Ozone Improvement and Household Adjustments: Revisiting EPA's Prospective Analysis*

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1. Introduction

Benefit-cost analysis is often characterized as an unfair basis for public policy. Its critics allege that people are given different weight based on their ability to pay for the specific policies under review. In the case of environmental policy, this critique has been suggested to be especially salient.[1] As a practical matter, it is irrelevant to most of the benefit cost analyses as they are actually conducted. Thus, while the theoretical definition for willingness to pay implies differences in income should affect the benefits associated with an exogenous change in environmental quality, the current practice for policy analyses never falls victim to this criticism. Even when the benefit estimates available allow consideration of the effects of income, average benefit measures are applied to all households. As a rule, however, most of the methods used are incapable of consistently describing how income and, equally important, private adjustment would alter the gains realized from changes in any policy.

This paper demonstrates how a new framework, using the necessary conditions for a locational equilibrium, offers the potential to transform this policy landscape. The new

[1] A recent example of these criticisms can be found in Heinzerling and Ackerman [2002], who summarize their critique in the executive summary of their report as follows:

> "Cost-benefit analysis is a deeply flawed method that repeatedly leads to biased and misleading results. Far from providing a panacea, cost-benefit analysis offers no clear advantages in making regulatory policy decisions and often produces inferior results, in terms of both environmental protection and overall social welfare…" (p. 1).

These authors highlight the equity issues as one of four fatal flaws that they identify, noting that:

> "…cost-benefit analysis ignores the question of who suffers as a result of environmental problems and, therefore threatens to reinforce existing patterns of economic and social inequality…Poor countries, communities, and individuals are likely to express less 'willingness to pay' to avoid environmental harms simply because they have fewer resources. Therefore, cost-benefit analysis would justify imposing greater environmental burdens on them than their wealthier counterparts" (p. 2).

approach, developed by Epple and Sieg [1999], allows unobserved individual heterogeneity in preferences for public goods as well as differences in household income to be: (a) incorporated in the estimation of household preferences for spatially delineated non-market goods; (b) used in the computation of the new locational equilibrium from large and locally differentiated changes in public goods; and (c) consistently represented in Hicksian welfare measures that account for the change in quality, the resulting equilibrium relocation, and the price changes that are required for the new equilibrium.

We demonstrate in this paper that the framework can be used as part of a benefit analysis of current environmental policy alternatives. We use our earlier estimates of household preferences derived within a locational equilibrium framework for the Los Angeles area (see Sieg et al., [2002a]). These findings are combined together with the spatially delineated, air quality projections developed by EPA for the evaluation of the 1990 Clean Air Act Amendments reported in EPA's [1999] first Prospective Analysis. Our approach is capable of accommodating the levels of detail generated for this policy assessment. It uses the same projected spatial variation in ozone concentrations in the computation of general equilibrium price effects as was developed for the agency's benefit analysis.

Our findings indicate that the estimated annual general equilibrium benefits in 2000 and 2010 associated with the ozone improvements due to continuing the policies mandated under the 1990 Clean Air Act Amendments will be dramatically different by income group and location within the South Coast Air Quality Management District.[2]

[2] This area includes most of Los Angeles, Orange, Riverside, San Bernadino, and Ventura counties.

The gains range from $33 to about $2,400 per household (in 1990 dollars).[3] These differences arise from variations in air quality conditions, income, and the effects of general equilibrium price adjustment. To date, existing methods have been unable to measure consistently all of these effects together.

The policy background and context for our analysis of EPA's projections for the ozone improvements to take place in the Los Angeles area are described in the next section. Section 3 provides an overview of the Epple-Sieg estimator and a brief summary of our earlier estimates of preferences based on data for households in the LA region. Section 4 outlines the specific details of our policy evaluation and the results. The last section describes their more general implications.

2. Background

2.1 Context

Section 812 of the 1990 Clean Air Act Amendments (CAAA) requires periodic assessments of the benefits and costs of the regulations intended to reduce the concentrations of criteria air pollutants. The first Prospective Assessment (U.S. EPA [1999]) estimated the annual human health benefits (in 1990 dollars) of Titles I through V of the CAAA to be $68 billion in 2000 and $110 billion in 2010.[4] These results imply an

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[3] This range is based on the average welfare gain computed by income quantile in each of the 102 school districts in our model. It is the range from the smallest mean to the largest across the school district/quantile groups.

[4] The Titles for the CAAA are given as follows:

- Title I – volatile organic compounds (VOC) and nitrogen oxide (NO_X) satisfy reasonably available control technology and reasonable further progress requirements for ozone non-attainment areas.
- Title II – motor vehicle and non-road engine provisions are met.
- Title III – the 2 and 4-year maximum achievable control technology standards are met.
- Title IV – the SO_2 and NO_X emission programs for utilities are met as relevant for each region of the U.S.
- Title V – the permitting system for primary sources of air pollution is implemented as mandated.

approximate per household annual benefit of $648 and $1,048 in 2000 and 2010, respectively.[5]

The methodology used for these estimates begins with a detailed inventory of the baseline emissions for both major point as well as mobile sources and an evaluation of how they would change with different regulatory regimes. The projected emissions are introduced into comprehensive air diffusion models to produce estimates of the ambient concentration for each criteria pollutant included in the assessment.[6] For ozone, the air pollutant of primary interest here, the spatial resolution varies depending on the region where these models are applied. For urban areas in the Western U.S., the Urban Airshed Model's (UAM) spatial resolution is either 4 or 5-kilometer grids. These analyses produce hourly ozone concentrations for specific time periods. As a result, EPA selected a set of design days (with weather conditions and other factors that might influence ambient pollution concentrations specified) to represent a time span most likely to be relevant to the regulatory standard. In the case of ozone this set corresponds to conditions yielding the highest concentrations. In their analysis, this predicted ambient concentration was used together with the relevant health effect concentration-response (CR) functions at a spatial resolution matching the air quality monitoring. The predicted difference in the count of each type of health effect from each of the CR functions, comparing with- and without- CAAA ozone condition, is then "monetized" with constant unit values to develop benefit measures for pollution reductions.

[5] In 2000 the U.S. population was approximately 275 million. In 1993, the average household size was 2.62. This would imply approximately 105 million households, the basis for our per household estimate.
[6] The Prospective Analysis considered ground level concentrations of ozone, particulate matter 10 microns in size, particulate matter 2.5 microns in size, sulfur dioxide, nitrogen oxide, and carbon dioxide. It also considers acid deposition and visibility impacts as well as stratospheric ozone concentrations.

The last step, associated with the economic analysis of ozone's effects, stands in sharp contrast to the earlier stages of analysis. No attempt is made to account for the potential heterogeneity in the unit benefits attributed to avoiding these health effects or the adjustments households might make to mitigate the effects of pollution. People are passive receptors.[7] This premise is inconsistent with the behavior relied upon to develop the unit benefit estimates. Unfortunately, there has been little ability to gauge the importance of these restrictions. As noted in the introduction, we find, using the same air quality modeling results for ozone in the Los Angeles area, that the overall average estimates are comparable to average household estimates from the EPA assessment.[8] However, there is a dramatic difference in the average, annual, household benefits across school districts comprising our study area. Our estimates (computed as the average for each school district) range from about $53 to $1,694 (in 1990 dollars) for the projected CAAA ozone improvements in 2000. Equally important, these gains are unequally distributed by income group and geographic area in Southern California. Thus, heterogeneity in benefits is the rule, not the exception.

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[7] The concentration response functions are generally estimated by linking existing air pollution concentrations to observed health outcomes. For example, in the case of particulate matter the focus is the non-accidental death rate. For ozone, several health endpoints are considered including: chronic asthma, cardiovascular admissions, and others (see EPA [1999], Table 5-3). The concentration response function is a reduced form relationship. It can be interpreted as reflecting some level of adjustment. Our point here is that if adjustment as reflected by the baseline conditions is assumed, then changes in pollution should induce some further adjustment. The functions used do not allow for this type of change. By applying them as estimates for a baseline set of conditions, we implicitly assume whatever concentration change takes place – whether increases or decreases – people do what they did under the baseline conditions. This is the sense in which people are assumed to be "passive receptors."

[8] As noted in footnote #6, the Prospective Analysis was for a number of pollutants at a national level. In the Los Angeles area most (but not all) of the air pollution problem is due to ozone concentrations. This comparison implicitly assumes that our estimates are serving as proxy measures for the effects of all policies on changes in all of the air quality conditions in the area. In estimating the model for the area, we found high levels of correlation between the ozone measures we were using and available measures of particulate matter (see Sieg et al., [2002a]). As a result, our estimates were unable to distinguish separate effects for each pollutant. This inability to estimate separate effects is partial support for our interpretation of the benefit estimates from our locational equilibrium framework.

This finding should not be surprising. Revealed preference (RP) approaches rely on observing a differential pattern of amenities and people's responses to that heterogeneity in order to recover estimates of their willingness to pay for any changes. Unfortunately, most RP methods do not allow this heterogeneity to be consistently incorporated from estimation to general equilibrium benefit assessment. This last step is necessary when the policy change involves a large and diverse set of changes in pollution conditions.[9] Consistency requires that the heterogeneity in tastes for environmental quality affect how individuals respond to changes in the amenity. The market consequences of their adaptation, along with the change in environmental conditions, should then contribute to the benefit measure used in the policy evaluation. To date, this integration has not been possible.[10]

2.2 EPA's Prospective Assessment for Southern California

The EPA Prospective Assessment of how the CAAA would affect future air quality conditions identified five major source categories for air pollutants: industrial point sources, utilities, non-road engines/vehicles, motor vehicles, and area sources.[11]

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[9] Analysts have appreciated that when regulations are expected to create large changes in environmental conditions, the benefit measures should incorporate induced price changes that result. One of the first studies recognizing that aggregate benefit measures needed to account for these general equilibrium effects was Lind [1973]. Subsequent discussion by Freeman [1975] and Starrett [1981] refined the conceptual analysis of conditions when a partial equilibrium measure would reasonably approximate the aggregate benefit measure. Palmquist [1988] uses a hedonic framework to provide a convenient graphical description of the partial and general equilibrium welfare measures and rent changes (see his Figure 1).

[10] Ideally, one would also consider the potential for feedback effects between adjustment in household behavior and the resulting change in environment quality. We do not consider these effects here. With sufficient information, it is possible to incorporate them in this type of general equilibrium assessment. Walsh [2001] illustrates the logic for the case of open space amenities.

[11] EPA's definition for the source categories are given as follows:

(a) Industrial Point Sources – boilers, cement kilns, process heaters, turbines
(b) Utilities – electricity producing utilities
(c) Non-road Engines/Vehicles – air craft, construction equipment, lawn and garden equipment, locomotives, and marine engines
(d) Motor Vehicles – buses, cars, trucks
(e) Area Sources – agricultural tiling, dry cleaners, open burning, wildfires

For each source both a base year level of emissions and projected growth of the specific pollution generating activities were developed for 2000 and 2010 in the absence of CAAA requirements. These projections were modified to reflect control assumptions in each of two "future years." For volatile organic compounds (VOC) and nitrogen oxide (NO_X), both contributors to ambient ozone, the national assessment estimates a 27% reduction due to CAAA's effects on VOCs in 2000 and a 35% reduction in 2010. For NO_X, the reduction is comparable for 2000 (i.e., 26%) and a little larger in 2010 (39%).

Sectoral emission projections were disaggregated to the state/industry level or below.[12] Spatially differentiated emission estimates, at least at the county level, were then introduced into one of several air quality models. Our analysis focuses on ozone, whose concentrations were estimated using the Urban Airshed Model (UAM) and the variable grid UAM (UAM-V). For the Los Angeles area, the EPA analysis supplemented the regional scale modeling results with higher resolution analysis. As a result, ambient concentrations on an hourly basis are available at a 4-kilometer resolution for this area.

Before describing these results, a brief outline of the UAM framework provides some perspective on the effort devoted to developing a detailed, spatially differentiated description of the with and without policy alternatives. The UAM framework is a three-dimensional, photochemical grid, model that simulates the physical and chemical processes underlying the ambient concentration of pollutants. Four steps are involved in the computation of these estimates for ambient concentrations: emissions are introduced; horizontal diffusion is computed; vertical diffusion and deposition are calculated; and, finally, chemical transformations are evaluated for reactive pollutants. These

[12] Appendix A of EPA [1999] provides a detailed description of the models used in the sectoral emission analysis.

computations are undertaken within each time step of the model. In the use of the ozone models relevant for our analysis this was done every few minutes.

Our analysis focuses on the Los Angeles area. The EPA air quality modeling for this area relied on input data from the South Coast Air Quality Management District (SCAQMD) data.[13] The EPA projections with and without CAAA considered the conditions for two separate three-day periods (June 23-25, 1987 and August 26-28, 1987) with baseline conditions augmented by the emission profiles associated with each scenario. Table 1 summarizes the VOC and NO_X emission totals for each scenario in Los Angeles. With the assistance of EPA staff and its contractors, the three analyses undertaken for California were interpolated to a consistent 5-kilometer by 5-kilometer grid cell pattern for the study area included in our analysis.[14] For each scenario, the latitude and longitude of the centroid for all cells in California were computed. Hourly ozone values were summarized for each grid cell with 10 hourly ozone values (measured in parts per billion) as the 5th percentile through the 95th percentile of all the modeled hours in the six day simulation period. As we discuss below, there are marked differences in the baseline ozone distributions in different areas. Moreover, the with and

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[13] The SCAQMD was also the source for the monitoring data used to estimate our economic model, discussed below in section three.

[14] James DeMocker of EPA's Office of Policy Analysis and Review arranged for these data to be developed. Kenneth Davidson of Abt Associates, Inc. developed the specific decile distributions geo-coded by latitude and longitude form the three California analyses. These were:

(a) San Francisco – August 3-6, 1990: a 4km x 4km urban scale analysis covering San Francisco Bay area, Monterey Bay, Sacramento, and a portion of the San Josquin Valley.
(b) Los Angeles – June 23-25, 1987 and August 26-28, 1997: a 5km x 5km grid covering the South Coast Air Basin from Los Angeles to beyond Riverside, including part of the Mojave Desert.
(c) Rest of California – July 1-10, 1990: a 56km x 56km (regional scale) covering the 11 western most states.

See private correspondence Kenneth Davidson, December 17, 2001.
Most of our analysis is focused on the South Coast Air Basin, but this additional analysis was required to assure the outermost areas of the counties included in our locational equilibrium analysis could be included in the evaluation of these policies.

without CAAA policy scenarios also display substantial differences in their implications for different locations within the area comprising the spatial market for our analysis. Thus, we expect considerable scope for household adjustment to the differences in the projected air quality conditions.

3. The Locational Equilibrium Model

Our policy evaluation uses estimates of the preference parameters for housing and public goods based on applying the Epple-Sieg [1999] locational equilibrium estimator to 92 school districts in the Los Angeles Metropolitan Area. The specific details underlying those estimates are described in Sieg et al., [2002a]. In this section we outline the basic structure of the model, describe how it relaxes the Willig [1978] condition and why this property is important, and then summarize some of the features of our estimates. Our objective is to provide background for our policy experiment discussed in the next section.

3.1 Context

The locational equilibrium framework, suggesting that households adjust to spatial differences in local public goods and fiscal variables, finds its origin in Tiebout [1956]. A number of authors have used the logic of inter-jurisdictional mobility, together with preference restrictions, to prove the existence (with heterogeneity in income) of sorting equilibria and to describe their properties.[15] Recently, Epple and Sieg [1999] have demonstrated that the necessary conditions for a locational equilibrium, together

[15] Early examples of this work include Ellickson [1971] and Westhoff [1977] for locational equilibrium models. Epple et al., [1993] demonstrate existence of an equilibrium with income heterogeneity. Most of the recent work has either computed equilibria for specific parameterizations of the model (Epple and Platt

with preferences that satisfy the single crossing condition, provide sufficient restrictions on the equilibrium allocation of households to estimate the model. Their estimator considers both the parameters of the preference function and the parameters describing the distribution for the heterogeneous households represented in that equilibrium.

The Epple-Sieg framework is an important advance for environmental applications. Three aspects of the approach are especially noteworthy. First, the single crossing property relaxes the Willig [1978] condition that has been required, along with weak complementarity, to use many of the revealed preference methods for recovering Hicksian measures of the willingness to pay for improvements in non-market environmental amenities (see Bockstael and McConnell [1993]). Second, their framework readily accommodates spatially differentiated environmental conditions. The model estimates preference parameters based on observed measures of public goods and housing prices for each community and the observed sorting of individuals among communities. The third feature arises because the same necessary conditions for a locational equilibrium used in estimating the preference parameters allow the framework to be used "in reverse." That is, with estimates for household preferences, including the parameters describing the heterogeneity, it is possible to use the model to compute the prices required for any new locational equilibrium due to an exogenous change in the vector of spatially delineated public goods. It is this last feature that allows the model to evaluate the general equilibrium implications of the changes in ozone concentrations for the with and without CAAA scenarios.

3.2 Structure of the Model

[1998]) or used the necessary conditions to estimate the parameters describing household preferences (see Epple and Sieg [1999]).

The locational equilibrium model is a mixed discrete/continuous framework that maintains households' decisions can be described as involving two stages – the selection of a best community and, then, conditional on that choice an optimal demand for the community specific good. In our case, this community specific good corresponds to housing. Equation (3.1) describes the first stage of this hypothesized choice process with m_i the ith household's income, p_j the jth community's price for housing, $g(q_j,a_j)$ a separable sub-function providing an index, θ_j, of the local public goods, q_j, and air quality, a_j, and α_i an unobserved taste parameter.[16] By treating α_i as a random variable, jointly distributed with income, the model allows for unobserved heterogeneity in household preferences for public goods.

$$j_i^* = \underset{j \in A}{arg\,max} \left\{ V\left(\alpha_i, m_i, g(q_j, a_j), p_j\right)\right\} \quad \forall_i \tag{3.1}$$

where A = set of communities

The optimal housing demands for the ith household, h_i, given j_i^* (the optimal community for household i) is given in equation (3.2).

$$h_i = -\frac{V_{p_{j^*}}}{V_{m_i}} \quad \forall_i \tag{3.2}$$

The locational equilibrium requires a set of prices such that market demand for housing equals supply in each community. We omit the subscript i in what follows because households are identified thru the joint distribution for α and m, $f(\alpha\ , m)$. Using this continuous formulation the market equilibrium is defined in equation (3.3).

[16] In the estimation of the model $g(\cdot)$ is assumed to be linear with the coefficient of q_j, normalized to unity. Thus, $\theta_j = q_j + \gamma\, a_j$.

$$S_j(p_j) = \int_{c_j} h\ (\cdot) f(\alpha, m) d\alpha\, dm \quad \forall_j \tag{3.3}$$

where c_j = set of all households such that:

$1(j_i^* = j) = 1$ where $j_i^* = j$
$= 0$ otherwise

$S_j\,(p_j)$ = supply of housing in community j

A locational equilibrium, with no two communities having the same housing prices, and preferences satisfying the single crossing condition, implies an ordering of the pairs of public goods index ($\theta = g(.)$) and the housing price across communities that satisfy three conditions: boundary indifference, stratification, and ascending bundles.[17]

Our empirical application of the framework (see Sieg et al., [2002a]) uses a preference specification consistent with a constant elasticity of demand for housing and separability of community specific public goods from that housing demand. Equation (3.4) provides the specific form that is consistent with the single crossing condition .

$$V(\alpha, m, \theta_j, p_j) = \left[\alpha \cdot \theta_j^{\rho} + (exp((m^{1-v} - 1)/(1-v)) \cdot exp((1 - Bp_j^{\eta+1})/(1+\eta)))^{\rho}\right]^{1/\rho} \tag{3.4}$$

3.3 <u>Single Crossing Property and Welfare Measurement</u>

[17] These conditions are described in detail in Epple and Sieg [1999]. Boundary indifference refers to the existence of households that are indifferent between two adjacent communities. Stratification implies that households are distributed across communities with an ordering by income and the taste parameters for public goods. Ascending bundles implies the level of the index of public goods, housing prices (for a homogeneous housing unit), and the highest income for each type of taste for public goods all increase in the same order.

The single crossing property requires the slope of the indifference curves for indirect utility functions with respect to θ and p to be monotonic in m, given α, (and in α given m), as in equation (3.5) (for the case of income).

$$\frac{\partial}{\partial m}\left(\frac{dp}{d\theta}\bigg|_{V=V_0}\right)=\frac{\partial}{\partial m}\left(-\frac{V_\theta}{V_p}\right)>0 \qquad (3.5)$$

where θ = the index for public goods

If p were the price of a private good that was not essential and could be assumed to be a weak complement to the composite public good (θ), then the Willig condition would require the same slope to be invariant with respect to income, as in equation (3.5').

$$\frac{\partial}{\partial m}\left(-\frac{V_\theta}{V_p}\right)=0 \qquad (3.5')$$

The locational equilibrium framework does not use weak complementarity as it is usually conceptualized in most environmental applications. Housing is not a weak complement to the public good index. In fact, for our preference specification a given individual's demand for housing in a particular community is independent of the level of that public good. Most applications of weak complementarity involve a situation where enhancements in the environmental quality increase the demand for the private commodity that is the complement. For example, improved water quality at a freshwater lake or river is usually assumed to increase the recreationist's use of the site.

The locational equilibrium model can be considered to have two goods bundled together – the community which conveys the public good and homogeneous housing. The latter is assumed to be equivalent across communities. This feature is central to the development of the price indexes for the model (see Sieg et al., [2002b] for further discussion). The public good is a weak complement to the community in that the individual does not gain from improvements in public goods in other communities (unless this causes a relocation at the extensive margin and, in that case, there is no gain from an improvement in the public goods in his initial community). There is, however, no added "consumption of the community" with increases in the public goods. Thus, the Willig condition is not needed to limit the role of income effects (see Smith and Banzhaf [2001]).

The model resolves the issues associated with recovering Hicksian welfare measures for quality changes because the necessary conditions for equilibrium provide sufficient information to estimate a price index for quality. A utility consistent price index that defines when communities are equivalent, or, in other words adjusts for quality differences between them, is defined from the boundary indifference condition. In Epple and Sieg [1999] the community specific constants recursively define prices that are adjusted for the quality or public good differences in each adjoining location.[18]

The potential significance of relaxing the Willig condition can be gauged using the size of estimates of the incremental change in the willingness to pay for a specified change in the public good to a change in income. As Palmquist [2002] notes, the Willig restriction implies that the income elasticity of demand for the weak complement will exactly equal the income elasticity of the marginal willingness to pay for the related public good.[19]

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[18] The boundary indifference condition can be rewritten to express the community specific housing prices as a recursive function of the community specific intercepts, K_j. For example, this relationship is given as:

$$p_{j+1} = ln(exp(-\rho B p_j^{\eta+1}/(1+\eta)) - (\theta_j^{\rho} - \theta_{j+1}^{\rho})exp(K_j - \rho/(1+\eta)))$$

[19] This result can be extended for discrete increments in the public good (see Smith [2001]).

Equation (3.6) defines the general equilibrium willingness to (WTP_{GE}). We can gauge the importance of relaxing these restrictions by considering the responsiveness of the WTP_{GE} to income, labeled as WTP_m in Table 2 below. Equation (3.7) demonstrates that WTP_m is simply a measure of how the policy affects the marginal utility of income.

$$V\left(\alpha, m - WTP_{GE}, \theta_k^*, p_k^*\right) = V\left(\alpha, m, \theta_j, p_j\right) \tag{3.6}$$

$$WTP_m = \frac{\partial WTP_{GE}}{\partial m} = \frac{V_m\left(\alpha, m - WTP_{GE}, \theta_k^*, p_k^*\right) - V_m\left(\alpha, m, \theta_j, p_j\right)}{V_m\left(\alpha, m - WTP_{GE}, \theta_k^*, p_k^*\right)} \tag{3.7}$$

3.4 <u>The Los Angeles Metropolitan Area Model (LAM)</u>

The Sieg et al., [2002a] estimates for LAM use sales prices and housing characteristics between 1988 and 1992 to develop housing price indexes for an area that closely matches the SCAQMD. It is divided into the 92 school districts in Los Angeles, Orange, Riverside, San Bernadino, and Ventura counties west of the San Gabriel Mountains. These price indexes were based on fixed effects for each school district and controlled for the characteristics of the house and the lot.[20]

The index of local public goods was composed of an output-based measure for education, the average math test scores of the schools in each district from the 1992-93 California Learning Assessment System Grade Level Performance Assessment test, and the average of the top 30 one-hour daily maximum ozone readings at a given monitor in a year. These data were obtained by monitor and year from the California Air Resources Board. The ozone measure used for the model was a centered (by the sale year) three-year average, using the actual distribution housing sales as weights, for the readings to the closest monitor to each house. The average for the school district corresponds to the overall average for the houses in each district selling between 1988 and 1992. With these two public good measures, along with the estimates for the housing price indexes for each school district, the model was estimated with a generalized method of moments framework defined to match the computed (for each vector of parameter estimates) quantiles of the distributions of housing expenditures to their empirical counterparts. Table 2 reports the resulting estimates. As noted earlier (footnote #16), the parameters for education are set to unity to meet the normalization condition in the index of public goods.

To evaluate how the model performs in computing the prices required for a new locational equilibrium in response to change in amenities, we developed two comparisons. The first computes for 1990 the equilibrium prices implied by the observed levels of public goods and preference parameter estimates, with housing supply assumed inelastic, at levels consistent with the initial expenditures on housing (and estimated price indexes in 1990). These computed prices will be different from our estimates derived using the fixed effects in our hedonic model for housing sales in the area. A comparison of the two prices for 1990 is not simply a within sample prediction based on the fitting criteria used for the model. It is a gauge of the performance of our strategy using the necessary conditions for a locational equilibrium to compute equilibrium prices. In this case, we ask whether the results reproduce the initial price indexes used in estimating the model. Figure 1 plots this comparison and indicates a fairly close correspondence between the estimated and computed prices for 1990 with only Beverly Hills and Malibu as outliers.

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[20] Sieg et al., [2002b] evaluated the consistency with other approaches for developing price indexes and found a high level of consistency as well as indirect support for the locational equilibrium framework.

The second comparison is an out-of-sample evaluation of the necessary conditions for a locational equilibrium. In this case, we evaluate the plausibility of the model's estimated parameters for periods significantly outside the conditions used to fit the model. We altered ozone levels to correspond to 1995 conditions and recomputed the prices for a locational equilibrium with nothing else changed. Housing supply and measures of educational performance are held constant. These computed prices are then compared to new hedonic price estimates based on the normalized fixed effects derived from 1995 housing sale prices in the same area. Figure 2 plots the computed prices against the normalized fixed effects. This "out of sample" comparison also suggests a reasonably close correspondence, especially recognizing that a variety of factors, including housing supply, school quality, and overall growth in the area could well have had a marked effect on housing prices.

4. Using LAM for Policy Analysis

An important advantage of the locational equilibrium framework from the perspective of environmental applications is the ability to describe behavior in a spatially delineated context. We exploit this feature to compute the general equilibrium consequences of the scenarios that were evaluated in EPA's Prospective study to compute the general equilibrium price changes due to the ozone changes implied in each policy alternative. Figure 3 provides some indication of the scale of these projections in relation to the school districts that provide the lowest level of spatial resolution for our model. The "dots" falling within the boundaries of each school district identify the number of projected ozone distributions from EPA's air diffusion analysis.

Our analysis had access to the results of three sets of simulations from the air diffusion models: (1) summaries for baseline runs for ambient ozone concentrations projected using the air diffusion models for 1990; (2) air pollution regulations “frozen” at federal, state, and local controls corresponding to their 1990 levels of stringency and effectiveness; and (3) projected ozone levels corresponding to the situation where all federal, state, and local rules promulgated under the 1990 CAAA were implemented and the reduced emission levels presented in Table 1 were realized. Under both of these “future” regimes economic activities are allowed to increase and the projections of new emission patterns are developed for 2000 and 2010. All of these scenarios were developed by EPA staff to mimic the effects on the Los Angeles area.
Both of these second two cases were evaluated for each of two target years, 2000 and 2010.

Access to these data offers an unusual opportunity. It is possible to use the LAM framework for a policy analysis with the ambient ozone concentration data developed for that assessment. This section describes our findings. First, we describe the process used to initialize the model’s equilibrium prices to correspond to each of the business-as-usual scenarios and to compute the enhanced control cases for the with CAAA cases. Then, we outline the adjustments made to our initial model to enhance its resolution. Finally, with that background, we summarize three sets of welfare computations: (a) average general and partial equilibrium measures of Hicksian willingness to pay, homeowner rents, a relocation index (count), and the general equilibrium price and public good changes for the area as a whole; (b) average welfare measures for selected school districts; and (c) measures of the distribution of gains by income group identified through the LAM framework's ability to track income heterogeneity.

4.1 Implementing the Policy Scenarios

As we noted earlier, EPA's Prospective Analysis compares two situations describing the concentration of air pollutants in a future year – one with regulations held at their 1990 levels and a second where the regulations become more stringent to meet the mandates of the 1990 CAAA (recall Table 1 for our aggregate comparison). The first case is labeled "ba" for business-as-usual and the second "ct" for control in our graphs describing their implications for ozone concentrations in individual school districts.

The two years considered in EPA's Assessment were 2000 and 2010. Both are simulated outcomes because their analysis was undertaken between 1997 and 1999 and reported at the end of this period. In our comparisons, we also report the simulation runs developed for emissions associated with 1990 for the same six days. This benchmark year, together with our measures of actual conditions in 1990, was used to calibrate the simulated air quality (see footnote #21 below).

The community choice set used in our computations of different locational equilibria is different from what was used to estimate the model as well as what underlies our assessment of its performance in Figures 1 and 2. In April 2000 the Los Angeles Board of Education adopted a reorganization plan that replaced the Los Angeles Unified school district with eleven sub-districts. Figure 3 identifies the overall Los Angeles Unified district as the shaded area and the sub-districts within the boundary lines within this shaded area. We took advantage of this change, obtained the geo-coded boundaries for the new sub-districts, and recomputed the housing expenditures and math scores for the new school districts. This process allowed an expansion in the choice set for the LAM analysis. It provides enhanced spatial resolution for one of the largest and most diverse of the school districts. To implement the expansion the 1990 general equilibrium prices were recomputed for the expanded community choice set and serve as the starting point for our evaluation of the EPA policy alternatives.

The EPA simulations provide distributions for the readings based on the simulation period for each latitude and longitude in 1990, 2000, and 2010. The ozone levels defining ten deciles from 0.05 to 0.95 of the hourly readings were available for the centroids of each element in a 5-km grid overlapping our study area. Our estimated model relied on the average of the highest thirty hourly ozone readings for a year, which does not have an exact counterpart in the available data. As a result, we used the average (across the centroids of the 5 km grids assigned to each school district), for the readings defining the 0.95 decile to measure the highest readings. To assure consistency between the monitored and simulated readings, we constructed school district specific scale adjustments based on the average monitored ozone readings in 1990 for each school district relative to the average of EPA projected concentrations for the 0.95 decile in 1990.[21]

Figure 3 labels seven of the school districts in our revised choice set with identifying numbers. Figures 4 through 9 present six examples of the average projected concentrations (before adjustment, in parts per billion of ozone) for these six school districts. Each graph provides five empirical distribution functions, distinguished by year (1990, 2000, 2010) and air pollution control scenario (ba, ct). We present a few cases to illustrate the diversity of conditions across school districts. In some cases there is little difference in these functions with either the year or control conditions. In others, there are pronounced differences between ba and ct, but they vary by year. Other cases suggest air quality deteriorates relative to 1990 regardless of whether or not new controls are implemented. The ct cases simply reduce the extent of deterioration. For example, considering the 0.95 decile (the right-most point on each graph) in Figure 4 for the Santa Monica/Malibu Unified school district (ID = 102) along the coast (left side of Figure 3) of these highest readings, all are below the current 0.12 primary standard (parts per million). Moreover, the anticipated changes over time are modest, closely aligned with the 1990 levels. By contrast, if we consider La Canada Unified (ID = 88) in Figure 5, one of the new sub-districts from LA Unified (ID = 201) in Figure 6, or other districts away form the coast (e.g., Claremont Unified (ID = 75) in Figure 7 or Upland Unified (ID = 52) in Figure 8), the picture is quite different. Another coastal school district, Long Beach Unified (ID = 89) in Figure 9 displays an even more constant pattern of ambient ozone. All are dramatically below the standard and largely constant with respect to the target years and the level of control. Baseline conditions in 1990 can significantly exceed the standard (for ID = 52, 88, and 201) and controls will mean the difference between attainment of the standard versus non-attainment. The striking feature of these graphs is the heterogeneity of potential outcomes across school districts for a specific comparison year (e.g., 2000 versus 2010).

Our policy computations initialize the model and the locational equilibrium with the 1990 actual conditions. This price vector is used to compute the baseline equilibrium associated with each business-as-usual solution (i.e., 2000 and 2010). These equilibria assume that only the ozone concentrations in each school district change. The measures

[21] This process parallels EPA's practice in using their simulations (see EPA [1999], Appendix C, p. C-25).

assumed for education (math scores) are held at their initial levels (i.e., the 1992-93 averages used to estimate the model). Housing supply is constant at the baseline levels defined in our 1990 solution (disaggregation of the LA Unified supply to the 11 sub-districts is based on the housing expenditures implied in each sub-district in 1990). Finally, the with CAAA prices are defined starting from the without prices and calibrated ozone concentrations (ba) in each relevant year by introducing the new ozone concentrations implied by the regulations (ct) and computing the resulting locational equilibrium.

Figures 10 and 11 provide comparisons of the equilibrium prices and public good indexes for the without and with CAAA cases in 2000 and 2010, respectively. We also plot the initial baseline 1990 conditions for comparison. Movements from left to right of the schedule connecting the price/public good index pairs in each graph indicates that at each level of housing prices, a greater level of the composite public good is available. The increases in the public good index arise because the ozone concentrations are being reduced between the ba and ct cases for a number of school districts. Nonetheless, as our earlier discussion suggested, the changes are certainly not uniform. There are quite diverse outcomes. When households are allowed to move in response to these exogenous changes in pollution, there is a need to consider each equilibrium as a potentially different ordering of price and public good pairs. From the perspective of renters, the horizontal shift of the price/quality locus in the region of their initial location choice captures their welfare gain (this is not the case for owners). This point is important for the general equilibrium analysis of a large improvement at one location. From the perspective of renters, it is the shift of the price/quality locus that determines their welfare gain and not the new price and quality of their initial location choice. In the case of a large improvement at one, or a small number of locations, the impact on the location of the entire locus will be minimal. The improved locations will be reordered along the locus, but the locus itself will shift very little – leading to very little welfare gain for the renter households. This is not the case for owner households who will capture the impact of the quality improvement as it is capitalized into housing prices.

The close clustering of the observations between the with and without CAAA over the mid-range of values for the public good index, θ (labeled as "theta" in the Figures 10 and 11) indicates the modest changes in ozone and impact on prices for these communities. This pattern is especially pronounced for the 2010 scenarios in Figure 11. These changes are typically local shifts in the ordering of price/public good pairs (see the Appendix, Figure 2a -- we have included a graph with a few of the position shifts labeled).

4.2 General and Partial Equilibrium Benefit Measures

Table 3 summarizes the benefit calculations conducted for each scenario. Our policy comparison initializes the locational equilibrium for each year with household assumed to be located in communities based on the without CAAA ozone concentrations and the associated equilibrium prices for 2000 and 2010. When we allow ozone concentrations to correspond to the with CAAA controls, households can move and prices adjust to define the new locational equibrium. Thus, our definition for willingness to pay must take account of both potential changes. That is, as equation (3.6) suggested, a general equilibrium measure would recognize that each household can experience both new prices and new levels of the composite public good as a result of both the CAAA regulations and their relocation to a new school district. Equation (3.6) identifies these effects by allowing both p and θ to change (with θ^*, p^* designating after ozone change values). Relocation and the policy change imply that households with an initial location can realize change due to either or both influences. As a result, there is the potential for different community subscripts for θ^* and p^* versus θ and p on the left and right sides of our definition equation (3.6).

The computation of our locational equilibrium draws one million pairs of α and m from the joint distribution implied by our parameter estimates in Table 2. Our measures of housing expenditures in each school district serve to define the available housing supply. Each benefit measure reported in Table 3 varies with household. They are averages computed for the households (i.e., pairs of α and m) initially assigned to each school district. More formally, the average WTP_{GE}^{j} for school district j is defined in equation (4.1).

$$WTP_{GE}^{j} = \int_{c_j^0} WTP_{GE}(m,\alpha) f(\alpha,m)\, d\alpha dm \,/\, p(c_j^0) \tag{4.1}$$

where c_j^0 = baseline community designation

$p(c_j^0)$ = measure of number of households in c_j^0

The remaining statistics in Table 3 correspond to the general equilibrium *WTP* relative to income, the partial equilibrium *WTP*, defined in equation (4.2) below, the change in general equilibrium willingness to pay with income (WTP_m), as defined earlier in equation (3.7), measures of the average proportionate change in prices (Δp) and the public good ($\Delta\theta$) experienced by the households identified by their initial school district assignments, and the average proportionate reductions in ozone implied by the without and with CAAA scenarios for the initial school district (*Δ ozone*). The variable labeled count measures the fraction of the initially assigned households who move from their initial school district. *Δ Rent* is defined in equation (4.3) and offers an approximate gauge of the importance of the owner/renter distinction, which we do not explicitly address in the model.

$$V(\alpha, m - WTP_{PE}, \theta_j^*, p_j) = V(\alpha, m, \theta_j, p_j) \tag{4.2}$$

$$\Delta Rent_j = (p_j^* - p_j) \cdot H_j \tag{4.3}$$

There are wide discrepancies in the average general equilibrium willingness to pay (computed over all school districts) and the measures when we disaggregate based on the initial locations. The differences presented in Table 3 are small because they were selected to match the graphs for the changes in the ozone concentrations. The full range of average values, considering the WTP_{GE} averaged over all households in each school district, for 2000 is from \$53 (in the Anaheim Union High School district) to \$1694 for the Palos Verdes Peninsula Unified. The differences between partial and general equilibrium measures vary with the size and magnitude of the price changes as we might expect. Average rent changes are less than twenty percent of the general equilibrium willingness to pay for the 2000 comparison, but there are cases where they are large (e.g., Santa Monica/Malibu Unified). They are much larger for the projected effects of the CAAA controls in 2010 where the ozone improvements are smaller but price changes are somewhat larger in absolute magnitude. Finally, the implied responsiveness of *WTP* to income (WTP_m) is consistently greater than zero (a value of zero would be required to satisfy the Willig condition).

Our estimates for the per household benefits in 2010 are generally smaller than for the ozone concentrations implied by regulatory effects in 2000 if we exclude changes in rents. Comparing the WTP_{GE} plus the *Δ Rent* for the two years implies that 2010 would have larger gains for homeowners than 2000. Neither our study nor the EPA analysis allows for real income growth at the household level to affect the benefit measures.[22] Thus, our findings for 2010 arise solely from the implied public good and general equilibrium price changes induced by the spatially delineated pattern of ozone concentrations for the business-as-usual and control scenarios.

4.3 Distributional Effects of Policy

Table 4 summarizes the *WTP* estimates comparing without and with CAAA in 2000 and 2010, averaged (across school districts) by income quantile. As with our other summaries, results for 2010 generate lower benefits to all groups and higher rents than those in 2000. On average the highest income group realizes twice as much in willingness to pay as the lowest quantile. This comparison holds regardless of whether we consider the general or the partial equilibrium measures. In some respects it understates the heterogeneity in gains by income group and location. Figures 12a and 12b graph the average general equilibrium and partial equilibrium measures of *WTP* by school district (ranked by p and θ before the change) for the first three quantiles for the without and with CAAA comparison in 2000. The distinctions by quantile are relatively easy to identify in Figure 12a, with the approximately parallel top line the average WTP_{GE} for the group between the median and the top seventy-five percent income quantile and the middle line corresponds to the average WTP_{GE} for the group between the

[22] Thus, there is a subtle contrast between the assumptions used to compute emissions which assume growth and what was used to compute benefits which implies growth in the level of economic activity does

median income and the boundary for the lowest twenty-five percent. The lowest line is the average for this lowest group. Figure 12b repeats this plot for the WTP_{PE} but it is much more difficult to separate them without identifying the means for each quantile group and community.

The pattern displayed in Table 3 is also apparent from Figure 12a in that higher benefits are experienced with each increase in income, as theory would suggest. However, the range of gains is much wider than what is implied by the overall means, with the lowest community and lowest quantile gaining about $33 in 2000 and the second highest school district and quantile at $2,317. Figure 12b considers the WTP_{PE} for the same policy. Here, the communities are also ordered by the initial p and θ, but the welfare evaluation considers only the public good changes, holding price at its initial level. The resulting discrepancy in the smooth ordering for the middle communities arises because the prices do not reflect the induced relocation after the change in ozone conditions and prices.

Thus, heterogeneity in income, taste for public goods, and spatial differences in the implications of environmental policy induce a diverse pattern of gains that would be overlooked with area wide averages, even when they are disaggregated by income quantile.

5. Implications

The locational equilibrium framework provides a basis for computing consistent benefit measures at a level that identifies how diverse households (in terms of income and tastes for public goods) adjust to "the environmental cards they are dealt" by the

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not affect real income.

combination of policy and nature. The results of our re-evaluation of EPA's Prospective Analysis are relevant to several on-going controversies in benefit cost analysis, including the issues associated with accounting for general equilibrium effects and incorporating environmental equity. We consider each in turn.

The Epple-Sieg framework is the first (to our knowledge) to allow Hicksian welfare measures to consistently account for heterogeneity in incomes, tastes, and environmental effects in the activities associated with preference estimation, general equilibrium price computation, and benefit assessment. We have found that there are insights available when economic models are up to the task of matching the potential for economic adjustment on the part of heterogeneous agents with the diversity in policy outcomes projected by modern air diffusion models.

The estimated annual benefits for different groups, as a result of the environmental conditions experienced, their income, and their tastes for public goods, can vary by a multiple of over 50 -- from about $30 to over $2,000 (in 1990 dollars) for the ozone changes in Los Angeles due to continuing to implement the mandates of the Clean Air Act Amendments. The current methodologies used for benefit assessment have no consistent way to account for most of the sources of these differences.

Environmental equity defined in terms of which income groups receive what environmental benefits from existing and new policies cannot be considered in isolation from the spatial distribution of the changes in amenities arising from policies <u>and</u> the potential for household adjustment. While our analysis assumed negligible transactions costs, it is clear that any evaluation of the distributional effects of large-scale policy changes cannot rely exclusively on partial equilibrium measures or ignore the role of rent changes for owners versus renters. A simple comparison of the average general and partial equilibrium measures of annual willingness to pay for the ozone changes due to the CAAA would lead to very different conclusions about the distribution of benefits from these policies (i.e., Figures 12a and 12b).

Heterogeneity in the outcomes and benefits of environmental policies should be treated as the norm. When the differential effects of environmental policies can be identified in spatial terms, we have suggested location equilibrium models offer a consistent framework to estimate and evaluate policy. In the end, this method brings the analysis closer to the theoretical ideal usually sought by most economists and often criticized by those concerned with its propensity to accept the status quo (in terms of ability to pay). The challenge that remains is in determining how these estimates of heterogeneous gains derived by tracking of distributional effects can be used as part of an informative assessment of the equity effects of environmental policies.

Table 1: EPA Projected VOC and NO_X Emissions for Los Angeles (tons per day)

Source/ Pollutant	Base 1990	Without CAAA 2000	Without CAAA 2010	With CAAA 2000	With CAAA 2010
VOC					
Area	758	770	871	607	700
On-Road Mobile	1,179	999	1,168	410	213
Point					
Low Level	197	196	196	196	158
Elevated	1	3	2	3	2
Total	2,135	1,968	2,237	1,216	1,073
NO_X					
Area	450	467	529	453	463
On-Road Mobile	993	1,280	1,573	879	626
Point					
Low Level	216	186	186	139	139
Elevated	19	19	12	18	8
Total	1,678	1,953	2,300	1,489	1,236

Source: U.S. Environmental Protection Agency [1999]. These estimates were taken from Table C-4.

Table 2: LAM Parameter Estimates

Parameter	$\mu_{ln(m)}$	$\sigma_{ln(m)}$	$\lambda_{ln(m),ln(\alpha)}$	$\rho / \sigma_{ln(\alpha)}$	v	η	B	$\mu_{ln(\alpha)}$	$\sigma_{ln(\alpha)}$	γ
Estimate	10.52	0.34	-0.31	-0.26	0.86	-0.17	1.19	-0.39	0.42	-1.59
Std. Error	(0.01)	(0.01)	(0.04)	(0.03)	(0.02)	(0.06)	(0.28)	(0.94)	(0.03)	(0.95)

Source: Sieg et al. [2002a]

$\mu_{ln(m)}$ = estimated mean of log of income

$\sigma_{ln(m)}$ = estimated standard deviation of log of income

λ = estimated correlation log of income with log of tastes parameter

$\mu_{ln(\alpha)}$ = estimated mean for log of α (taste parameter)

$\sigma_{ln(\alpha)}$ = estimated standard deviation of α

v = estimated income elasticity

η = estimated price elasticity

γ = estimated parameter for ozone in $\theta(.)$

Table 3: Alternative Benefit Estimates With and Without CAAA for 2000 and 2010

	ΔOzone	Δp	Δθ	count	WTP_{GE}/m	WTP_{GE}	WTP_{PE}	ΔRent	WTP_m
2000									
area-wide	-0.128	-0.002	0.014	0.401	0.023	910	817	94	0.102
Upland Unified (52)	-0.204	0.015	0.021	0.164	0.016	617	541	111	0.076
Claremont Unified (75)	-0.233	-0.005	0.013	1.000	0.018	676	569	109	0.078
La Canada Unified (88)	-0.184	0.003	0.015	0.916	0.035	1434	488	-217	0.154
Long Beach Unified (89)	-0.019	-0.016	0.009	1.000	0.028	1084	676	126	0.116
Santa Monica/Malibu Unified (102)	-0.106	-0.012	0.009	0.254	0.040	1629	1025	606	0.165
"Area B" new LA Unified Sub-district (201)	-0.208	0.015	0.017	0.142	0.027	1076	1006	137	0.123
2010									
area-wide	-0.107	-0.001	0.013	0.274	0.022	846	679	180	0.095
Upland Unified (52)	-0.180	-0.027	0.003	0.020	0.017	651	711	-122	0.071
Claremont Unified (75)	-0.204	-0.015	0.008	1.000	0.009	651	332	323	0.073
La Canada Unified (88)	-0.205	0.022	0.019	1.000	0.028	1135	2005	-901	0.132
Long Beach Unified (89)	-0.009	-0.023	0.006	0.000	0.027	1070	387	710	0.113
Santa Monica/Malibu Unified (102)	-0.187	0.008	0.016	1.000	0.033	1383	1839	-472	0.150
"Area B" new LA Unified Sub-district (201)	-0.181	-0.003	0.011	0.000	0.010	1075	380	784	0.118

Table 4: Willingness to Pay by Income Quantile

Policy Scenario/Quantile	m	WTP_{GE}	WTP_{PE}	ΔRent
2000				
First Quantile	22,478	604	543	62
Second Quantile	33,400	793	712	82
Third Quantile	41,675	961	863	100
Fourth Quantile	58,216	1,282	1,151	133
2010				
First Quantile	24,443	560	451	118
Second Quantile	33,376	736	593	154
Third Quantile	41,611	891	717	187
Fourth Quantile	58,101	1,189	956	249

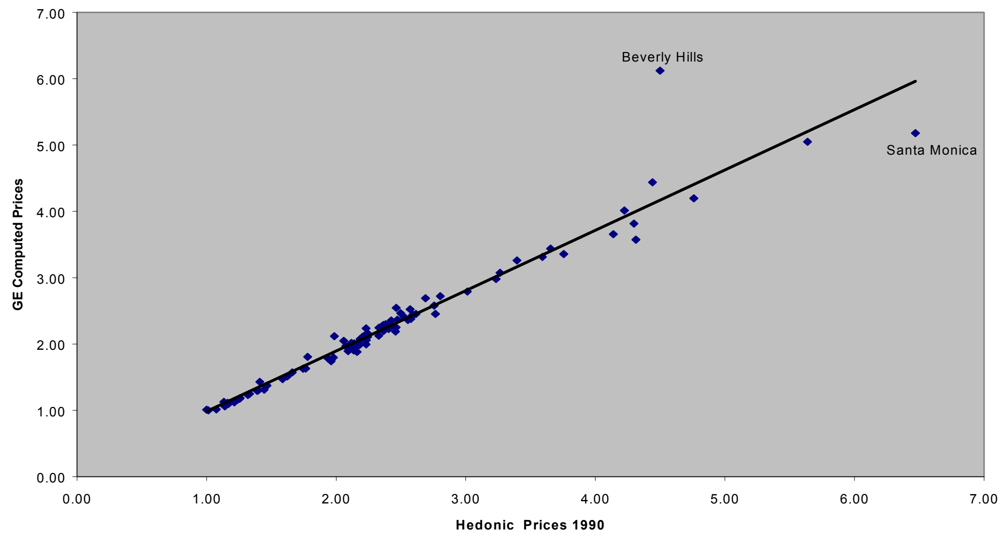


Figure 1: A Comparison of the Normalized Hedonic Price Index Versus Computed General Price Indexes

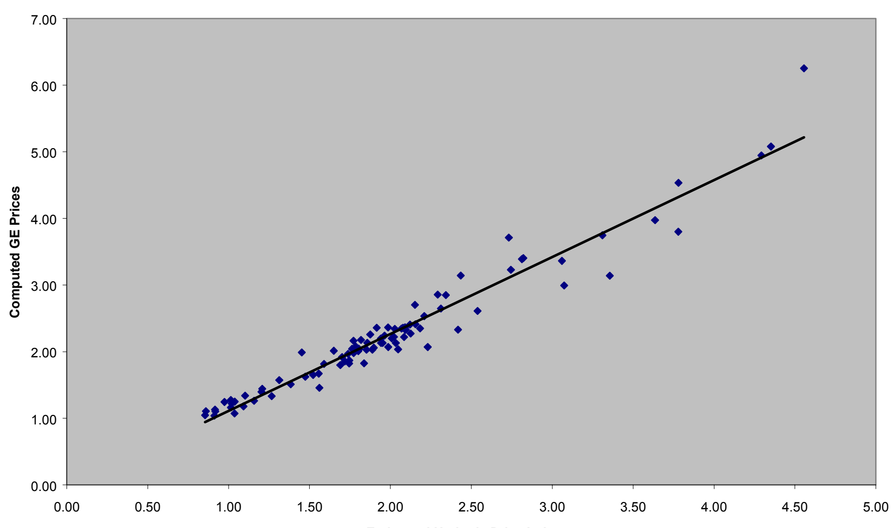


Figure 2: Comparison of Hedonic Price Indexes and LAM – GE Solutions for 1995

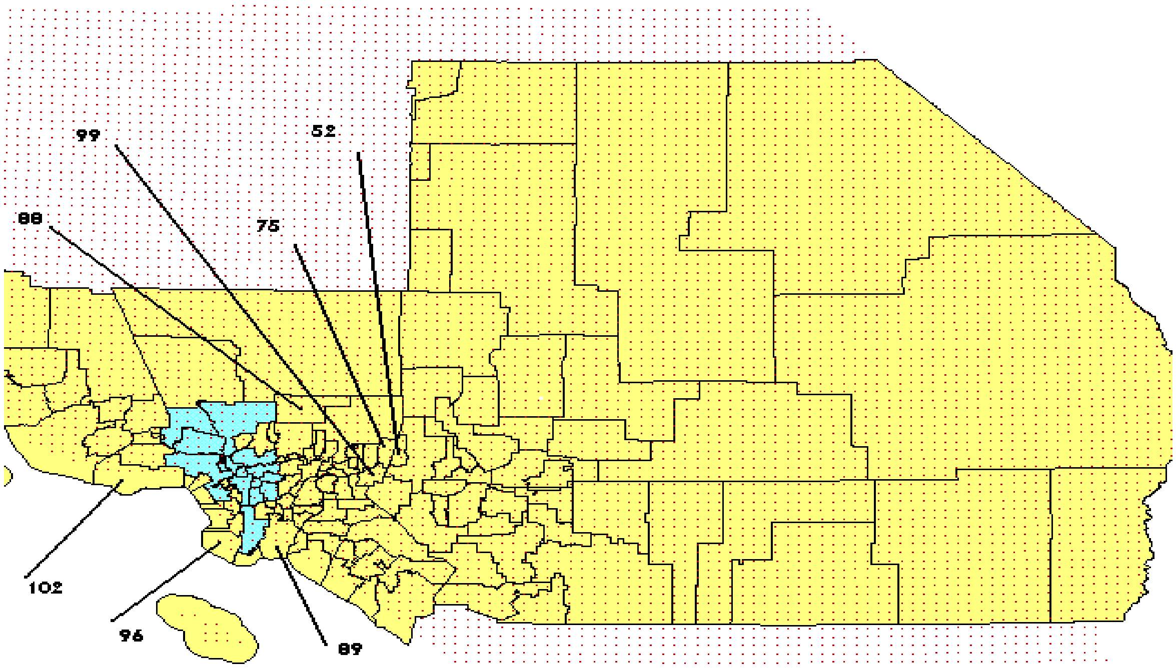


Figure 3: LAM School Districts and EPA UAM Locations for Estimated Ozone Readings

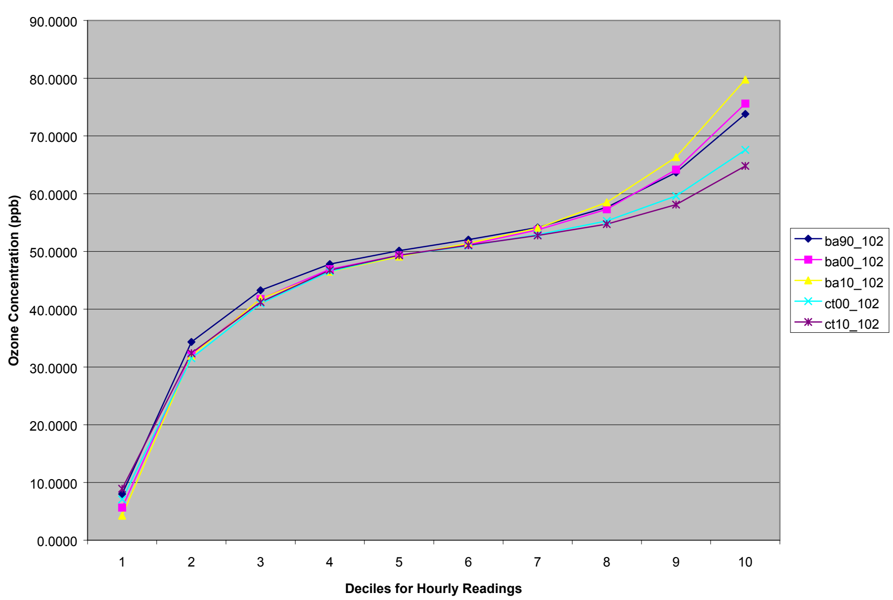


Figure 4: A Comparison of Projected Ozone Concentrations for Santa Monica-Malibu Unified School District

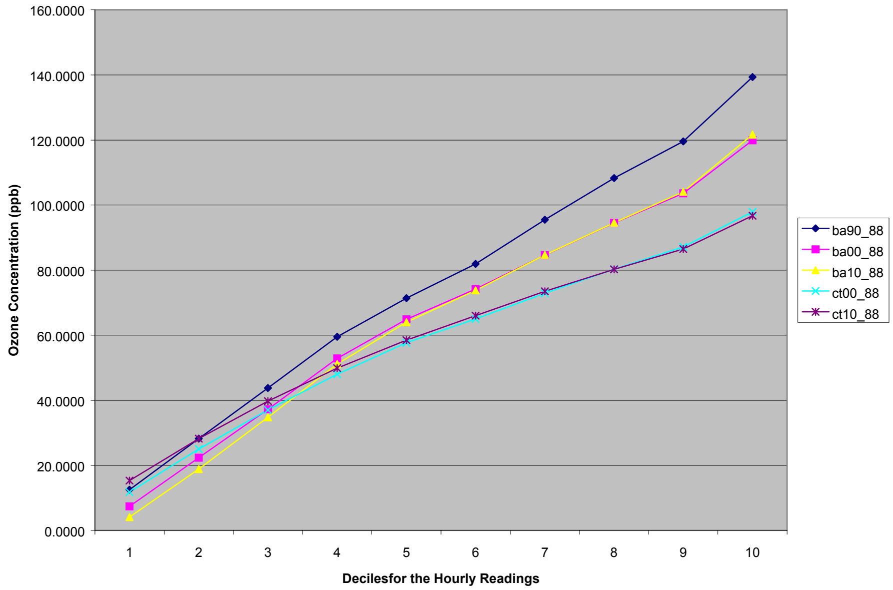


Figure 5: A Comparison of Projected Ozone Concentrations With and Without CAAA for LA Canada Unified School District

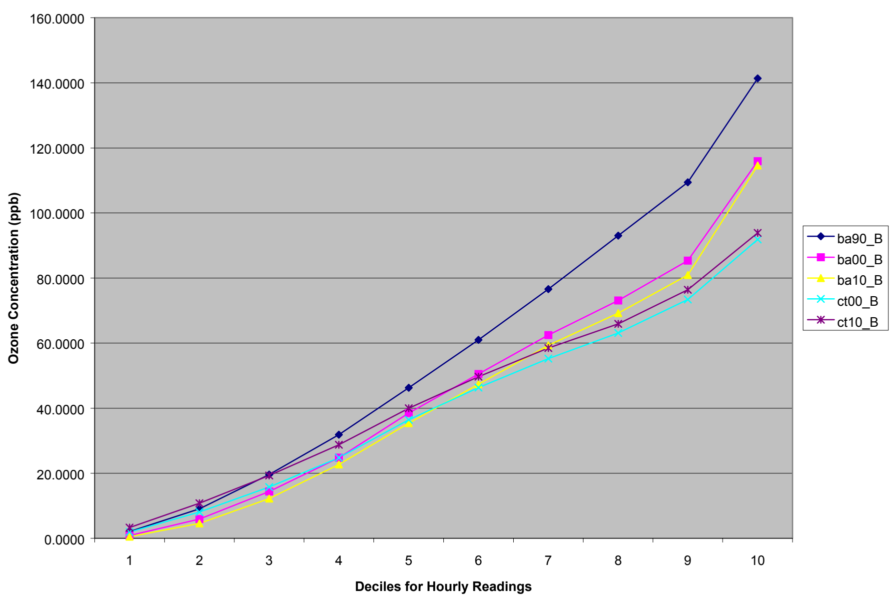


Figure 6: A Comparison of Projected Ozone Concentrations With and Without CAAA for New LA "Area B" School District

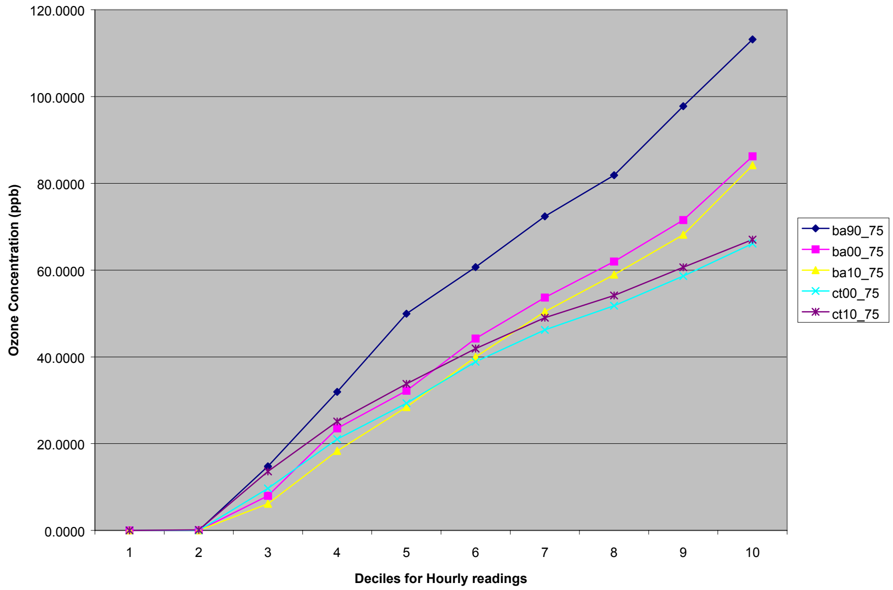


Figure 7: A Comparison of Projected Ozone Concentrations With and Without CAAA for Claremont Unified School District

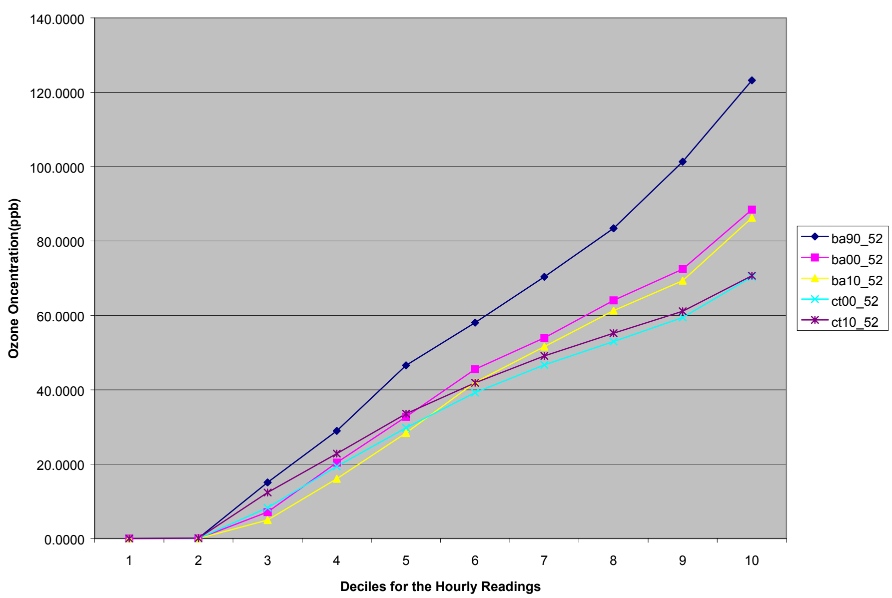


Figure 8: A comparison of Projected Ozone Concentrations for Upland Unified School District

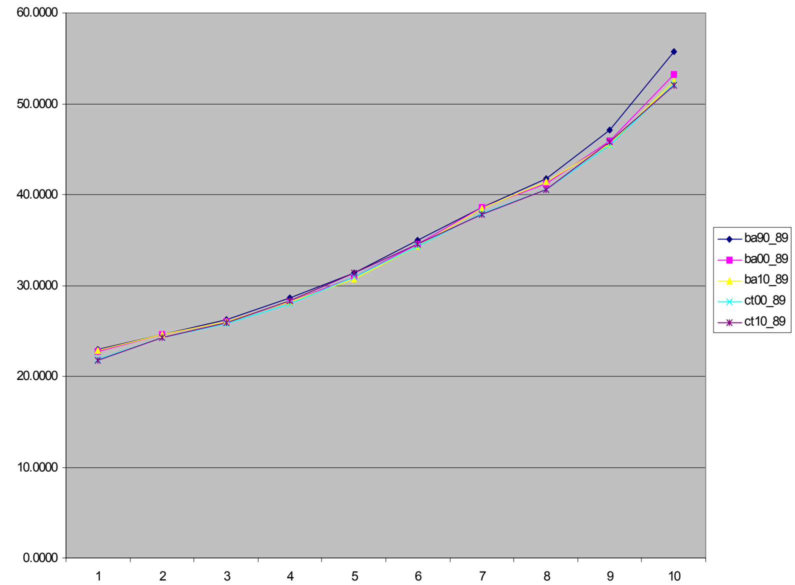


Figure 9: A Comparison of Projected Ozone Concentrations With and Without CAAA for Long Beach Unified School District

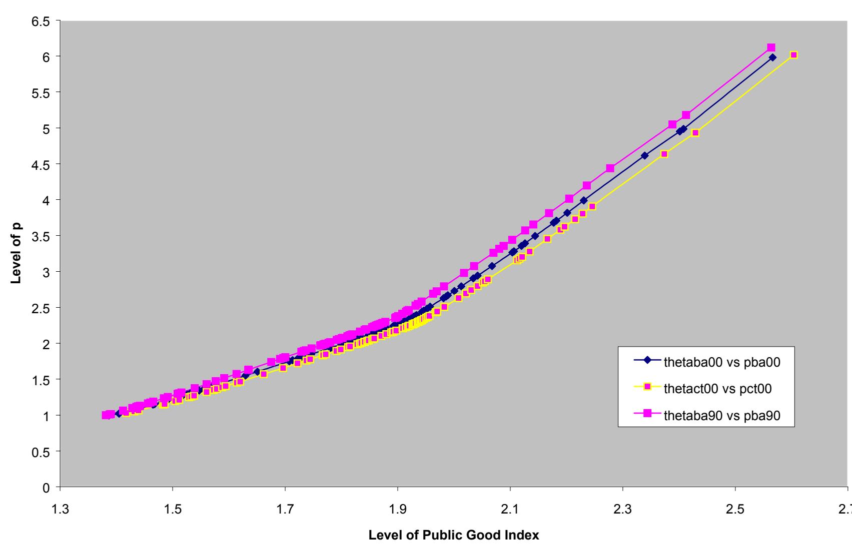


Figure 10: Computed General Equilibrium Prices for With and Without CAAA 2000 Compared to Baseline 1990

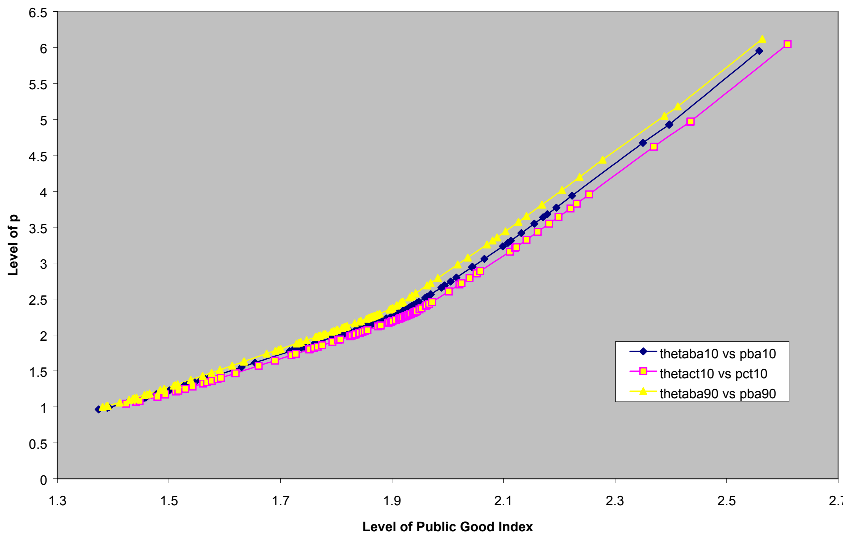
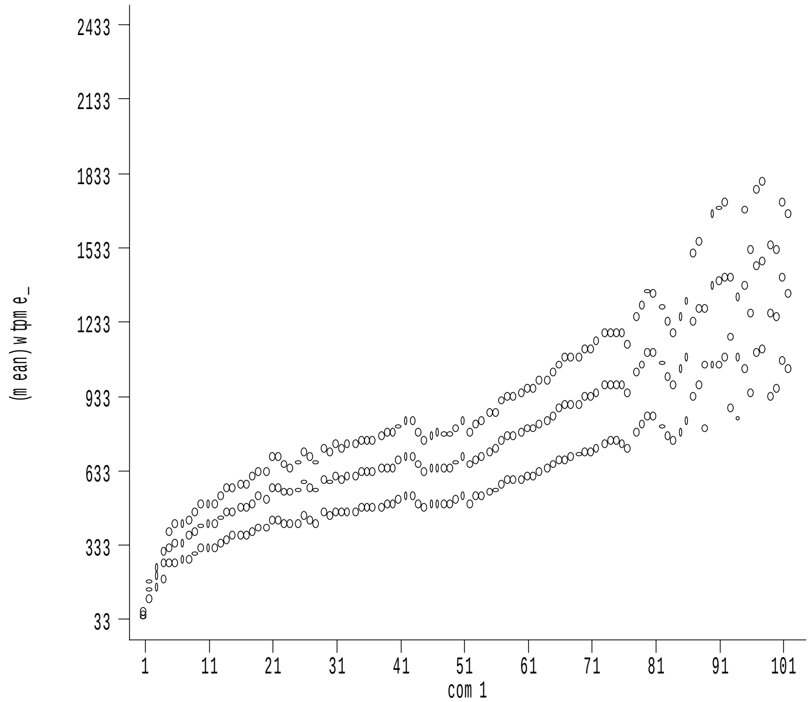


Figure 11: Computed General Equilibrium Prices for With and Without CAAA 2010 Compared to Baseline 1990



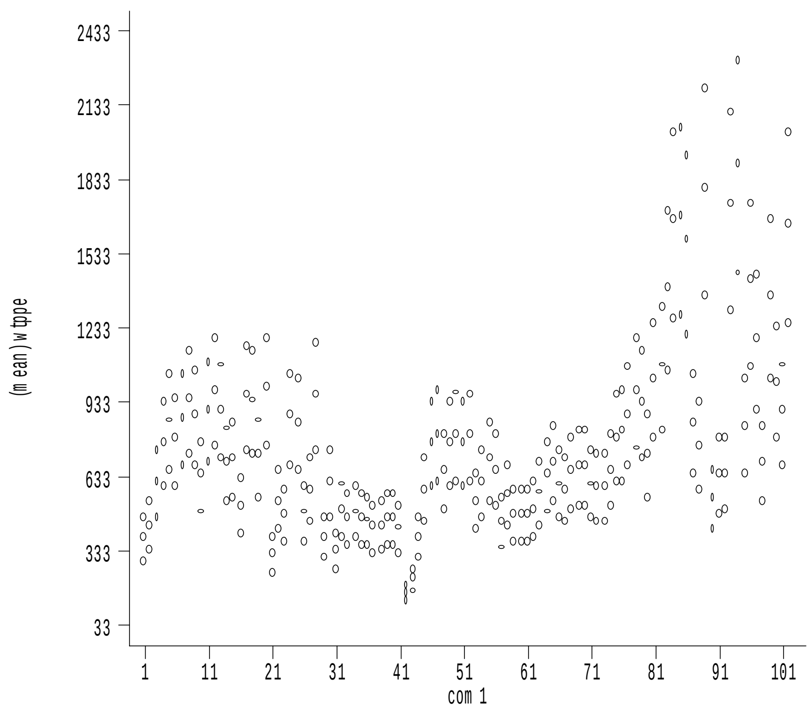


Figure 12a and 12b

Appendix

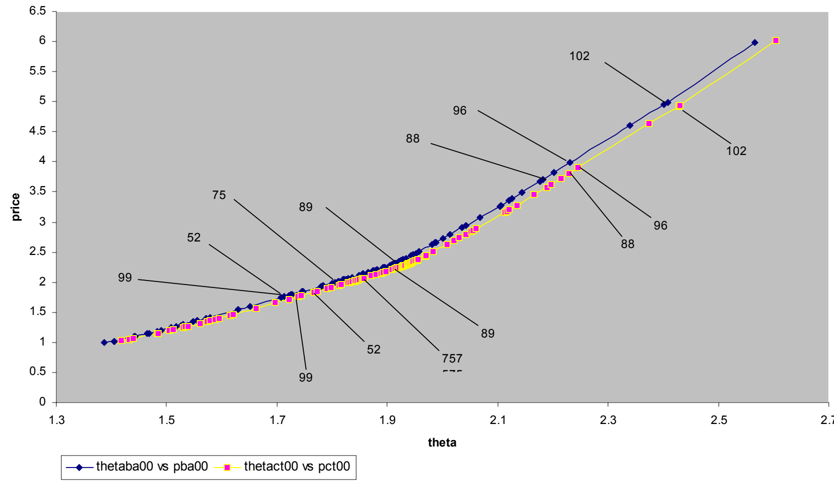


Figure 1a: Change in Ordering of Price/Public Good Pairs for 2000

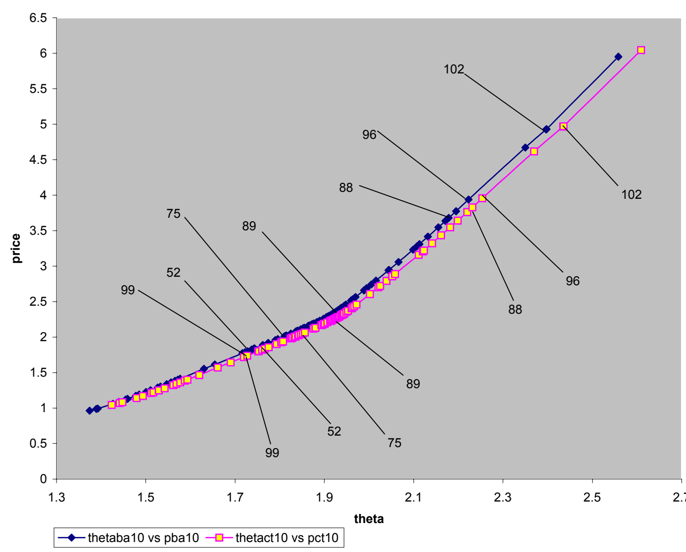


Figure 2a: Change in Ordering of Price/Public Good Pairs for 2010

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