The Costs of Imposing Monocentricity:

Uncovering the Dynamics of Emerging Centrality in Post-Socialist Krakow's Land Markets.*

by

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Abstract

In 1989, Poland undertook a series of institutional reforms that effectively introduced economic competition into land markets. Over the next several years ownership rights to land previously under government control were distributed to individuals and firms. Prior to reforms, land had been allocated by central planners, leaving land use in Krakow substantially at odds with that typically found in market-oriented cities. This paper analyzes the extent and speed of adjustment to the price surface for residential land in Krakow's new markets for land. In particular, the paper focuses on the establishment and evolution of a system of centers in which land trades at a premium relative to its physical characteristics. The data employed are vacant parcels, which afford a clean measure of land prices and their spatial distribution. Using an nonparametric approach to identify pricing centers – "nodes" of similarly-sized hedonic regression residuals – a clear trend towards centrality is found. While the traditional city center emerges as the dominant node, the evolution of the price surface is far more complex than that found using alternative approaches. The nonparametric method reveals an evolving and polycentric price surface. Accordingly, it yields superior explanatory power compared to simpler monocentric models and should provide some caution to their use in metropolitan areas in transition or those that are polycentric.

Key Words: Intrametropolitan land dynamics, land price gradient, spatial econometrics, emerging markets.

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1 Introduction

In 1989, Poland began the process of legal and institutional reforms that introduced competitive economic forces into land markets. In contrast to the previous forty-five years of central planning, individuals were able to buy and sell land with full ownership rights. At the time of the reforms, the patterns of urban land use were the result of decades under an economic system designed to minimize inputs rather than maximize profit (Kornai 1992). Thus, the resulting urban spatial organization of Krakow deviated substantially from what would typically occur in market-oriented cities. Krakow, like many of the major cities of Eastern and Central Europe, shared features with the modern cities of the Soviet bloc, as well as with their historical counterparts in Western Europe (Bertaud 2004). Like the other European cities, Krakow's center was its historic core with a network of arterial roads radiating outward from the core. However, like other planned cities in Socialist economies, Krakow had unusually high residential densities in distant suburbs and an inordinate amount of urban land dedicated to industrial uses.[1] Market forces may ultimately remake Krakow's urban form, but only over the longer-term. However, prices were free to adjust in the new markets for land– reflecting collective expectations about fundamentals and sending signals to developers that may have presaged future changes in urban form. This paper focuses on the evolution of Krakow's price surface for vacant land that is zoned for low-density residential use.

The dynamics of land prices could not have been clear at the time of reform: market institutions were very much works in progress, and legal rights – indeed, clear titles to parcels – remained untested. Expectations must have been clouded by great uncertainty as to the success of economic reforms and as to the future of the national and regional economies. Moreover, the values of location had yet to emerge. In economies with long histories of free (if regulated) markets for land, equilibrium is seldom far off. Shocks to fundamentals occur, agents incorporate the new information, and markets adjust. In Krakow, the starting point was substantial *dis*equilibrium with little local guidance as to what would become of various neighborhoods and their desirability. The self-organizing nature of market economies would

[1]This pattern of shared attributes is well-discussed in (Bertaud 2004). While sharing features with cities of the USSR, Krakow avoided the perverse land-use scenarios of other Russian cities, where land-use gradients were *positively* sloped. Bertaud and Renaud (1997) formally discuss land use in socialist economies, and comparisons of market and non-market cities can be found in Bertaud (2001).

likely lead to the emergence of a dominant center or system of centers, but how quickly this would occur, where they would be located, and how much the market would pay for access to them, remained uncertain.

Previous research on Krakow's post-reform evolution suggests a rapid transition to a typically monocentric price surface. Bertaud (1999) argues that "although land markets have been operating for no more than 6 years in Krakow, the land price gradient is exactly what one would expect from a monocentric city in a market economy." (page 24) His conclusion is drawn from a simple monocentric metric of Krakow's price surface that has little power against alternative hypotheses. The approach employed in this paper is agnostic as to the shape of the surface – both the location of centers and their shape. This is important because, as Bertaud reports in the same paper, job growth in Krakow is largely a suburban phenomenon. The traditional center appears to be following the path of other European centers: becoming a agglomeration of consumption and service amenities. Growth of employment in the suburbs is likely to support the evolution of suburban price gradients that reflect changes in the value of land – this would give rise to a polycentric price surface.

The data used to explore these price dynamics are sales of vacant parcels of land zoned for low-density residential development. As a result of four decades without market forces to drive development of land to "highest and best" use, vacant parcels are scattered throughout Krakow. The parcel sales vary only across access to infrastructure and location – there are no structural improvements to control for that would complicate the analysis. The 4582 parcel sales are divided into two-year intervals covering a period from 1993 to early 2004. These cross-sections allow for a detailed examination of the dynamics of land markets as they evolve.

Two types of results are presented in this paper. The first are a set of comparisons between the mono- and polycentric methods for estimating price surfaces. The second are a set of metrics that attempt to collapse the complex cross-sectional price surfaces into single numbers so that inferences can be drawn regarding the the concentration of land pricing and the value of centrality. The comparison between mono- and polycentric approaches suggests that use of monocentric approaches may be inappropriate even if the coefficients on the distance parameters are significant. That they are significant speaks to the magnitude of the average slope rather than to tests of alternative hypotheses regarding the spatial structure of prices. The second set of results suggest that, indeed, Krakow moved towards a dominant center of pricing – but the city's price surface is never monocentric. Rather, in each cross-section, there is a *system* of pricing centers. Moreover, the city center is not uniformly the most valued of these centers – in the early years of the sample period, the dominant node is well west of the city center. This may be better explained by the initial distribution of wealth in the new Polish economy than by the basic models of urban economics.

The evolution of this system of priced centers leaves open the question of equilibrium. The dominant trend in the spatial distribution of land prices revealed by the nonparametric approach is towards monocentricity. However, equilibrium is not reached during the sample period. [That is, each two-year cross-sectional price surface varies from those in adjacent periods.] Moreover, the final price surface's two secondary nodes are durable features of all six cross-sections. This implies either an equilibrium system of three centers or that equilibrium has still not arrived, with one or both of the secondary centers yet to fade. This will be left to future research.

The paper is organized as follows. The following section discusses the data in more detail. Section 3 introduces both traditional and newer approaches to estimating price surfaces. Regressions results and inferences about the shape and dynamics of the price surface are presented in Section 4. Section 5 closes.

2 Data

Most discussions of land rents in urban areas are complicated by the fact that raw land sales are generally quite scarce. As a result, research on the spatial distribution of land rents is frequently undertaken with data on real estate sales - bundles of both the land and whatever improvements have been made to it. Price gradients are then estimated using hedonic analysis to control for the physical heterogeneity of the structures on each parcel. This is, of course, an improvement over the use of raw price data, but it is far from perfect. Hedonic data are frequently restricted to a handful of variables – often omitting important determinants of value, limiting explanatory power, and, to the extent that omitted amenities are correlated with distance from city center, resulting in biased estimates of the effect of distance on land price. The analysis in this paper is based on data from vacant land sales and is therefore free of the complications that arise from variation from structural improvements.

The use of vacant land sales is not common in this type of research. Land in market-based cities is under constant pressure to be utilized at "highest and best" use. The result is that essentially no vacant parcels can be found in urban areas where markets value land. However, the socialist system in Poland in place from after World War II to 1989 allocated land via administrative fiat. Absent market forces, vacant parcels of land can be found throughout Krakow. In fact, over the sample period from 1993-2004, the spatial distribution of land sales is remarkably uniform. Figure 1 shows the location of sales for the entire 12-year sample period.

Figure 1 does not include natural features or neighborhood boundaries, although both are readily seen by the absence of sales and the clustering of sales, respectively. For example, there are no parcel sales where the Visla river runs across the map, about 4000 meters south of the center of the city. A slightly less-discernible ribbon without sales runs roughly parallel further to the south – about 7500 meters south of the city center. This is the southern side of the ring road that will eventually encircle Krakow.

Krakow shares some features common to European cities - a historic core and radial road structure. The core is indicated on the map by the cross, but is also clearly visible as the blank spot at the center of the map where there are no vacant parcel sales. Main radial roads can be traced by broad lines of sales west and southeast of the city center. The map also reveals some features not common to market-based European cities: large parcels of land for industrial purposes. Many of the blank spots on the map to the east of the city center are industrial sites – in fact, approximately 28% of the municipal land area is dedicated to industrial uses (Bertaud 2004). (By far, the largest of these sites is the Sendzimar steel mill, the edge of which is defined by the eastern-most set of sales on the map.)

Despite being vacant, parcels vary along three dimensions: access to infrastructure, access to local amenities, and the types of development that can occur on each. Previous research using land in Krakow zoned for investment properties (commercial, industrial, multifamily, and mixed-use) found a marked trend toward centralization of land pricing, but also the existence of distinct subcenters or "nodes" of pricing outside the city center (Dale-Johnson, Redfearn, and Brzeski 2005). This study, however, did not reveal any strong sense of that equilibrium in the location of the nodes or in the concentration of pricing had occurred. In part, this resulted from the need to aggregate sales into just three subsamples – allowing only a limited view of temporal dynamics. But this also stemmed from the complexity of the market for investment properties. These parcels were often multiply-zoned – implying a set of options that complicated the analysis – and were occasionally purchased by foreign firms that appear to have paid more for parcels than was warranted based on the hedonic models.

In order to avoid these complexities and to make use of larger data set, this analysis focuses on land zoned solely for the development of single-family dwellings. No parcels are multiply-zoned, nor are any sales to government entities or cooperatives included because it was impossible to determine whether these transactions occurred at market prices. The remaining transactions are believed to be "arm's-length" sales between individuals, housing cooperatives, and privatized entities.

Additionally, parts of the periphery of Krakow are excluded because these areas do not generate sufficient observations to estimate the surrounding price surface with any confidence. The final subsample is the "compact" set of 4582 observations based on arm's-length transactions of parcels zoned for single-family dwellings. For each parcel sale, the data include the parcel's location, size and a set of discrete variables indicating relative access to infrastructure: gas, heat, telephone, electricity, water, and sewage. For the discrete variables, a five-point scale is employed that rates parcels from one – indicating no access – to five, which indicates that the services are "ready-to-use."

Table 1 reports the means for the entire sample as well as for each cross-section. The notable tendencies are the rise in real price per square meter (and the variance of prices) and the absence of any significant trends in the typical attributes of parcels sold over time. Where parcels sold after 2000 are slightly smaller, there is no other indication that there is significant clustering of sales by type or location over time.[2]

Table 1 also reports average real price per square meter for the entire sample period as well as for the six cross-sections. Average real price per square meter for unimproved parcels varies by a factor of three over the sample period; the standard deviation shares a similar range. These sales observations are vacant lots – price increases may result from changes

[2]The data set from which these residential observations are drawn is described in more detail in Dale-Johnson and Brzeski (2001).

in any number of fundamentals, but the rise in price variance is likely to reflect a growing diversity of the premium paid for the location of each parcel. Capturing and describing this diversity is the subject of the next section.

3 Empirical Approach

The goal of this research is to shed light in the land price dynamics of Krakow's transition from planned economy to one with market orientation. In an urban area with a history of functioning land markets, land-rent gradients should be closely matched to land-use density gradients; profit seeking agents are constantly investing in and redeveloping under-utilized land. As of 1989, Krakow had been absent these forces for over four decades.

The issue of the behavior of land markets in Krakow is non-trivial. Where the center's advantages tend to be self-reinforcing in market-based cities, the initial conditions for Krakow included high residential densities in distant suburbs, a very-high proportion of urban land dedicated to industrial uses, and a market without historical references as to the value of location.[3] Moreover, with so much uncertainty as to the course of urban development – the broad set of locational amenities that drive variation in land prices – it could not have been clear how to value land. Against this backdrop, it may be that simple approaches to assessing land-rent gradients are inadequate.

There are two simple approaches that have been used frequently to estimate land-rent gradients in the Eastern Europe context. The first calculates average prices within concentric rings around the city center. The second employs various parametric forms of distance from the city center in a regression. Both have long histories, and both suffer from maintained hypotheses. In the former, the price averages are often taken without control for quality differences across parcels. And, in both, the center is frequently imposed rather than inferred. Moreover, neither approach offers a means to capture any of the dynamics occurring outside the center.[4]

The approach used in this paper is explicitly agnostic as to the shape of the land-rent gra-

[3] Poland had, in fact, allowed private markets in single-family residences. These were very limited however. See Buckley and Tsenkova (2001) for more on these exceptions.

[4] It is worth considering that if a significant node of higher prices (or agglomeration of population/employment, in the case of land-use gradients) developed in a suburb, neither approach would register much change in slope parameters – averaging over the whole circumference implies little overall change in the monocentric view of the city.

dient. In brief, the residuals from a hedonic regression are used in a series of locally-weighted regressions to estimate the city's price surface – observations from the market "decide" both the center and shape of nodes of pricing. If the city is truly monocentric with a gradient that declines according to a negative-exponential function, the nonparametric approach will approximate the appropriate gradient without imposing it. And, at the same time, it is capable of capturing far more complex pricing dynamics both spatially and temporally.

3.1 Monocentric Measures of Land Rents

It is first useful to construct the two simpler approaches to assessing the price surface using the same data, for the sake of comparison. Figure 2 shows the average real price per square meter of vacant land by distance from the city center. The evolution of the measure of the land-rent gradient is clear: prices rose near the center by a factor of four. However, using the same measure, so did prices at the periphery. The ratio of prices at the center to those at the periphery is roughly constant. This is consistent with the unlikely hypothesis that markets moved quickly – in the two years prior to the beginning of the sample period – to a spatial equilibrium, with relatively little price variation over the 1993-2004 time period. There is nothing here that contradicts the hypothesis that the shape of the price surface for low-density residential land in Krakow is monocentric and stable over time.

The second approach – simple parametric hedonic regressions – yields similar results. Table 2 reports statistics from a series of hedonic regressions of the natural log of real price per square meter on the natural log of parcel size, the set of discrete infrastructure access variables, and on the log of distance from the city center. The coefficients on the distance variables are uniformly highly significant. The coefficients suggest a steepening price surface around the city center through the 1999-2000 subsample, after which the gradient decreases somewhat. The statistical significance of the coefficients is only useful to indicate whether or not the average slope for the center is different from zero. It is not a test against alternative shapes of the price surface. Note, for instance that the explanatory power of the model is low and fades somewhat over time – despite a t-statistic on the distance variable of 7.56, 80% of the variation in land prices is not explained by this simple price surface.

Table 2 also reports the ratios of land prices near the center to those at the periphery. The first line of ratios are those calculated using the results of same regressions reported in the upper half of the table. These suggest a rise and then a fall in relative prices, but with so much of the price variance unexplained that this conclusion may be premature. The second line reports the same ratios using average prices across concentric rings. Here there appears to be a steep increase from the 1993-1994 period to the 1995-1996 period, but little change afterwards. Figure 2 hints at measurement error, and so a third set of ratios based on spatial-moving average prices is reported on the third line. This suggests even less change in the relative prices of land near and far from the city center over the 12-year sample period.

In summary, the monocentric approaches to measuring prices find what they impose – evidence of a monocentric price surface with little change over time and no indication of significant price concentrations outside the center itself. They offer no power against the alternative hypothesis that there is a highly dynamic system of pricing centers that may include, but not be limited to, the city center.

3.2 Assessing a Polycentric Price Surface

The monocentric model is the bedrock of urban economics, but the modern metropolis is becoming less-well described by the original models of Alonso (1964) and Mills (1970). Recent work by McMillen and Smith (2003) underscores the extent of the trend towards polycentricity in the United States. There is also evidence of systems of concentrations within European metropolitan areas, notably in Muñiz, Galindo, and García (2003). As noted previously, Bertaud observes the basic building block of this trend in the cities of Central and Eastern Europe – suburban employment growth. In Europe, the historic core has become less an employment center in the traditional sense of the CBD. Rather, it is an agglomeration of consumption opportunities and services. Bertaud (2004) notes that this is also true of Krakow, which he describes as "more European than Socialist."

Given these trends, it is not unlikely that prices should follow a more complicated configuration than that allowed by simple monocentric models. Indeed, these trends point to not only the price surface becoming polycentric, but also land use. It is therefore important to use methods that allow for this possibility in assessing the spatial pattern of land prices.

The most direct approach to test for polycentricity would be to identify candidates informed by some theory of transportation costs, spatial amenities (or disamenities), or public good directly in the hedonic pricing regression. The list of identifiable candidates is quite long, with a longer list of unknown sites that results from the lack of data on school quality, crime, view, traffic flows, mass transit schedules, etc. Lacking these an alternative approach is proposed that utilizes sales data to reveal which locales are particularly valued.

This nonparametric approach begins with a variation on the regression that produced the coefficients in Table 2,

$$(1) \quad lnV_{it} = lnP_t + X_{it}\beta + \beta^{dist} ln(dist^i_{cc}).$$

Here lnV_{it} is the log of the real price per square meters of land; X_{it} is the matrix of explanatory variables: parcel size and the access to gas, heat, telephone, electricity, water and sewage infrastructures, β is a vector of their implicit prices. $\beta^{dist} ln(dist^i_{cc})$ is the effect of proximity to the city center on parcel i's sale price. t indexes time.

This familiar hedonic regression is altered to omit the distance variable. Of course, the residuals are the commingled effects of all excluded variables and any other noise in individual prices. That is, if X^I are included variables and X^E are those excluded, the empirical pricing equation can be written

$$(2) \quad lnV_{it} = lnP_t + X^I_{it}\beta^I + e_{it}.$$

Here e_{it} is the regression error, which combines the independent influence of the excluded characteristics, X^E – notably the location of the parcel – and the idiosyncratic error.

Our data are spatially diverse, and where there are location-specific amenities among the excluded variables, the residuals will be correlated around these advantaged-locales. Traditionally, the city center is the most obvious example of an advantaged locale. But there are examples of downtowns that are not (Bruekner, Thisse, and Zenou 1999). In general, however, market participants value this central location for shorter commutes and amenities requiring high densities of consumers, such as restaurants, museums, mass transit, etc. In this case, an aspatial regression should produce residuals that are of like sign and magnitude around the city center.

Of course, the city center is easy to identify but may not, in fact, be the best choice of center for regression purposes. Moreover, what other locales are advantaged and should be included? What parametric form should be used to relate price proximity? Employment centers may have price gradients related to travel times. Other locales, like hills, may offer benefits that increase continuously with elevation, but that do not spill into parcels in surrounding flat areas. These issues point to the use of a flexible approach to the discover of pricing nodes and the the shape of their price gradients.

The nonparametric approach employed in this paper is iterative.[5] The initial model (Equation 2) regresses real log price per square meter (in Polish Zlotys) on quarterly trend variables and controls for access to infrastructure (gas, heat, telephone, electricity, water, and sewage) – there is no need to control for quality differences of structures on each parcel as the observations are vacant lots. From this first-stage regression, the geocoded residuals are used to construct a smoothed surface of residuals using locally-weighted regression (loess).

Each point on the loess surface is obtained from a regression of residuals in its neighborhood with the closest points more heavily weighted. The amount of smoothing is determined by the choice of the "window" size and the specification of the weighting function for data within each window.[6] For each point, the window size determines which observations are to be included in the local regression. These observations are weighted according to a function of distance from the surface point being estimated. We use a tri-cubic function to weight observations within each window of data.[7]

Our loess regressions reveal a polycentric residual surface with distinctly idiosyncratically-shaped subcenters – no single parametric specification of distance from these nodes should be applied to each. In order to capture the local asymmetries, a third-degree polynomial is fit to the surface around each node. Each node could then be described by the parameters of the polynomial as well as its extent – the range over which the polynomial is fit. The extent

[5]This procedure is described in more detail in Dale-Johnson, Redfearn, and Brzeski (2005).

[6]The window size refers to the proportion of sales used in the local regression at each point. Many window sizes were employed with little impact on the trend, ranging from more, smaller, nodes to fewer, larger, nodes. The window size used in the work presented here is 0.10, striking a balance between local specificity and adequate sample sizes. An alternative approach would be to make the window size adaptive on local density of observations. This is discussed in general in Brockmann, Gasser, and Hermann (1993); an application of an adaptive window size can be found in Clapp (2003). See Cleveland and Devlin (1988) for more on loess.

[7]The tri-cubic function is given by

$$w_j^i = \left(1 - \left(\frac{dist_j^i}{max(dist_k^i)}\right)^3\right)^3 \quad ,$$

where w_i is the weighting for each observation in the local regression that estimates the surface at point i. $dist_j^i$ is the distance between points i and j; $max(dist_k^i)$ is the largest distance between the reference point i and all of the observations in the subsample determined by the window size.

is defined as the lesser of two distances: the distance at which the polynomial function equals zero and the distance at which the function has slope zero. The intuition is that when the function reaches zero the node no longer influences prices; when the slope is zero, there must be either an adjacent node - the slope is zero where there is a boundary between the two - or the node is at the periphery.

At each iteration, the node with the greatest area under its fitted polynomial is included in the next iteration of the pricing regression. The function (the third-order polynomial) of the distance from the center of the node - not the distance itself - is included in subsequent regressions. This is directly analogous to the commonly used natural log of distance. Beyond the extent of the node, the distance function takes the value 0.

After the each iteration, Equation 2 is updated with the inclusion of the additional variable – the function of distance – intended to capture the value of proximity to its respective node. Ultimately, the pricing regression becomes

$$(3) \quad lnV_{it} = lnP_t + X_{it}^{I\prime}\beta^I + f_1(dist_{i1}) + f_2(dist_{i2}) + \ldots + f_N(dist_{iN}) + e_{it}.$$

The procedure is repeated until no new candidate node can be found to be a significant determinant of parcel prices. The procedure allows the data to reveal those locales and their price gradients rather than requiring their imposition.

4 The Spatial Distribution of Prices

This section undertakes formal comparison of the competing methods laid out above: an aspatial model of land prices, a simple monocentric model of land prices, and the nonparametric model of land prices. It is clear from these comparisons that the nonparametric model best captures the irregular price surface of Krakow and its evolution over the sample period. Based on this result, the nonparametric surfaces for six two-year periods from 1993 to 2004 are rendered to illustrate the temporal dynamics of land pricing. In addition, a set of simple metrics of centrality based on these surfaces are introduced in an attempt to reduce the evident complexity in the surfaces into statistics that may be used for comparison.

The first task is to compare the competing methods of estimating price surfaces. Table 3 reports the r-squared for each subsample for each of three models of pricing. The first model is aspatial. That is, no variable that explicitly controls for location – central or otherwise –

is included. The second model is the monocentric model. Specifically, this row reports the r-squared for the regression of log of real price per square meter on the infrastructure access variables and the log of distance to the city center. The third model – labeled "Full Spatial" – is the outcome of the nonparametric procedure described above, with all significant nodes included. (The number of nodes is reported in the table as well; this is discussed below.)

These three rows contain several trends. First, the explanatory power of the aspatial model is weak and fades considerably over the sample period, accounting for approximately 10 percent of the variation in land prices over the last four cross-sections. This is consistent with the notion that absent markets to value location, physical attributes become all that differentiate parcels. As locational premia become established, the value of urban land becomes more determined by its location. This is supported by the full spatial model as well, as the proportion of variance explained by the nodes remains two to three times that of the attributes after the first period.[8] The r-squared of monocentric model substantiates the hypothesis that Krakow's land price surface is polycentric, performing poorly relative to the fully-spatial model built from the nonparametric approach described above.

Table 3 also reports two different counts of nodes, both of which suggest a polycentric price surface that is concentrating over time. The first is the number of statistically significant nodes from the spatial regressions. The second row is an informal count of distinct nodes. That is, those nodes which are visibly their own center. Because the nodes often overlap, it is common to have two or more nodes collectively form a single center. The city center is the best example of this. It is the most extensive node, whose boundary include the center of several other nodes during most of the subsamples. This is easily seen by viewing the fitted price surfaces for the six cross-sections.

Figures 3 through 14 illustrate the fitted price surfaces for each of the cross-sections via three-dimensional perspectives and contour maps. The evolution of the market is clearly not a simple rise in prices around the city center. Quite the opposite. The dominant node of pricing for the first six years of the sample period is well west of the city center. This neighborhood is the location of high-quality homes that abuts a ridge-line of open space. The rapid rise of prices in this part of Krakow likely speaks more to changes in the distribution

[8]The last cross-section, 2003-2004, actually contains only 16 months of data. And, while providing results that are broadly consistent with the other cross-sections, the estimated price surface is slightly odd and some of the statistics based on it are as well.

of income and the increase in demand from a small segment of the population for homes in a desirable neighborhood.[9] This node remains significant and distinct throughout the sample period.

Several other trends are visible in the figures. First, the series of perspectives and contours makes it clear that more than the city center is valued. Second, the city center become relatively more valued than the secondary nodes during the sample period. Third, the dynamics are interesting in their own right, independent of the question of whether or not the city exhibits mono- or polycentric pricing. Indeed, the more interesting questions regarding the formation of expectations, the set of fundamentals that drive prices, and the role of regulation may be fruitfully examined through these spatial variations in price over time. These questions are beyond the scope of this paper, but it is apparent that – unlike the monocentric models, which report relative stability of the city center – Krakow's land markets went through significant evolution during this period.

The last table reports attempts to collapse the three-dimensional fitted surfaces into a set of simple metrics that might be used to address the question of pricing centrality and the emergence of an equilibrium in residential land markets. Table 4 displays statistics meant to capture the dimensions of the fitted surface; that is, the concentration and magnitude of the value of location. The first is a simple conversion of the irregularly shaped surfaces seen in the figures. The price-weighted radius calculates the average distance from the city center of each point weighted by the price premia at that point – a trend towards monocentricity would be seen in a decline in this figure. The second statistic is the distance of the price-weighted center of the fitted surface to the city center, measuring the dispersion of prices around the locale that is typically considered the center. The mean of the fitted surface measures the average value of the locales *within* the extent of the nodes. Trends toward increasing value of centrality should be seen with higher values in the centers. The fourth row is another way of measuring the same phenomenon. It reports the relative premium paid for parcels *within* the extent of the nodes over the same parcels absent the bonus paid for location.

Each of these metrics has its faults, but collectively they strongly support the hypothesis

[9] It may be premature to conclude this, as no formal work on the distribution of income in Krakow or in this neighborhood has yet been undertaken. This inference is drawn from casual observation.

that the center has become more valued over the sample period. The price-weighted radius declines steadily; the price-weighted center of the fitted surface migrates generally toward the city center. And, the value of land within the fewer, more concentrated nodes becomes higher.

The last two rows of Table 4 report a variation on the Gini coefficient. In this application, the points on the fitted surface are ordered by their distance from the city center and the price-weighted center of the fitted surface, respectively. As such, a Gini coefficient of zero would imply evenly distributed prices around the city center; a Gini coefficient of one would imply a perfectly monocentric price surface. Both Gini coefficients indicate increasing concentration of pricing around their respective centers – but they are similar, as the center of the pricing surface and the city center move closer together over the sample.

No one of these metrics could adequately describe the fitted surfaces illustrated in Figures 3 to 14, but taken together they provide solid evidence of the emergence of the city center as the most valued location in Krakow. However, to stop at this generalization would obscure the important finding that the general trend towards concentration of pricing included significant and distinct nodes of pricing outside the city center. As the spatial regression indicates, the price surface has been continuously polycentric over the sample period.

5 Conclusion

Monocentric models have been the workhorse of urban economics. While there is still ample evidence that they remain appropriate in many settings (Bertaud and Malpezzi 2003), they should be applied with care. In the setting of the newly formed markets of Krakow, they are incapable of capturing the dynamics of evolving prices during a decade of transition.

The nonparametric approach employed in this paper exploits information about the value of location in the sales prices of vacant parcel zoned for single-family homes. By allowing the data to reveal how markets value location, a more complex picture of the spatial distribution of prices is revealed. Rather than a single pole implied by the monocentric models, multiple nodes are found in each cross-section; in the 1995-1996 subsample, fully 11 locations were found to be statistically significant. Because the influence of some nodes overlaps, collectively these nodes made up a price surface that contained five distinct centers – none of which could be consider the city center.

Over time, the city center become the value center of Krakow. This is consistent with what urban economists would have predicted. Indeed Bertaud (2004) recognized that Krakow's urban form, while sharing traits with both Socialist cities and those of Western Europe, is more European. And, in agreeing with the amenity driven model of Bruekner, Thisse, and Zenou (1999), he suggested that Krakow would follow the path of the Western European cites. The historic core would become a center of culture, consumption, and service, while most of the job growth would occur outside the core. While this dynamic explains rising prices in the city center, it also provides the justification for avoiding monocentric models of prices – and perhaps, ultimately, of land use.

Much remains to be done to explore the fundamentals of the complex price dynamics found in this research. But as a starting point, they offer an interesting set of results that, at first glance, are not readily explained with simple models of transportation costs or reservation wages. It is heartening to see the speed with which markets responded, ultimately valuing the center as urban models predict, but the path between starting and ending points warrants closer examination.

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Figure 1: Single-Family Residential Parcel Sales, 1993-2004

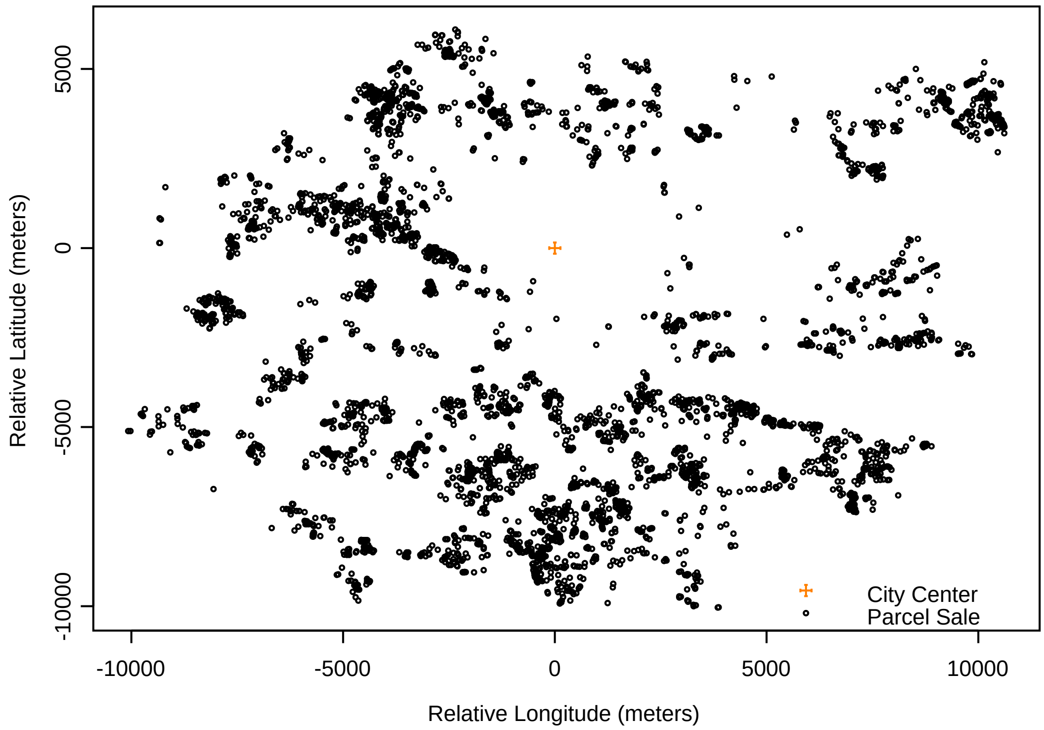

Table 1: Mean Parcel Characteristics by Subsample

(Standard Deviation in Parentheses)

Time Period:	All Parcels	1993-94	1995-96	1997-98	1999-00	2001-02	2003-04
Observations	4582	815	1064	1050	960	907	280
Real Price[a]	21.0	12.5	13.6	16.8	30.6	29.5	32.6
	(22.7)	(11.1)	(13.5)	(19.1)	(30.7)	(26.2)	(25.3)
Parcel Size[b]	910	918	1104	948	864	702	705
	(1638)	(755)	(2926)	(1205)	(949)	(685)	(1052)
Dist. to Center[c]	6736	6391	6526	6988	6805	6970	6661
	(2147)	(2139)	(2167)	(2154)	(2172)	(2095)	(2078)
Gas[d]	2.97	3.00	3.05	3.02	2.96	2.98	2.45
	(0.76)	(0.43)	(0.63)	(0.77)	(0.82)	(0.77)	(1.22)
Heat[d]	1.37	1.43	1.47	1.42	1.29	1.29	1.18
	(0.80)	(0.76)	(0.82)	(0.83)	(0.77)	(0.77)	(0.93)
Telephone[d]	2.60	2.52	2.50	2.70	2.68	2.74	2.28
	(0.89)	(0.79)	(0.90)	(0.85)	(0.84)	(0.84)	(1.25)
Electricity[d]	3.03	3.12	3.11	3.07	3.01	3.03	2.52
	(0.76)	(0.47)	(0.57)	(0.74)	(0.81)	(0.81)	(1.29)
Water[d]	2.90	2.90	2.94	2.96	2.89	2.95	2.40
	(0.83)	(0.65)	(0.75)	(0.82)	(0.87)	(0.79)	(1.24)
Sewage[d]	2.43	2.33	2.51	2.49	2.44	2.47	2.05
	(1.06)	(0.98)	(0.99)	(1.04)	(1.06)	(1.10)	(1.34)

Notes on observations and units of measurement:
a – Real price per square meter is in Polish Zlotys.
b – Area in square meters.
c – Distance in meters.
d – Ranked on a five-point scale from 'no access' (=1) to 'ready-to-use' (=5).

Figure 2: Empirical Land-Rent Gradients, by Subsample 1993-2004

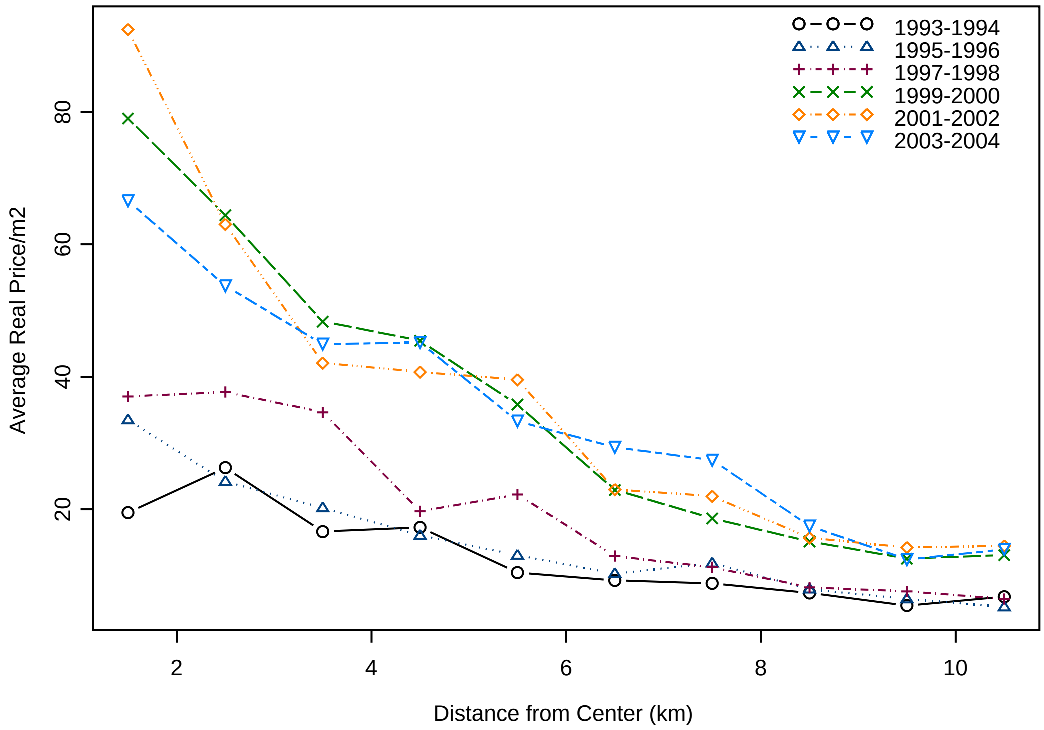

Table 2: Monocentric Measures of Centrality, by Subsample 1993-2004

Time Period:	1993-94	1995-96	1997-98	1999-00	2001-02	2003-04
Regression Statistics & Coefficients[a]						
R^2	0.38	0.27	0.32	0.32	0.26	0.21
β_{dist}	-0.76	-0.77	-1.24	-1.37	-1.17	-1.12
(t-stat)	(11.6)	(12.1)	(18.8)	(17.9)	(14.6)	(7.56)
Center/Suburb Price Ratios:						
Regression	4.53	4.68	7.29	8.87	6.42	5.45
Empirical[b]	2.87	6.40	5.75	6.04	6.40	4.78
Smoothed[c]	4.70	5.58	5.52	6.55	5.85	5.51

Notes:
a – Regressions include parcel characteristics, but are not reported.
b – Ratio of prices in center-most to outer-most ring.
c – Ratio of spatial moving average of prices in center-most to outer-most ring.

Figure 3: Perspective of Fitted Price Surface, 1993-1994

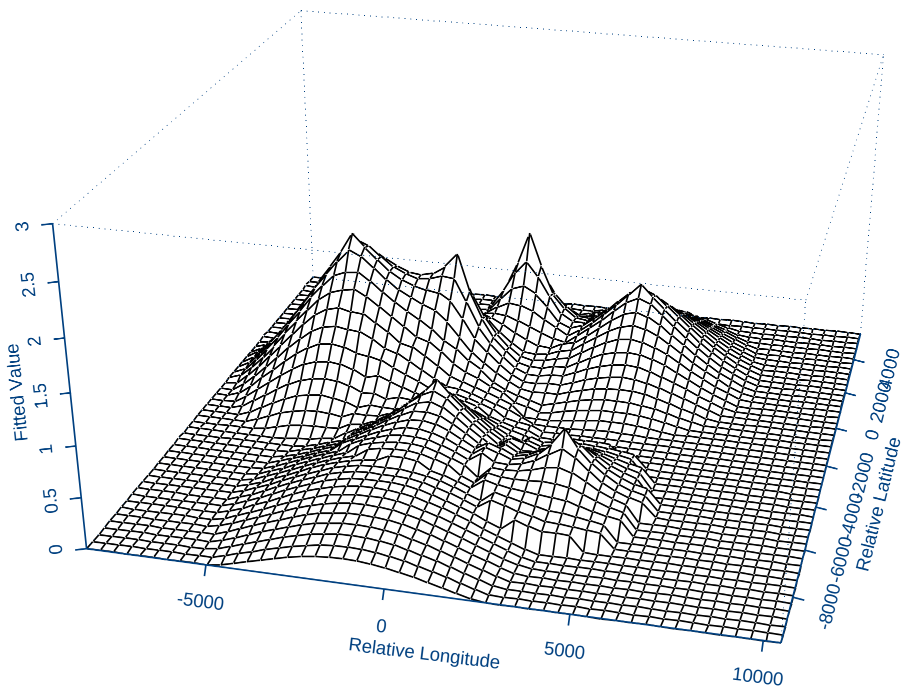

Figure 4: Contour Map of Fitted Price Surface, 1993-1994

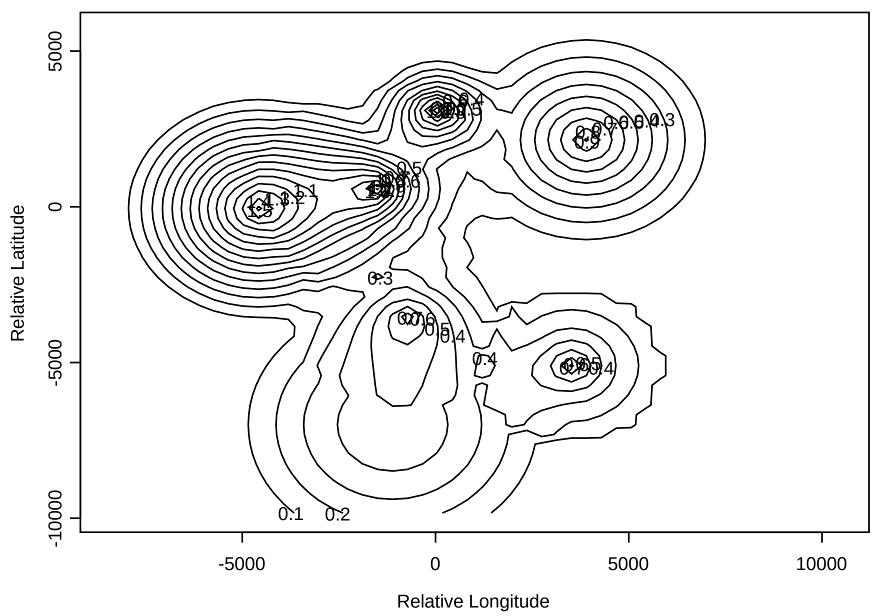

Figure 5: Perspective of Fitted Price Surface, 1995-1996

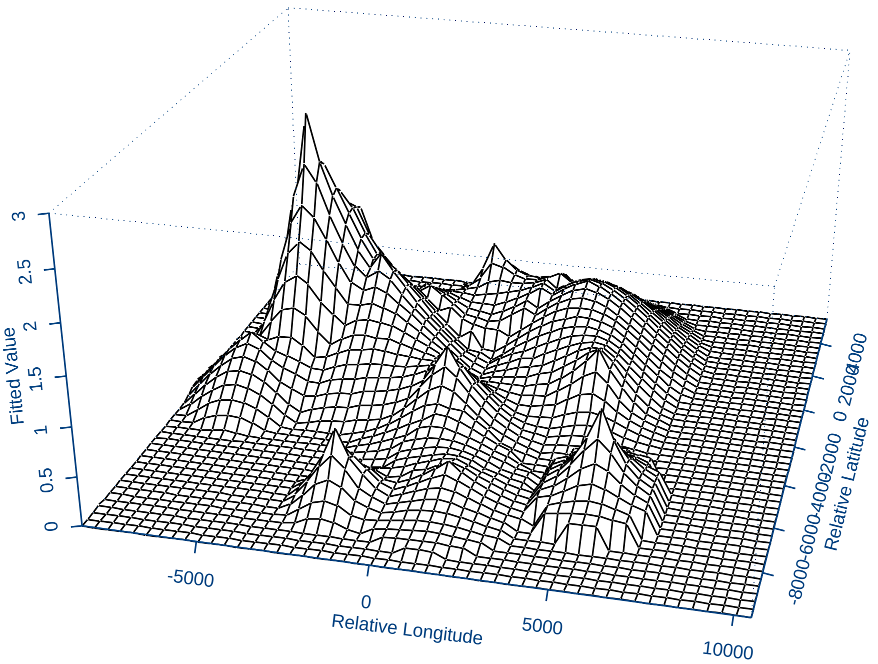

Figure 6: Contour Map of Fitted Price Surface, 1995-1996

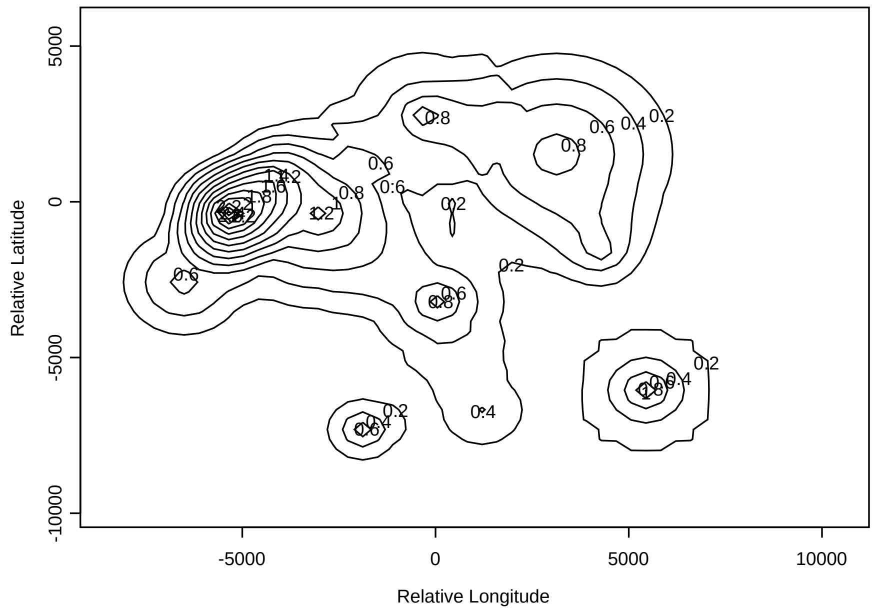

Figure 7: Perspective of Fitted Price Surface, 1997-1998

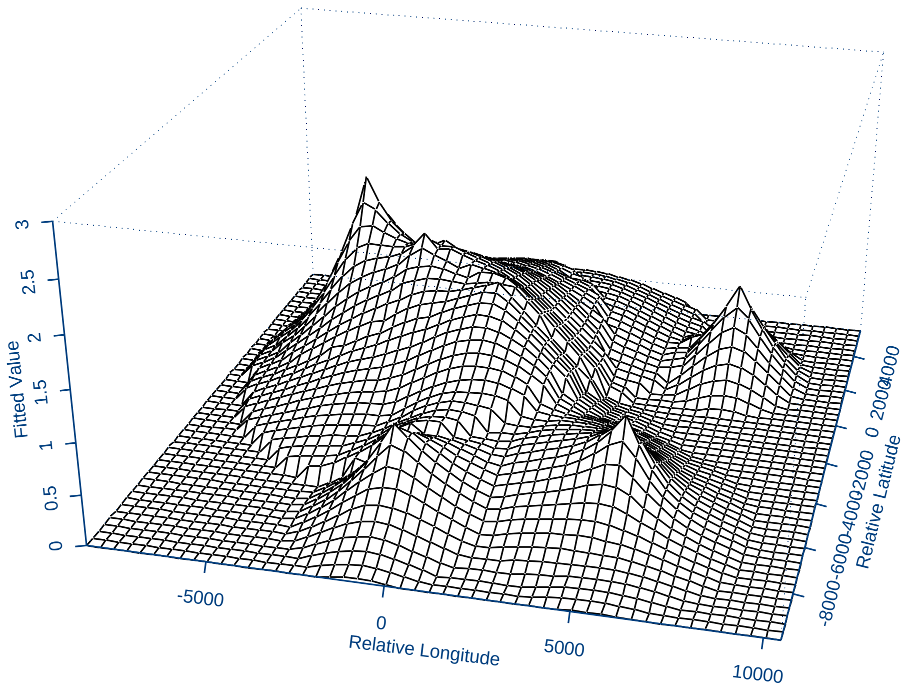

Figure 8: Contour Map of Fitted Price Surface, 1997-1998

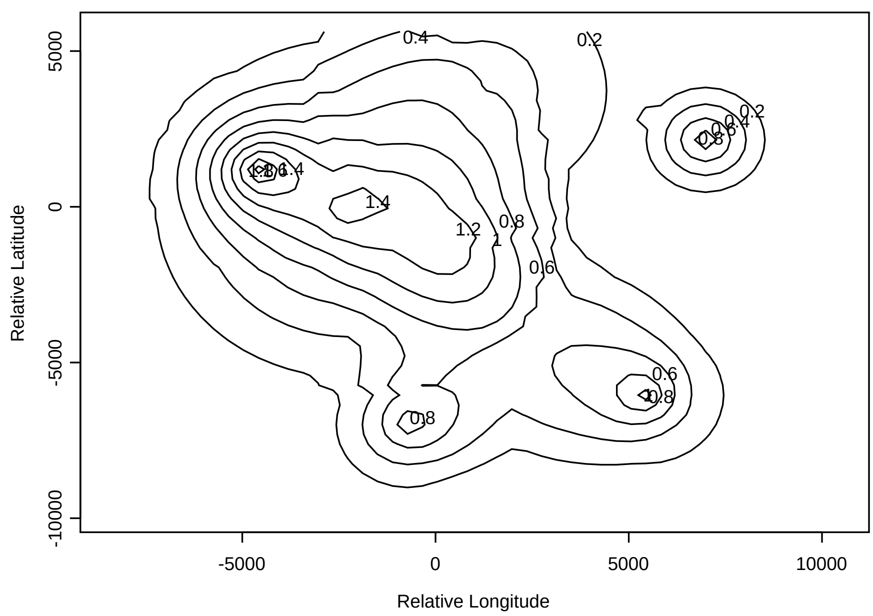

Figure 9: Perspective of Fitted Price Surface, 1999-2000

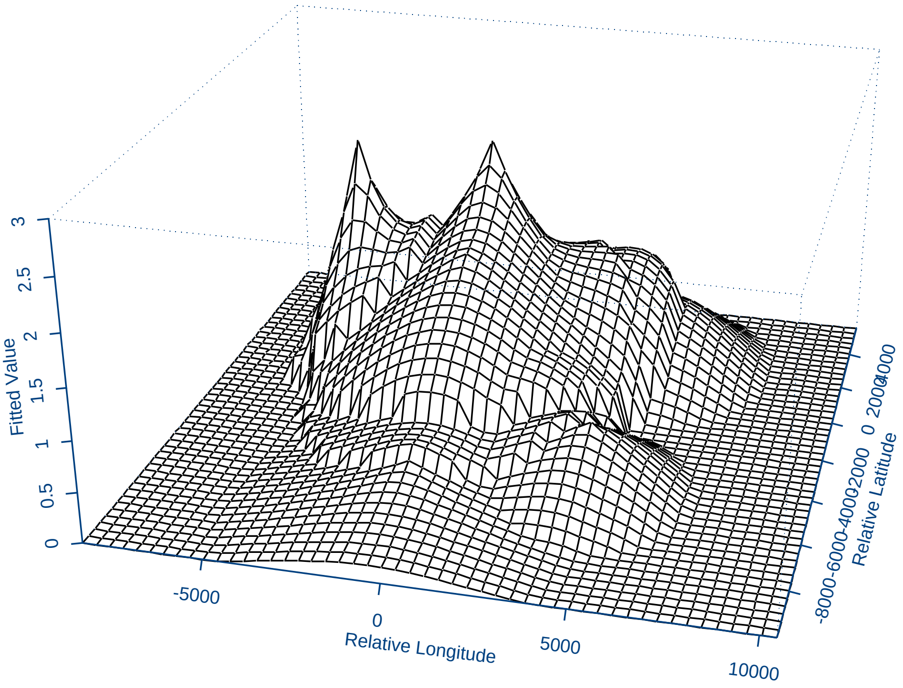

Figure 10: Contour Map of Fitted Price Surface, 1999-2000

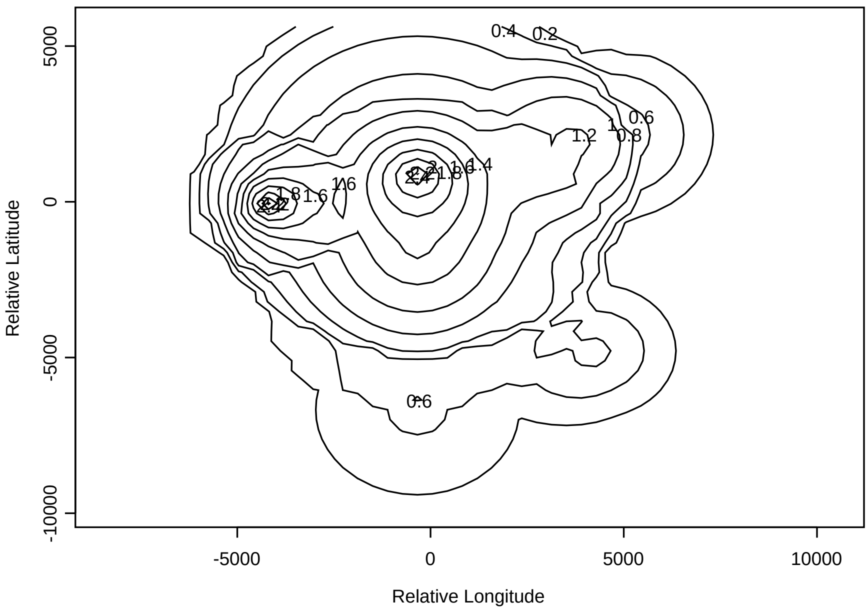

Figure 11: Perspective of Fitted Price Surface, 2001-2002

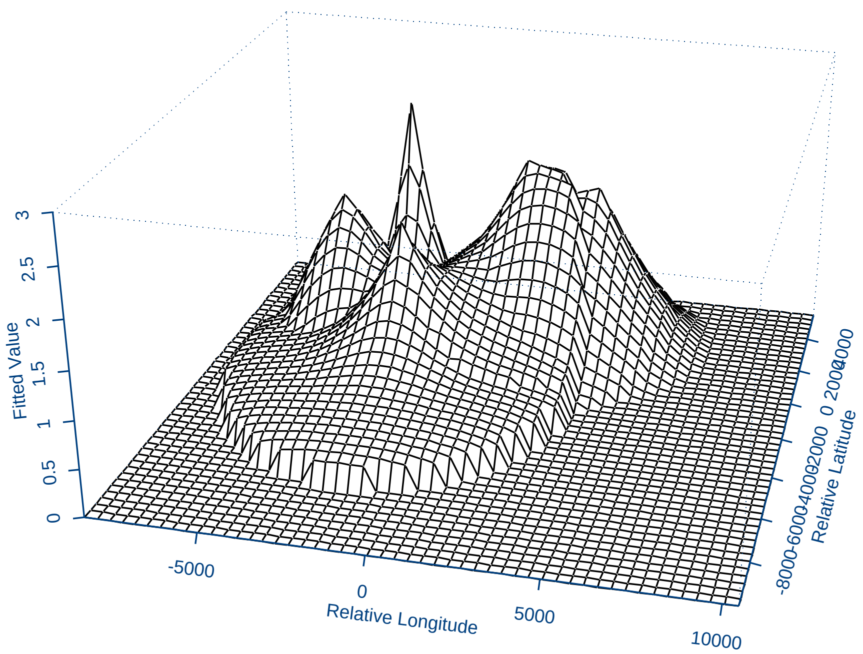

Figure 12: Contour Map of Fitted Price Surface, 2001-2002

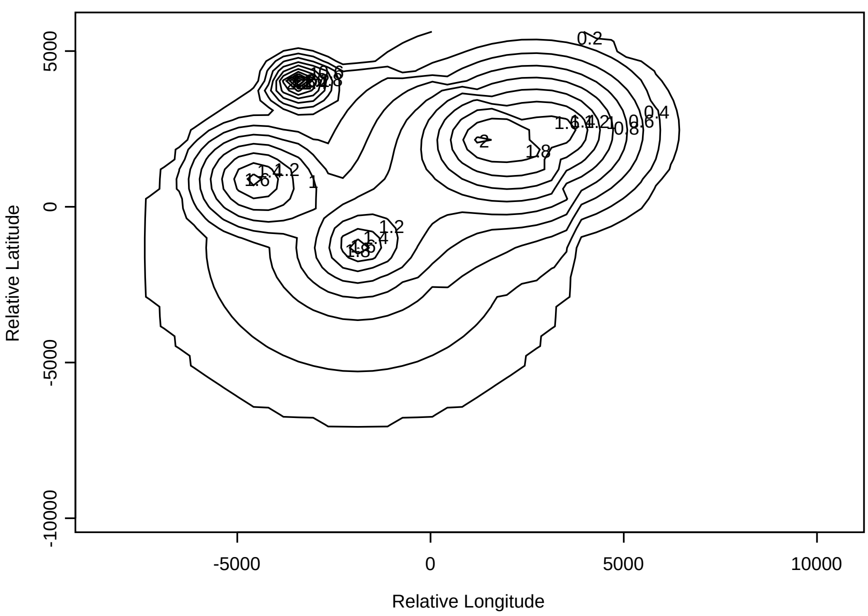

Figure 13: Perspective of Fitted Price Surface, 2003-2004

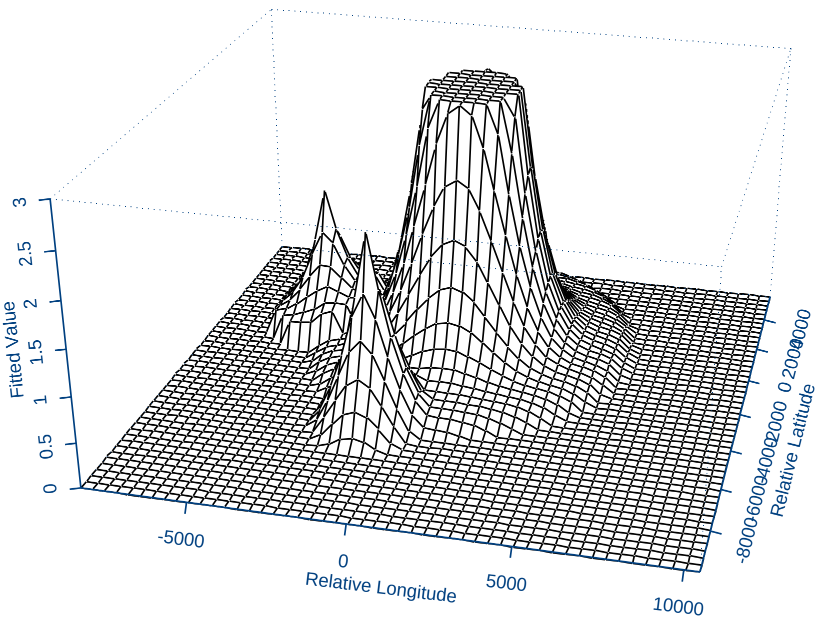

Figure 14: Contour Map of Fitted Price Surface, 2003-2004

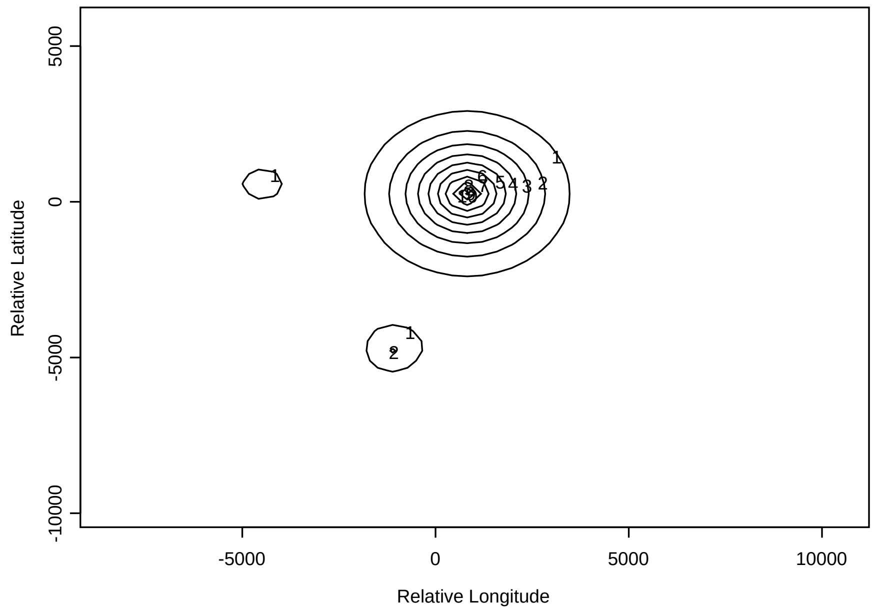

Table 3: Regression Statistics & Comparisons

Time Period:	1993-94	1995-96	1997-98	1999-00	2001-02	2003-04
Regression Comparisons:						
Aspatial R^2	0.302	0.191	0.129	0.135	0.103	0.116
Monocentric R^2	0.384	0.269	0.318	0.322	0.261	0.210
Full Spatial R^2	0.560	0.469	0.508	0.449	0.382	0.256
Statistically Significant Nodes vs. Distinct Centers of Pricing:						
Significant	7	11	8	6	5	3
Distinct	5	5	4	2	3	3

Table 4: Nonparametric Price Surfaces: Metrics of Centrality

Time Period:	1993-94	1995-96	1997-98	1999-00	2001-02	2003-04
Fitted Price Surface Statistics:						
Price-Weighted Radius	4758	4715	4679	4180	4019	2339
Distance to City Center	2209	1538	1497	602	1132	432
Mean of Fitted Surface	0.35	0.41	0.50	0.68	0.69	0.89
% Diff: Priced/Unpriced	41.9	50.7	64.9	97.4	99.4	143.5
Modified Gini Coefficients:						
City Center	41.26	48.27	47.72	60.90	61.80	83.52
Center of Surface	48.56	51.87	50.33	61.39	64.49	83.91