Valuing Incremental Highway Capacity in a Network*

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Abstract

The importance of increments to an existing highway system depends upon the values they add to the pre-existing network. Over 50 years ago, Mohring [1965] suggested this logic for planning optimal highway investment programs. Moreover he argued it could be implemented by measuring the quasi-rents generated by specific additions to an existing roadway system. To our knowledge no one has managed to apply his ideas. This paper uses a unique set of additions to a loop roadway in metropolitan Phoenix, together with detailed records of housing sales over the past decade, to meet this need. We find that the capitalized value of four segments added during this period range from 54 to over 350 million dollars per mile of the roadway addition. These differences suggest there is significant potential for using this strategy in prioritizing highway projects. Our analysis also exploits the ability to identify distinct subdivisions to develop a two-step method, analogous to the Athey-Imbens [2006] difference-in-difference estimator, which provides an economically consistent measure of capitalization integrating Starrett’s conditions for full internal capitalization into the design of the estimator.

Keywords: Infrastructure; Difference-in-Difference; Quasi-rents; Capitalization; Highways

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I. Introduction

A highway is a network whose economic value depends on its inter-linked connections. Some links have greater value than others. While this judgment is common sense, to our knowledge no one has confirmed this basic logic by measuring how specific roadway segments contribute to a highway network. It is especially relevant for current policy discussions because one third of the eighty one billion in spending on infrastructure in the stimulus package under the American Recovery and Reinvestment Act of 2009 is for highway and bridge projects. There has been little guidance offered on how to select among competing projects, aside from the criterion of being ready to start quickly. Nearly fifty years ago one of the early leaders in transportation economics, Herbert Mohring [1965], answered the priority setting question by calling for segment specific measures of the quasi rents associated with additions to capacity as part of policies designed to maximize the benefits from a highway network. He argued that pricing and investment decisions should take into account the differential economic importance of the links in these networks. Much of the literature since that time has grappled with the congestion pricing component of his two decision criteria (see Parry [forthcoming] as an example). However, his recommendation to add capacity based on the incremental value of such investments by link has not. A key reason has been the challenges posed in estimating these quasi-rents. This paper demonstrates that quasi-rents can be estimated based on a housing markets’ ex post responses to new highways and suggests how the results from these types of assessments can be used for ex ante analyses.
Using four new highway segments developed around metropolitan Phoenix, Arizona between 2000 and 2007, we estimate the effect of freeway additions as separate treatments influencing residential housing values. Our strategy exploits a framework similar to the Athey-Imbens [2006] change-in-change method and recovers estimates for the separate residential land capitalization for each new highway segment. We use subdivision fixed effects to control for unobservable (to the analyst) attributes of neighborhoods and of the households that select them. Within a Tiebout framework we expect households with similar preferences for neighborhood features will sort into similar subdivisions. Under the assumption that the distribution of these unobservables does not change over time, we can relax some of the assumptions of a conventional difference-in-difference estimator and use a straightforward two step regression model to estimate the treatment effect across multiple groups and time periods.

Our application is also consistent with the sufficient conditions for full internal capitalization of projects yielding local public goods based on Starrett’s [1981] classic analysis of what can be learned from land markets. As such, it measures the quasi-rents provided by segments to a loop highway network in Phoenix. By using a set of fixed effects models, one for each time period, we are able to: estimate the relative value of each new highway link; control for unobserved land uses affecting private homes at the subdivision level; and use a feasible GLS estimation that takes account of covariance structures for the estimated fixed effects in each time period. The empirical model confirms Mohring’s intuition. That is, we identify a clear ranking of the highway segments based on their estimated quasi-rents.
Section two develops the context for interpreting estimates of the residential land capitalization of new highway segments as measures of the benefits generated by increments to highway capacity. Section three summarizes the key elements of our estimating model and describes the data used in measuring the segment specific benefits. Section four presents the findings and discusses their role in judging the net benefits from the new highway segments adding to metropolitan Phoenix’s loop road system. In the last section we describe how this logic could be adapted to consider ex ante assessment of infrastructure to assist in better rationalizing the choice among “shovel-ready” investments in the future.

II. Land Capitalization and Highway Quasi-Rents

Starrett [1981] identified two types of capitalization as conceptual extremes. External capitalization derives from forces between communities and internal is associated with forces inside communities. Internal is most relevant to local public goods where proximity to the public good matters. In fact, Starrett used highways as one of his examples of local public goods relevant to this type of capitalization. We adapt his basic conceptual framework to explain how residential housing capitalization measures the effects of increments to highway capacity. Our model begins at the household level. Each is assumed to have a preference function, \( U(\cdot) \), that includes a measure of the public good associated with the highway system, \( q \), and a measure of that household’s use of the system along with the amount of land and a numeraire good. Following his notation we designate the use of the highway capacity as \( g \). The location of links to the network will affect the cost of a trip and the value of \( q \).
Our empirical strategy uses neighborhood fixed effects to control for unobservable variables including the contribution of new or enhanced highway segments that improve the accessibility of the neighborhood to the transportation network. A subdivision or a group of homes built approximately the same time, usually by one builder, on a specific tract of land is used to designate a neighborhood. As a rule, each subdivision has a bundle of attributes including size and quality of homes together with the surrounding landscape and a location that targets specific types of households. Thus, this designation fits Starrett’s second requirement for full internal capitalization that households are reasonably homogeneous in their attitudes toward the public good, controlling for other attributes of the houses and locations they select.

The household decision process envisions a conditional choice of \( g \) and \( l \) (land) for each location, or in our case, each subdivision. Thus, maximizing equation (1) for each location (where the budget constraint is substituted into the function) defines a conditional indirect utility function, \( \nu(\cdot) \), that allows us to specify the conditions for full internal capitalization.

\[
\text{Max } U^i(g, l, m^i - T^i - f(g, s) - r_s l) \\
\]

where:

\( m^i \) = household income

\( T^i \) = a head tax on each household

\( f(\cdot) \) = cost of highway use

\( r_s \) = rental price of land in subdivision \( s \).
There will be no internal capitalization if the conditional indirect utility function derived from this choice problem, \( v_i^j \), is independent of the subdivision. This condition must be satisfied before and after a project adding to the highway system. Thus, following Starrett and assuming preferences are additively separable with \( q \) and \( g \) entering one component, land another, and quasi linear in the numeraire, the envelop condition defines cases that preclude internal capitalization\(^1\). These situations arise when the expression defined in equation (2) is independent of \( s \). This case contrasts with one where the equilibrium assures that the effects of a change in the public good are independent of the neighborhood selected (in this case the \( s \) and \( m \) neighborhoods) in equation (2). When the indirect utility function is independent of the neighborhood then there is no scope for the rent to adjust to \( q \). In effect there is no spatial differentiation across neighborhoods.

\[
\frac{dq}{d\mathcal{U}} = \frac{dq}{d\mathcal{U}} (q, g_s) + l_s \frac{dr}{dq} = \frac{dq}{d\mathcal{U}} (q, g_m) + l_m \frac{dr}{dq}, \text{ for } s \neq m \tag{2}
\]

Our empirical model tests the internal capitalization condition directly. We can consider the subdivision fixed effects as measuring the contribution to the housing prices of a neighborhood as a result of its attributes, including location. These effects account

\(^1\) This structure is consistent with the use of subdivision fixed effects (in a hedonic model for housing prices) to capture the capitalization of enhanced local access in land values. The hedonic controls for housing attributes. The features of households causing them to select a subdivision are reflected thru the impact of household sorting on the estimates of the subdivision parameters. Because land is assumed to make a separable contribution to preferences the fixed effects will measure the impact of new highway segments on the locational value of parcels in each area. Starrett’s theoretical result resolves concerns Mohring [1961] raised twenty years earlier about the ability to use land capitalization to measure highway benefits. He noted that: “Increases in land values are not in themselves net highway benefits… They reflect an actual or potential transfer of benefits derived from highways from one population group to another” (p.236)
for the unobserved factors that distinguish home prices in a particular neighborhood from all others, after controlling for the house attributes, the lot size, and other observables. Changes in these fixed effects corresponding to changes in local public goods capture the effects of the \( \frac{dr_j}{dq} \) terms in equation (2). The subdivision fixed effects are specified to be a function of added highway segments completed before the sales of homes used to measure these effects. A failure to detect differences in the contributions of new highway segments to proximate sub-divisions would suggest no internal capitalization.

Internal capitalization also requires that the benefits are “intra-marginal.” Starrett explains that in cases like ours this condition means that some neighborhoods realize no value from increments to the local public good. In our case it translates into an assumption that not all subdivisions within the overall area gain from each new highway segment. Within the logic of quasi-random experiments we can define a set of subdivisions that serve as controls. At some distance from a new highway segment the segments role in creating increased access to the network has no value. This condition is consistent with the features of a loop roadway that provides a highway network within a metropolitan area but is not enhancing connections to outside metropolitan areas. The highway segments we focus on serve metropolitan Phoenix, but do not change the area’s accessibility to other more distant population centers. As a result, any added segments to the roadway have primarily a local incremental value. The assumption of limited scope for each segment’s effects on neighborhoods is broadly consistent with our findings. To
meet this condition we impose a three mile threshold for effects as a maintained hypothesis for our second step estimates.²

When these conditions are satisfied the incremental benefits of additions to a public good are measured by residential land capitalization. These increments can be used to estimate the net quasi-rents due to the project. Starrett’s proof of this result assumes the lump sum taxes imposed on households cover the incremental costs of the increases to public goods and that household income includes profit shares, rental income on land, and labor earnings, with the latter unaffected by increments to q.³

While there are a number of important assumptions maintained in his general capitalization result, the framework nonetheless provide a starting point for gauging the existence of differential quasi-rents for highway segments. In our application, these differences are based on differences in residential housing capitalization by neighborhoods. We expect that these neighborhoods are affected in different ways by the addition of incremental links to the highway infrastructure.

III. Empirical Model and Data

A. Empirical Model

The analysis is based on a two step hedonic property value model. Separate first-stage models are estimated for housing sales in each of five periods – a control and four other periods with time spans defined by the sequential dates for the opening of each

² We investigated the sensitivity of our results to alternative specifications of this threshold and the basic conclusions are maintained. In particular, we examined a 5 mile cutoff and found that magnitudes of parameters decreased, but signs and significance were maintained.

³ There are differences in property tax rates across some of the municipalities and school districts within our study area, Maricopa County, but these will also be controlled with our subdivision fixed effects.
highway segment. The samples include all subdivisions with at least 12 sales per time period. Each model includes a full set of variables describing the homes’ characteristics and location as well as fixed effects identifying the subdivisions that contain the homes involved in the sales for that time span. Equation (3) specifies the general form for the first-stage hedonic model specification, a semi-log equation. It maintains that the housing sales price is a function of housing and lot characteristics, a monthly time index, and subdivision fixed effects.

\[
\ln P_i = \alpha_0 + \sum_j \beta_j c_{ji} + \sum_k \gamma_k s_{ki} + \sum_l \theta_l M_{kt} + \epsilon_i
\]  

(3)

where:

- \( t \) identifies the time periods for each sample
- \( c_{ji} \) designates housing and lot characteristics
- \( s_{ki} \) corresponds to subdivision fixed effects
- \( M_{kt} \) = month fixed effects
- \( \epsilon_i \) = unobserved error

The second step “stacks” the five sets of estimates for the fixed effects relating them to two different characterizations of highway effects on subdivisions. The model is an unbalanced panel with different subdivisions affected by the highway segments in each time interval.\(^4\) When subdivisions appear in repeated sub-samples over time the qualitative terms for highway segments are coded so that they influence land values (thru

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\(^4\) In addition to different segments, it is possible that we might not observe a minimum of twelve sales within a subdivision for some time periods. Either outcome would remove a subdivision from the housing sales included in the first step model and thus the corresponding subdivision fixed effect for the time period in which this occurs.
the subdivision fixed effects) from the point of completion until the end of the sample period. Equation (4) specifies the estimated subdivision fixed effects to be a function of a measure of distance to the highway segment along with an indicator of whether the highway segment opened before each of the sets of housing sales represented in the separate first stage hedonic models providing the fixed effect measures. The model also includes a qualitative variable for noise and dis-amenity effects attributed to subdivisions where the median household is within 1500 feet of a highway segment and a measure of distance to the central business district. The distance measure to each highway segment is considered in two different formats—as a dummy variable for the subdivisions within three miles of the roadway segment and, as a robustness check, using the inverse distance to the roadway truncated to zero at 3 miles. As noted above, after three miles we assume there is no influence of the roadways on subdivisions. This distance cutoff is consistent with the maintained assumption of the Starrett framework. After each roadway opens these variables (and the fixed effects identifying subdivisions adjacent to each segment) influence the estimated subdivision fixed effects from the hedonic price models.

\[ \gamma_{kt} = \alpha + \sum_{l=1}^{4} b_{l} d_{lk} D_{kt} + \sum_{l=1}^{4} e_{l} A_{lt} + c d_{CBDk} + u_{kt} \]  

(4)

\[ d_{lk} = \text{corresponds to either the dummy variable for the distance interval or the inverse distance of road segment } l \text{ from subdivision } k \]

\[ D_{kt} = 1 \text{ If the road segment was opened in the time period defining interval } t \text{ or in a previous time period} \]

\[ = 0 \text{ otherwise} \]
$A_{ikr} = 1$ if the subdivision was adjacent to a completed highway segment during the period

= 0 otherwise

$d_{cbd_k} = \text{distance of subdivision } k \text{ to the central business district.}$

The two step strategy assures we have estimates of both the fixed effects and their covariance structure. Applying a Cholesky decomposition to each estimated covariance structure the variables in equation (4) may be transformed so that the feasible generalized least squares estimator required for the second stage model can be derived applying OLS to the transformed data. This decomposition is especially convenient because there are over 11,000 subdivisions included in the full sample defined across our 5 sub-periods which comprise our unbalanced panel of subdivision fixed effects.

By allowing the housing price effect of the roadway segment to depend on unobservable characteristics of households that cause them to sort to specific subdivisions our model is consistent with the Athey-Imbens generalization of a difference-in-difference (DD) framework. In their framework these unobservable attributes are constant over time and the effect of the treatment is increasing in these unobservable attributes. We need only assume they are constant for households selecting each subdivision and constant over time. Furthermore, this homogeneity is also consistent with Starrett’s assumption of the preference heterogeneity underlying full internal capitalization. That is, similar households sort to the same subdivision and the differences in preferences are part of the unobservables reflected in the subdivision fixed effects. The relationships can be different with treatment versus control. Both are unobserved, as in
the DD framework, and the fixed effect is assumed to control for the unobserved household attributes that cause households to select a particular neighborhood after controlling for housing characteristics.

The estimated parameters for the interaction terms with the fixed effects associated with falling within the three mile proximity zone in (4) measure the effects of each highway segment on residential land values, after controlling for housing attributes and influences of unobservable household attributes inducing them to sort into specific subdivisions. The second model specification allows the treatment effect to vary with the inverse of the distance to a roadway up to three miles and is considered a robustness check.

(B) Implementing the Two-Step Framework

Our analysis of the sub-division fixed effects takes advantage of the ability to use a large number of housing sales to estimate hedonic price functions for the sub-periods affected by each highway segment’s opening. Equation (3) defined the first stage hedonic for each sub-period. The sample for each model is composed of sales within the sub-period defined to match the timing of completion of each segment or to serve as a control. During the period of our overall sample of housing sales for Maricopa county (1993-2008) four major highway segments, located in the East Valley were added to the loop road system. Each segment opening defines a time period allowing estimation of four separate sets of subdivision fixed effects along with control variables as well as an additional set of estimates for the period before the first segment completion which serves as a control. Stacking these estimates as in (5) we have measures of the effects
attributed to each subdivision in each time period. These estimates control for all unobservables distinguishing subdivision features for the sets of households selecting each and offer the basis for recovering measures for the effects of new highway segments on land and housing values. The dimensionality of each estimated vector of fixed effects depends on the number of subdivisions influenced by each highway segment.

\[
\Gamma = \begin{bmatrix}
\gamma_c \\
\gamma_1 \\
\gamma_2 \\
\gamma_3 \\
\gamma_4
\end{bmatrix}
\]  

(5)

where \(\gamma_\ell = \) vector of estimated fixed effect \(\ell = c, 1, 2, 3, 4\)

Equation (6) reproduces the second stage model in matrix format from what was given in equation (4) as

\[
\Gamma = Z\beta + u 
\]  

(6)

with \(Z\) consisting of qualitative variables (additional fixed effects) controlling for proximity and adjacency to the roadway. The vector representation, \(u\), represents the errors from (4) acknowledging that these effects are likely to include unobservable features that are best treated as random variables with covariance structure given in (7).

\[
E(uu^T) = \Sigma 
\]  

(7)
The covariance matrix, $\Sigma$, is assumed to be block diagonal such that homes sold in one time period, and their associated subdivision fixed effects, do not influence the equilibrium in separate time periods (earlier or later). The OLS estimates of equation (3) also provide estimates of these covariance matrices unique to the hedonic models for each sub-period. As a result, we might expect that a feasible GLS estimator was straightforward and given by

$$\beta = (Z^T \Sigma^{-1} Z)^{-1} Z^T \Sigma^{-1} \Gamma,$$  

(8)

where $\Sigma = \hat{\Sigma} \otimes I$ with $\hat{\Sigma}$ corresponding to the OLS estimates for each of the sub-periods covariance matrices. However the dimensionality of each sub-period implies $\Sigma$ is of the order of $11,000 \times 11,000$.

The block structure of $\hat{\Sigma}$, allows this dimensionality to be easily resolved. More specifically we can write $\Sigma^{-1}$ as

$$\Sigma^{-1} = \hat{\Sigma}^{-1} \otimes I.$$  

(9)

If we use the Cholesky decomposition for each $\hat{\Sigma}^{-1}$, and transform the elements of $\Gamma$ and $Z$ separately for each sub-period, we recover the feasible GLS estimates of $\beta$ as OLS estimates from the transformed variables. This strategy overcomes the dimensionality issues raised by the 11,000 fixed effects associated with our sub-period/sub-division

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5 Thanks are due Michael Keane for suggesting this strategy.
framework. More generally it is an approach that could be used for any number of observations. It relies on the assumption that there is no correlation in effects across sub-periods (i.e. $\Sigma$ is block diagonal). For our situation where the model is describing market equilibrium in sub-periods after each new segment is added, this assumption is not limiting.

C. Data and First Stage Results

Our application involves over 500,000 sales of private homes in Maricopa County from January 1, 1999 to June 30, 2007. During this time span several segments of two major loop freeways in the Phoenix area were completed. Figure 1 provides a map of the area identifying how each segment contributed to the network associated with each loop. This overall process for expanding the loop roadway involved two major segments. The southern segment of Loop 101 connecting the cities of Tempe and Chandler was completed in December 2000. The northern segment connecting Scottsdale to Tempe was completed in April 2002. Another project linking the Loop 101 with Interstate 10, a major interstate, opened in November 2003. The second loop roadway, Loop 202, opened in June 2006 with the completion of a 12 mile segment of the Loop 202 completing the southern section of the Loop 202 Freeway linking Loop 101 and US 60 through the cities of Chandler and Gilbert.

Table 1 identifies the time period corresponding to each completed segment, the number of subdivisions that had sales affected by each highway segment, as well as the control time period. Table 2 provides summary statistics for characteristics of the properties involved in housing sales, including an indicator of the locations of each home.
to each roadway. Table 3 provides estimates from each of the first stage hedonic models associated with each time period. We do not report specific estimates for the fixed effects for subdivisions estimated separately for each time period. Significant parameters at the 90 percent level are identified by the bold coefficients in the table. Following many previous hedonic studies our specification includes quadratic effects for age, lot size, and house size. Overall the effects of housing attributes were quite stable over the eight years comprising our sample period and generally agree with our expectations for the effects of each of these structural variables. The relative stability of the estimated parameters over time suggests that these coefficients are reflecting construction costs and that the locational effects of where the house is placed is being captured by the subdivision fixed effects.

IV. Estimates of the Incremental Values for New Highway Segments

Table 4 provides the results of the feasible GLS estimates of our second step models. We focus primary attention on the estimates treating the highway as a fixed effect with an implied constant mean effect (in percentage terms) for the subdivisions impacted by each new highway segment. These results are in the first panel. To gauge robustness of our findings, as we noted in the previous section, we estimate a second specification including the inverse distance between the subdivision and the new highway segment up to three miles. The fixed effects (and inverse distance) measures are hypothesized to influence subdivision fixed effects from the point that the highway segment opens until the last period covered in our sample.
There is a clear ranking of the contributions of different highway segments to housing prices, with the north / south Pima segment the most important, increasing housing prices by about twenty four percent. The Price / 10 connection and the Santan as links within the same east / west system have about the same impact on housing values. The north / south component of the Price segment has the smallest impact presumably because of the alternatives. Connection to the 202, 60 and Pima component of the 101 is valuable for the southern part of the metropolitan area but not as valuable as the other linkages. As we noted earlier, all of these segments are primarily intended to enhance local traffic flows. The cross-state and interstate highway connections to Tucson, Flagstaff, and Los Angeles were established before these segments were planned and introduced. Thus, the capitalization effects being measured are likely to be due to these local enhancements.

The fixed effects for adjacent impacts are only statistically important for the north / south Pima segment using the full fixed effects specification. This impact likely reflects a large set of land use changes that took place in the areas around this segment because of its enhanced accessibility. An important aspect of our estimates for the capitalization of each segment is the ability to isolate subdivisions with sufficient sales for each highway segment. Figures 2a thru 2d display the clustering of the subdivisions that are serving as the treated cases for each highway segment (in red) and the controls (in black). As the figures confirm there is a clear delineation of the treatments used for each segment. Comparison of the treated and control subdivisions for each segment documents the spatial distinctions that allow our two step strategy to estimate the effects of highway
segments in enhancing location specific values of land and thereby to estimate incremental values for each segment.

These estimates confirm highways affected the site value of specific subdivisions. To estimate the quasi-rents associated with each segment we need to consider the numbers of houses affected by each addition and to approximate the incremental gain in land values due to the differential increases in the prices paid for houses in the affected subdivisions. Table 5 reports the information we used in developing an approximate measure of aggregate quasi-rents for each highway segment. Starrett’s logic implies with full internal capitalization the aggregate of the incremental values can be measured using these differential values for land in the impacted subdivisions. Thus we seek to estimate the incremental increase in the value of land for each house and add these up over homes in the affected subdivisions. Because our analysis is illustrative we use the estimated parameters for the near fixed effect and the adjacent effects with the average housing price for subdivisions affected by each segment to compute representative incremental value and then scale these measures by the total number of houses in the affected subdivisions.

Table 5 reports the elements that contribute to our computations. The first two columns report the number of houses near each segment and those defined as adjacent to the roadway. Recall our estimates suggested that subdivisions near the roadway gained relative to controls but the gain was reduced somewhat if these areas had homes that would be judged to be adjacent to the roadway. Hence both factors need to be considered in judging the net increment to the land’s value and the quasi-rent attributed to the highway when aggregated over affected homes. The next four columns report the number
of sales and average prices for home affected by each highway segment. These are taken from the treated subdivisions. We distinguish whether they are near or adjacent to the highway.

The seventh column reports our estimate for the quasi rent as an asset value. Several qualifications are warranted. Mohring’s logic would imply we consider an annual quasi-rent. Such a measure could be derived by adjusting houses values to define an equivalent rent. Use of subdivision fixed effects would seem to simplify the logic here because we do not need to consider the age of the house. Our framework implies a separable contribution of the locational enhancement thru the fixed effect that is capturing appreciation in land values. The last column lists the length of each segment. Even if we adjust for length there are pronounced differences in the quasi-rents measured for each segment. Of course not all miles within a highway segment are equally valuable so our measures offer a rough guide. Comparing them to an estimate of the costs for each segment in the next to the last column it seems clear that further enhancement in all of the segments is warranted.⁶ This judgment is not the incremental comparison envisioned in Mohring's discussion but it is about as close as we can come with the information available. Quite clearly Mohring was onto a plausible strategy for setting priorities. State highway officials read the situation consistently with what these estimates imply. They recently completed efforts to add HOV lanes to the highest valued segment of the Pima/101 segment.

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⁶ Cost estimates are obtained from yearly certification reports prepared by the Arizona Department of Transportation. These reports show the progression of the freeway system as well as the costs for each segment. When possible, we use the cost associated with segments under construction rather than the estimated pre-construction costs.
No doubt, as Mohring [1961] suggested, there are both gainers and losers across the metro area. Starrett’s model assumes any income effects of capitalization will be reflected in the bids for residential properties. Nonetheless our statistical model does not allow us to measure them separately. A quasi-random model does not permit the estimation of the effects of the treatments on sub-groups (see Imbens and Wooldridge [2009]) We suspect due to the rapid population growth during the period of our sample’s transactions that these roadways influenced the placement of new subdivisions and thus channeled growth of residential housing. Real housing prices in other areas probably did not decline with re-sorting of a fixed population of households to exploit new access opportunities. Instead the influx of new households seems to have assured stability (or smaller increases) in real prices in areas that might otherwise have lost. In effect, they lost in relative terms. Thus, these aggregate estimates are probably understatements of the quasi-rents for these segments.

V. Implications

Mohring’s [1965] call for greater attention to marginal cost pricing and economic principles in managing existing roadways and in evaluating increments to their capacity seems especially relevant to today’s policy climate where infrastructure as a stimulus for aggregate economic activity dominated the first one hundred days of the new administration. Research considering the implementation of Mohring’s proposal for evaluating highway investments has been virtually non-existent. No doubt one reason for the paucity of information stems from the difficulties in evaluating the magnitude of the quasi-rents associated with different incremental changes.
Starrett’s [1981] extensions to the literature on land value capitalization provide a conceptual basis for measuring these gains. We demonstrated his logic can be effective for highway segments generating primarily local benefits within a metropolitan network. Our example is based on key segments added to the loop roadways around metro Phoenix between 2000 and 2007. A key question is whether it is possible to exploit the insights from this type of analysis to evaluate *ex ante* the incremental benefits from potential additions to other roadway systems.

The short answer to that question is we expect they cannot. The nature of both the conceptual argument allowing residential land capitalization estimates to measure these quasi-rents and the details of local circumstances suggest type of transfer is unlikely. However, the relative success of our application suggests that we should be able to use increasingly abundant housing sales data, together with parcel level geo-coded descriptions of the properties in relation to other new highway changes to relatively easily adapt our methods to other areas and accumulate the experience necessary for transfers. What is needed is to increase our understanding of the influence of the metropolitan context on how highway linkages add value to an internal network. By completing linkage in loop roadways or augmenting capacities to existing roadway segments travel time for trips individuals currently take is reduced. Adding new roadway segments also expand the scope of possible land uses. This later dimension will be more important to growing areas with large amounts of undeveloped land, like the Phoenix metropolitan area and less important to largely developed areas with smaller opportunities for “infill.” It is this type of context a wider set of studies would help to reconcile.
References


Table 1: Time Periods

<table>
<thead>
<tr>
<th>Time Period</th>
<th># Sales Cutoff</th>
<th># Subdivisions</th>
<th>Date Range</th>
<th>Segment Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>1,254</td>
<td>January 1, 1999 to December 22, 2000</td>
<td>Pre-completion</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>2,063</td>
<td>December 23, 2000 to April 7, 2002</td>
<td>Price</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>2,737</td>
<td>April 8, 2002 to November 16, 2003</td>
<td>Pima</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>3,730</td>
<td>November 17, 2003 to June 11, 2006</td>
<td>Price connector&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>1,759</td>
<td>June 12, 2006 to Jun 30, 2007</td>
<td>Santan</td>
</tr>
</tbody>
</table>

<sup>a</sup>Price connector includes houses near the new segment as well as along the existing Price Freeway.
Table 2. Housing Summary Statistics (N=503,133)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>243,798</td>
<td>281,614</td>
<td>17,000</td>
<td>7,900,800</td>
</tr>
<tr>
<td>Square Feet</td>
<td>1966</td>
<td>724</td>
<td>600</td>
<td>5997</td>
</tr>
<tr>
<td>Acres</td>
<td>0.18</td>
<td>0.11</td>
<td>0.05</td>
<td>5.53</td>
</tr>
<tr>
<td>Stories</td>
<td>1.26</td>
<td>0.44</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Bathrooms</td>
<td>2.71</td>
<td>0.81</td>
<td>0.5</td>
<td>6</td>
</tr>
<tr>
<td>Age</td>
<td>10.25</td>
<td>13.36</td>
<td>1</td>
<td>88</td>
</tr>
<tr>
<td>Garage</td>
<td>0.96</td>
<td>0.20</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Pool</td>
<td>0.28</td>
<td>0.45</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Price Distance a</td>
<td>18.86</td>
<td>9.77</td>
<td>0.01</td>
<td>63.19</td>
</tr>
<tr>
<td>Pima Distance</td>
<td>12.25</td>
<td>6.26</td>
<td>0.02</td>
<td>59.40</td>
</tr>
<tr>
<td>Price Connector Distance b</td>
<td>18.32</td>
<td>9.64</td>
<td>0.01</td>
<td>63.19</td>
</tr>
<tr>
<td>Santan Distance</td>
<td>18.73</td>
<td>12.30</td>
<td>0.03</td>
<td>65.62</td>
</tr>
</tbody>
</table>

*aDistance measures are not included in first-stage hedonic (in miles).

*bPrice connector distance includes minimum of distance to new segment or Price Freeway
<table>
<thead>
<tr>
<th>Variable</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square Feet (100s)(^{1})</td>
<td>0.048</td>
<td>0.044</td>
<td>0.044</td>
<td>0.042</td>
<td>0.042</td>
</tr>
<tr>
<td>Acres</td>
<td>0.587</td>
<td>0.607</td>
<td>0.577</td>
<td>0.550</td>
<td>0.680</td>
</tr>
<tr>
<td>Stories</td>
<td>-0.055</td>
<td>-0.055</td>
<td>-0.060</td>
<td>-0.042</td>
<td>-0.047</td>
</tr>
<tr>
<td>Bathrooms</td>
<td>0.032</td>
<td>0.034</td>
<td>0.035</td>
<td>0.025</td>
<td>0.024</td>
</tr>
<tr>
<td>Age</td>
<td>-0.003</td>
<td>0.001</td>
<td>-0.003</td>
<td>0.002</td>
<td>-0.007</td>
</tr>
<tr>
<td>Garage</td>
<td>0.045</td>
<td>0.036</td>
<td>0.043</td>
<td>0.013</td>
<td>0.008</td>
</tr>
<tr>
<td>Pool</td>
<td>0.035</td>
<td>0.037</td>
<td>0.043</td>
<td>0.049</td>
<td>0.053</td>
</tr>
<tr>
<td>Age Sq.</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Acres Sq.</td>
<td>-0.209</td>
<td>-0.191</td>
<td>-0.111</td>
<td>-0.123</td>
<td>-0.167</td>
</tr>
<tr>
<td>Square Feet Sq.</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Monthly Trend</td>
<td>0.006</td>
<td>0.000</td>
<td>0.004</td>
<td>0.022</td>
<td>-0.006</td>
</tr>
<tr>
<td># Observations</td>
<td>39,805</td>
<td>65,407</td>
<td>101,823</td>
<td>242,522</td>
<td>53,576</td>
</tr>
<tr>
<td>Adjusted R(^{2})</td>
<td>0.9998</td>
<td>0.9996</td>
<td>0.9997</td>
<td>0.9997</td>
<td>0.9998</td>
</tr>
</tbody>
</table>

\(^{1}\)Bold indicates 90% significance.
### Table 4: Fixed Effects Decomposition using FGLS

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dummy Variables</th>
<th>Inverse Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>Std Err</td>
</tr>
<tr>
<td>Price Dummy</td>
<td>0.040</td>
<td>0.014</td>
</tr>
<tr>
<td>Pima Dummy</td>
<td>0.243</td>
<td>0.008</td>
</tr>
<tr>
<td>Price/Connector Dummy</td>
<td>0.079</td>
<td>0.016</td>
</tr>
<tr>
<td>Santan Dummy</td>
<td>0.080</td>
<td>0.014</td>
</tr>
<tr>
<td>Price Inverse Distance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pima Inverse Distance</td>
<td></td>
<td>0.018</td>
</tr>
<tr>
<td>Price/Connector Inverse Distance</td>
<td></td>
<td>0.036</td>
</tr>
<tr>
<td>Santan Inverse Distance</td>
<td></td>
<td>0.018</td>
</tr>
<tr>
<td>Adjacent Price</td>
<td>0.010</td>
<td>0.055</td>
</tr>
<tr>
<td>Adjacent Pima</td>
<td>-0.059</td>
<td>0.029</td>
</tr>
<tr>
<td>Adjacent Price/Connector</td>
<td>-0.043</td>
<td>0.059</td>
</tr>
<tr>
<td>Adjacent Santan</td>
<td>0.002</td>
<td>0.022</td>
</tr>
<tr>
<td>Phoenix CBD</td>
<td>0.003</td>
<td>0.000</td>
</tr>
<tr>
<td>Constant</td>
<td>10.386</td>
<td>0.026</td>
</tr>
</tbody>
</table>
### Table 5. Benefit/Cost of Highway Segments

<table>
<thead>
<tr>
<th>House Population</th>
<th>Proximity Measure</th>
<th>Adjacent Prices$^a$</th>
<th>Near Prices$^b$</th>
<th>Value of Segment</th>
<th>Cost of Segment</th>
<th>Segment Length (mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adjacent</td>
<td>Near</td>
<td># Sales</td>
<td>Avg Price</td>
<td># Sales</td>
<td>Avg Price</td>
</tr>
<tr>
<td>Price Freeway</td>
<td>5,015</td>
<td>76,032</td>
<td>1,243</td>
<td>207,872</td>
<td>20,991</td>
<td>217,440</td>
</tr>
<tr>
<td>Pima Freeway</td>
<td>7,052</td>
<td>116,220</td>
<td>2,509</td>
<td>236,804</td>
<td>31,345</td>
<td>307,364</td>
</tr>
<tr>
<td>Price Connector Freeway$^c$</td>
<td>6,375</td>
<td>90,582</td>
<td>1,136</td>
<td>237,715</td>
<td>14,610</td>
<td>254,612</td>
</tr>
<tr>
<td>Santan Freeway</td>
<td>7,079</td>
<td>120,133</td>
<td>853</td>
<td>310,023</td>
<td>6,585</td>
<td>343,395</td>
</tr>
</tbody>
</table>

$^a$ Averaged over houses selling after freeway opening within 1500 feet of the specified freeway

$^b$ Averaged over houses selling after freeway opening within 3 miles of the specified freeway, but outside 1500 meters

$^c$ Price connector includes both the new connecting segment and Price Freeway

$^d$ Total includes pre-existing segments that received value from the "new" segment
Figure 1. Key Highway Segments
Figure 2. Housing transactions
Figure 2, continued