between S02 and W00

<table>
<thead>
<tr>
<th>DEMAND</th>
<th>BLUE COLLAR</th>
<th>WHITE COLLAR</th>
<th>TOTAL LABOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>total s02 demand for labor</td>
<td>26,071</td>
<td>51,873</td>
<td>77,944</td>
</tr>
<tr>
<td>total w00 demand for labor</td>
<td>25,765</td>
<td>51,119</td>
<td>76,884</td>
</tr>
<tr>
<td>difference (s02 - w00)</td>
<td>305</td>
<td>754</td>
<td>1,060</td>
</tr>
<tr>
<td>% difference (s02/w00)</td>
<td>101.19%</td>
<td>101.48%</td>
<td>101.38%</td>
</tr>
<tr>
<td>change in % in amount of labor</td>
<td>1.19%</td>
<td>1.48%</td>
<td>1.38%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WAGES</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum of (Q * P) in each LUZ in S02</td>
<td>26,671,582,024</td>
<td>53,310,935,236</td>
<td>79,982,517,260</td>
</tr>
<tr>
<td>Sum of (Q * P) in each LUZ in W00</td>
<td>25,981,321,138</td>
<td>51,610,570,603</td>
<td>77,591,891,740</td>
</tr>
<tr>
<td>difference (s02 - w00)</td>
<td>690,260,886</td>
<td>1,700,364,633</td>
<td></td>
</tr>
<tr>
<td>% difference (s02/w00)</td>
<td>102.66%</td>
<td>103.29%</td>
<td>103.08%</td>
</tr>
<tr>
<td>change in % in wages</td>
<td>2.66%</td>
<td>3.29%</td>
<td>3.08%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WEIGHTED AVERAGE WAGES</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>wages / demand in s02</td>
<td>1,023,042</td>
<td>1,027,721</td>
<td>2,050,763</td>
</tr>
<tr>
<td>wages / demand in w00</td>
<td>1,008,377</td>
<td>1,009,620</td>
<td>2,017,998</td>
</tr>
<tr>
<td>difference (s02 - w00)</td>
<td>14,665</td>
<td>18,100</td>
<td>32,765</td>
</tr>
<tr>
<td>% average wages S02 - w00</td>
<td>101.45%</td>
<td>101.79%</td>
<td>101.62%</td>
</tr>
<tr>
<td>change in % in average wages</td>
<td>1.45%</td>
<td>1.79%</td>
<td>1.62%</td>
</tr>
</tbody>
</table>

3.4. Rents

3.4.1. Changes in average annual rent for residential space by household unit

The average annual rent paid for residential space can be calculated. There are three types of residential space in the Demo Model, and three types of households categories that are willing to adjust their consumption of space in terms of both quantity and space type. The average of the rent paid for the three categories was calculated for medium income households and investigated.

In the S01 scenario, there were small increases in the average residential annual rent east and west of the new infrastructure. In the S02 scenario, average rent increased near the new commercial subcenter. In the S03 scenario, there are sharp decreases in the single zone representing the downtown harborfront area, and increases in the single zone where the new housing was constructed. In the S04 scenario the average rent generally increase in Baltimore City and the zones near Baltimore City while decreasing in the most suburban zones, although there are exceptions.

3.4.2. S01 Change in Commercial rents

The new infrastructure in S01 was shown to increase desirability of some locations in Baltimore City. FIGURE 9 shows the changes in commercial rents that follow from this change in desirability, with increases in rents in many of the zones in Baltimore City.
3.5. Space

Changes in quantities of space are simulated at the individual parcel level by the SD module, and generally mapped at the TAZ level, to provide more detail than the LUZ level. Generally the quantities of space follow the patterns of price changes (since the developers in the SD module want to construct buildings on parcels with high rents) and the patterns of locations in section 3.2 (since activities in AA need the space provided by SD.) The level of detail is very useful to analysts, as it allows them to better understand the operation of the model and the impact of policy at the individual parcel level, but the random nature of the simulation (each run of the model will show different results for individual parcels even if inputs are identical) and the detail in the output plots can make maps of changes in space quantity confusing to policy makers and the public.

3.6. Travel costs and disutility

In the S01 scenario, the households on either end of the newly constructed areas benefit in commuting time savings, as shown in the top map of FIGURE 10. Households in the most central areas see increased times, perhaps because they see more congestion or because surface roads were removed to make room for the freeway. However with random utility models, it is important not to assume that deterioration in one measurement of an attribute of a choice is
deterioration in utility, it could be that these most central households have additional access to new and better jobs, and are spending more time travelling because of this increase. The bottom part of FIGURE 10 shows the overall utility of selling labor by zone of production (i.e. by zone of household residence), and shows that indeed overall utility in the labor market is decreasing in these most central zones as travel times increase for work trips from these zones. This could be a major reason that the overall benefits of S01 are negative (Table 1). The new infrastructure, as implemented, hurts the center of the city it passes through.

In the S04 scenario, the travel times for work trips decreases, as commuters choose to travel shorter distances under less congested conditions to avoid the carbon tax policy, however the overall utility of commuting gets worse from every zone except one located in the SW of the region.
FIGURE 10 Changes in time disutility (top) and average disutility (bottom) for S01 versus W00 for commuting flows (production of labor).
4. CONCLUSIONS

The PECAS framework shows a rich potential for evaluating public policy. It represents a spatial economic system and essentially all of the spatial monetary interactions in a simplified allocation based on economic theory, with a special treatment of transportation and the development industry. The strong basis in random utility theory allows a calculation the system benefits to all of the households and businesses that choose to locate in the region and interact with each other, for comparison against the direct costs (or revenues) of policy.

The Demonstration PECAS model is a representation of Baltimore MD, but with a simplified representation of the transportation network and not endorsed nor validated by officials in the Baltimore region. This provides some freedom in showing the analysis of policy, showing for instance that the revenue from a carbon tax scenario barely outweighs the consumer and producer welfare disbenefit (and probably wouldn’t outweigh it after transaction costs are included), and that an increase in government production activity in the Baltimore region (perhaps a shift towards Baltimore from Washington DC) could benefit the region and especially certain suburban areas, and that new freeway infrastructure through the central area could benefit areas to either side of the central area, without benefitting the central area nor the region as a whole. If these policies were under serious consideration, they should be analyzed with the Baltimore PECAS Model; the demonstration model has simply demonstrated the potential of such analysis in a way that an official model cannot.

The framework allows analysts to tell a complete and consistent story about how policies affect different industries and household categories, with maps of rent changes, wage changes, location changes, travel time changes by type of interactions, job changes and changes in overall accessibility to jobs. These only scratch the surface of the full range of outputs of the model; this paper has focused on some that are easy to present and that have proven useful in discussions. The types of outputs available from an integrated framework should provide for a richer and more holistic discussion of the policy and future of a region.

5. REFERENCES


