Spatial Regression Analysis of Commercial Land Price Gradients

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Abstract

Commercial land price gradients for an emerging real estate market are estimated using spatial regression techniques. Spatial statistics are used to explore the extent of spatial autocorrelation in the residuals of an OLS land price gradient model. Spatial autocorrelation is present but not to the same degree for all time periods or commercial land uses. Maximum likelihood estimates of land price gradients are as one would expect in mature real estate markets.

Key Words: Spatial regression, spatial autocorrelation, land price gradients, emerging markets.

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Introduction

In this study, we use spatial regression techniques to estimate 'commercial' land price gradients for a seven year period during the 1990s in Cracow, Poland. The land transactions employed in this study reflect market transactions of undeveloped commercial parcels throughout the urban confines of the city of Cracow. By commercial we mean parcels that are zoned for multi-family, mixed-use (multi-family residential and retail and/or office), industrial and traditional commercial (retail and/or office) uses. Over forty years, there was no economic incentive to recycle or develop excess land or unused parcels within the city boundary thus there were, at the beginning of the transformation of the Polish economy in the early 1990s, many underdeveloped parcels. These had been allocated to producers during the communist prior 40 years. As part of transformation many of these parcels became marketable so, many have been sold creating a remarkable database of actual sales of undeveloped land within the boundaries of the urbanized area. Still, the physical landscape of Cracow reflects the legacy of forty years of central planning.[1]

The database we have developed is unique so there are no truly comparable studies in the literature. Our database includes the population of actual transactions of undeveloped commercial land over a several year period. The transactions are for different types of income producing land uses (zones) including multi-family, industrial, mixed use and commercial. In this study we focus on the commercial uses where there has been dramatic price appreciation since 1993. Many of these plots of land are within the boundaries of the city because during the communist period land was often allocated to low density uses (e.g., storage yards), not priced and thus not recycled to higher and better uses through time. As the city grew from 200,000 to 750,000 during the communist period, these parcels were surrounded by other land uses including residential. In Poland, the 'big bang' occurred in 1990 with the introduction of a comprehensive package of laws implementing the legal and institutional framework of a market economy. The recession triggered by the breakthrough lasted 3 years and by the end of 1992 the economy registered real growth. Since then Poland's economy has been able to maintain growth in the range of 5-7% per annum (Table 1).

Our data set allows us to break new ground examining a market that we know is out of equilibrium at the outset. Conditional on the existing city structure, we can examine market actors' responses to the

[1] See Bertaud (1999) and Bertaud and Renaud (1997).

incentives provide by a newly introduced market system. This large idiosyncratic shock affords us the opportunity to see if land markets behave as theory would predict and to explore new ground with respect to the spatial and inter-temporal pattern of price change. We are examining a market in which there were barriers to normal responses for over 40 years. The sudden removal of those barriers provides us with a unique opportunity to understand how land markets respond to change and how agents adapt to them. In general, US land markets are relatively stable and natural experiments are difficult to find. In the case of Cracow, we have a natural experiment in which the 'market' has experienced a significant shock.

We need to understand the economic fundamentals in place during the transformation so that we can better interpret what we observe in the marketplace. Urban theory provides strong predictions with respect to the impact of commuting costs, housing preferences, firm behavior and land values; and does so globally. While the specifics of the situation in Cracow are unique, the behavior of agents there is not.

Our goal in this paper is to understand how commercial land values have evolved in Cracow between 1993 and 1999 and to take advantage of spatial statistical techniques. In the next section, we summarize political and economic events leading up to, as well as the strategy implemented by the leadership in Poland to privatize land markets. In the third section, we discuss the theory and the statistics to be used. In the fourth section we describe the data set that has been accumulated. We follow that in the fifth section with our analysis and results. In the sixth section we offer our conclusions.

Background

The city of Cracow lies in the hills in the southeast of Poland, the center of the region known as Malopolska bordering the Ukraine and Slovakia. The city of 750,000 is divided into four areas or districts which are Srodmiescie (Central Cracow), Nowa Huta (the East Side), Podgorze (the South Bank of the Vistula) and Krowodrze (the West Side). In Central Cracow is the old fortified medieval city, the University, many historic and cultural buildings as well as the commercial core. Nowa Huta includes the Sendzimar steel mill, and surrounding lands.[2] The government introduced previously non-existent heavy industry when it built the mill in the 1950s. Nowa Huta was designed as a model socialist town, still recognizable by massive Stalinist multi-family housing units built directly to the west of the mill to provide employees with nearby housing. Later industrial development occurred in Wola, Duchaka and Nowy

[2] As part of the privatization process the mill workers and management now own the facility along with the land. The land offers development opportunity due to size and location and challenge due to the need for environmental clean-up.

Biezanow to the southeast of the old town and high-rise housing was built nearby. This group of communities and Nowa Huta were each established about seven kilometers from the old city core creating four high density nodes consistent with the socialist goals of providing cost effective high density housing close to nearby industrial employment centers. Krowodrze, to the northwest is primarily a residential community.[3]

While Poland has a rich history, prior to World War I Poland had spent some 120 years partitioned among Germany, Austria and Russia. The end of World War 1 resulted in liberation and intensive infrastructure investment, economic growth and commercial activity despite wartime destruction and the regional differences arising from partition. The Treaty of Versailles led to the outbreak of World War II and the occupation of Poland by German and Soviet forces and the end of World War II left Poland under the influence of the Soviet Union with boundaries moved to the west.

Beginning with the occupation of a redefined Poland by the Soviets in 1945, the decisions of central planners shaped the spatial development of cities in Poland. In the immediate post-War years Warsaw was rebuilt. However, by 1948, the private sector had been eliminated and a new centralized economy was being built around heavy industry. The land use pattern resulting from the allocation decisions made during this period remained forty years later when the transformation began. Socialism had left a durable imprint on the spatial organization of the city.

The transformation began in 1990 with a radical package of reforms dictated by the severity of the inherited economic problems and the expectation that the new regime's political capital would be rapidly consumed. The Balcerowicz plan involved macro-economic stabilization followed by restructuring and stimulation. Macroeconomic stabilization strategies included the liberalization of prices, the raising of interest rates to a positive real level and the support of internal convertibility of the Polish currency. Critical components of the restructuring included the privatization of some state-owned enterprises and the

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3 A USAID funded study of land use and economic development opportunities in Cracow included briefing materials for an Urban Land Institute Panel. These briefing materials provided a single source for much of the factual information in the background section of this paper. See *An Evaluation of Land Use and Economic Development Opportunities: Cracow, Poland, October 1-7, 1994,* Urban Land Institute Advisory Services Panel, USAID Contract No. EUR-003-C-00-0234-00.

liquidation of others, the encouragement of start-up firms and the return of the ownership of real estate assets to the private sector. See Slay (1994).[4]

The shock strategy resulted in real GDP declines in 1990 and 1991 of 11.5% and 7.6%, respectively. Inflation during 1990 and 1991 was 585% and 70.3%. To place the dynamics of the land market during the transformation in an economic context, we report changes in the nominal prices of consumer goods, public transportation, rents and automobiles as well as nominal wages in Table 1. Rents, transportation costs and the prices of automobiles outpaced wage increases and overall price increases. Wages outpaced price increases after 1995. Rents experienced large relative increases in 1992 and 1995. Public transportation costs jumped between 1991 and 1992 between 1992 and 1993. Because of higher fuel costs and the high costs of credit, the price of private automobile transportation has risen more than the cost of public transportation. As well, opportunity costs associated with commuting time would have increased after 1995 as real wages increased. These factors likely impacted the geographic distribution of rents and residual land values as location and accessibility took on greater value.

Part of the restructuring was reestablishing the bundle of property rights associated with real estate including forms of tenancy, transfer mechanisms, title and the rights and obligations of ownership through amendments to the Constitution of Poland and the Civil Code. Costs of transfer remain relatively high at about 10% of the price declared in the notarial deed (including brokerage fees). Privatization of real property is a work in progress as previous owners and their successors have employed the courts to seek restitution of properties illegally taken by the state between 1944 and 1962. Most urban property has been municipalized by transferring ownership of real estate to newly elected local governments (Local Self Government Act of 1990) and regulating their real estate asset management and condemnation practices (1990 amendment to the Land Management and Expropriation Act). Local governments have, to various degrees, transferred property rights to the private sector through auction, sale, exchange or grant. For example, the management and employees of a firm might be granted title to land occupied by their factory (e.g., the Sendzimar steel mill). Thus public sector property ownership rights have been clarified. However, due to transactions costs and the potential cloudiness of title many private sector possessors of

[4] Then Deputy Prime Minister and Minister of Finance Leszek Balcerowicz (currently, President of the National Bank of Poland) was the primary architect of the plan. He was one of a group of young economists who had worked during the 1980s developing economic strategies for transition.

property have chosen not to attempt to formalize title. Still other private sector owners fearful of the costs associated with ownership (particularly of rent-controlled residential units) have not revealed their claims.

There is relatively little organized public information about listings or transactions and individual real estate brokers have been reluctant to share information that they perceive has monopoly value. Although the data employed in this study is technically public information, its acquisition involves the investigation of individual files maintained in government offices not easily accessed by private citizens.

Theory and Literature

Urban theory predicts that land values should fall at a constant percentage per increment of distance from the city center. Firms are assumed to produce goods for consumption by residents of the city or for export and that business activity is focused on the city center. Henderson (1977) and Segal (1977) provide useful summaries of the theoretical framework. We model the relationship between land prices and distance using a semi-logarithmic functional form. This specification regresses the log of the land price per square meter on the linear distance from the center of the city. The semi-log functional form is given by:

$$lnP(x) = lnP_0 - g\,x + e \qquad (1)$$

$P(x)$ is the price of land at distance x from the center of the city and γ is the percentage rate of decline per distance measure. e is the residual. As transportation costs for the firm increase, the absolute value of γ increases and rental values at the center of the city increase. If the residual variance is constant and the residuals are spatially uncorrelated, ordinary least squares (OLS) would yield best, linear, unbiased estimators of the parameter g.

Many factors can complicate the fundamental relationship depicted in Equation (1). Polynomial terms and other descriptors that might proxy for some of the spatial variation in land prices may be included. A more general specification follows:

$$Z = Log\,P = X\beta + e, \qquad (2)$$

where $e \sim N(0, s^2 I)$ so that $Z \sim N(X\beta, s^2 I)$. The coefficients estimated with OLS are described in Equation (3):

$$b = (X^T X)^{-1} X^T Z, \qquad \text{where } b \sim N(ß,\ s^2 (X^T X)^{-1}). \tag{3}$$

Basu and Thibodeau (1998) and others focusing on hedonic house price models have shown that even with an exhaustive array of descriptors, there is the likelihood of spatial correlation among the residuals. We would expect the same to be true in a model of land prices. We employ their notation and their approach in the initial part of our analysis. When the residuals are spatially autocorrelated, $E\{ e\ e' \} = W$, a matrix with non-zero off-diagonal elements and *ß* can be estimated with the generalized least squares (GLS) estimator $B = (X^T W^{-1} X)^{-1} X^T W^{-1} Z$. It is necessary, however, to estimate W. We use a nearest a nearest neighbor approach to estimate W for the maximum likelihood estimates of the spatial regression model.

As a first step in evaluating the extent of spatial autocorrelation in our data, we generate and plot semivariograms. Here we employ the exposition in Basu and Thibodeau (1998) and Gillen et al. (forthcoming) to explain the approach used. $s_i = (x_i, y_i)$ specifies the location of parcel i where x_i denotes the longitude and y_i the latitude for property i. $x (s_i)$ denotes the land price gradient model residual for a parcel located at s_i. If the stochastic process is weakly stationary, the covariogram for the distribution of residuals is $C (s_i - s_j) = Cov \{ x (s_i), x (s_j) \}$ for all (s_i, s_j). $C (0)$ is the variance for the residual distribution and it is assumed to be constant. The semivariogram for the process is then:

$$g (s_i - s_j) = 0.5\ Var \{ x (s_i) - x (s_j) \} = C (0) - C (s_i - s_j). \tag{4}$$

The variable h denotes the distance separating locations s_i and s_j. Theoretically, $g (- h) = g (h)$ and $y\ g (0) = 0$. However, analysis of spatial data often finds that $g (h)$ is discontinuous near the origin and $g (h)$ ® $q_0 > 0$, as h ® 0. The discontinuity, q_0, is labeled the nugget.

Observations may eventually become spatially uncorrelated as the distance between them increases so that the semivariogram stops increasing beyond some threshold and becomes constant. That is, $g (h)$ ® C^*, as h ® ¥. This limiting value, C^*, is the sill of the semivariogram. The range of the semivariogram is the value h_0 such that $g (h_0) = C^*$. So the range of a semivariogram is the distance beyond which observations are spatially uncorrelated. Finally, a semivariogram is isotropic if $g (s_i - s_j)$ is a function of only the distance between s_i and s_j, $||s_i - s_j ||$, and not the direction separating s_i and s_j. Spatial data is anisotropic when spatial autocorrelation is a function of both the distance and the direction separating points in space.

The empirical semivariogram examines how the spatial autocorrelation between observations changes as the distance between observations increases. The method of moments estimator for an empirical semivariogram is:

$$g(h) = \sum_{N(h)} \left[?(s_i) - ?(s_j) \right]^2 \Big/ 2|N(h)| \tag{5}$$

where the average is taken over $N(h) = \{(s_i, s_j): s_i - s_j = h\}$ and $|N(h)|$ is the distinct number of pairs in $N(h)$. For real estate transactions which occur irregularly in space, $N(h)$ is modified so that $N(h) = \{(s_i, s_j): s_i - s_j \text{ Î } T(h)\}$, where $T(h)$ is a tolerance region around h.

Here we fit the spherical functional form to the points of the empirical semivariogram. There are three popular isotropic semivariograms used to empirically examine spatial relationships including the spherical, exponential, and Gaussian semivariograms. Dubin (1998) and Dubin et al. (forthcoming) argue for the use of the spherical semivariogram model as it has a finite range which seems to be consistent with the empirical reality of real estate markets. The functional form for the spherical model is:

$$?(h;\ ?) = \begin{cases} 0, & h = 0 \\ ?_0 + ?_1 \left\{ 1.5\left(\dfrac{||h||}{?_2}\right) - 0.5\left(\dfrac{||h||}{?_2}\right)^3 \right\}, & 0 < ||h|| \le ?_2 \\ ?_0 + ?_1, & ||h|| \ge ?_2 \end{cases} \tag{6}$$

The nugget for the spherical semivariogram is q_0, the sill is $q_0 + q_1$, and the range is q_2.

The parameters of the spherical semivariogram are estimated using nonlinear least squares. The three parameters of the spherical semivariogram model can be fit to the empirical semivariogram, $g(h)$, by minimizing the nonlinear function:

$$S(?)=\sum_{k=1}^{K}\left[g(h(k))-?(h(k),?)\right]^2 \quad (7)$$

with respect to the semivariogram parameters q . The sequence $h(1), \ldots, h(K)$ denotes the separation distances for which the sample semivariogram $g(h)$ are computed.

In addition to the computation and fitting of semivariogram functions, we undertook tests of spatial autocorrelation. Our approach to these tests and the subsequent spatial regressions required that we specify the weight matrix through the nearest neighbor approach. Dubin (1998) notes that the tests of spatial autocorrelation are sensitive to the number of nearest neighbors chosen. See also Can (1992). However, we tested the sensitivity of the spatial regression to our choice of priors regarding nearest neighbors and found that our results were robust to the assumptions regarding the number of neighbors and distance.

The approach is to specify a matrix of weights W where W is an N X N matrix with zero on the main diagonal and where the off-diagonal elements represent the spatial relationship between transactions s_i and s_j . If 'nearest neighbors' is used to construct W, as in our case, $W_{ij} = 1$ if i and j are such that there is no observation closer to either i or j, and zero otherwise. This approach can handle more than one 'nearest neighbor.' Once having determined W, we can determine O as follows:

$$e = (I - W)^{-1}? \quad (8)$$

and

$$E\{ e\ e' \} = W \quad (9)$$

Finally, let C denote a diagonal matrix of weights. Then a simultaneous autoregression (SAR) model assumes that

$$S= [(I-? W)^T C^{-1} (I - ? W)]^{-1} s^2 \quad (10)$$

where $?$ is a scalar parameter to be estimated, and s is a scale parameter which is also to be estimated. Note that T denotes a matrix transpose.

The SAR model can be expressed as an autoregressive model for the spatial parameters as follows:

$$LnP = Xß + ?W(y - Xß) + C^{-1/2} e \tag{11}$$

This allows one to decompose the sum of squares in y into three components (Haining, 1990): 1) the trend, $Xß$; 2) the noise, $C^{-1/2} e = (I - ?W)(y - Xß)$; and 3) the signal, $y - Xß - C^{-1/2} e$. Note that if ? = 0, Equation (11) collapses to the standard OLS model.

Two functions are required to compute the profile likelihood: 1) a function for computing the determinant |S|, and 2) a function for computing the vector $S^{-1}z$ for arbitrary vector z. When the single neighbor matrix W is symmetric, the determinant can be expressed and efficiently computed as a function of the eigenvalues of W. If W is not symmetric, or if the dimension of W is large (over 150), then sparse matrix routines by Kundert (1988) are used to compute the determinant of S. Because the covariance matrix is parameterized in terms of its inverse, the computation of $S^{-1}z$ is simple using (sparse) matrix multiplication.[5]

Data

This data base of land sales in Cracow was originally developed by the Cracow Real Estate Institute (CREI) as part of the USAID funded market value based property tax simulation project in Cracow in 1993 and 1994. Since that time, the database, the population of land transactions in the city, has grown from about 600 transactions to over 6000 spanning the time from 1992 to mid-1999. The transactions are 'arms length' sales between individuals, housing cooperatives, privatized entities or government entities. Additional data collection efforts have been funded in part through a Lincoln Institute of Land Policy research grant. Each sale is located spatially in an x-y grid system allowing the computation of distance to the center of the city. The data set used in this analysis is comprised of about 1500 sales of properties involving income producing real estate uses between 1993 and mid-1999. The 1992 sales are not included as they reflect a sample only of the pre-1993 sales. Appendix A includes a list of the variables in the data set and their definitions. The linear distance to the central reference point of Cracow, a town square dating from medieval times, was computed for each transaction. Figure 1 maps the location of individual

[5] We use the S + Spatial Statistics software in our empirical analysis.

transactions in the database. In order to facilitate analysis, we examine subsamples by time period and type of land use. Specifically, the three time periods are 1993:1 though 1995:3 (hereafter, Period 1), 1995:4 through 1997:6 (hereafter, Period 2) and 1997:7 through 1999:9 (hereafter, Period 3). The types of land use were noted previously. Table 2 reports the real price per square meter buy type of land use by year during the period of analysis. There is high variability in the price data evidenced by the high standard deviation for some land use types for some years. The data set is described in more detail in Dale-Johnson and Brzeski (2001).

Analysis and Results

Price Indexes

We begin by reporting price indexes for the commercial segments of the market by type of land use to provide some insight into market dynamics. Remember that by the term commercial, we mean parcels that are zoned for multi-family, mixed-use (multi-family residential and retail and/or office), industrial and traditional commercial (retail and/or office) uses. These are all income producing or uses typically of interest to investors or owner users. Table 3 and Figure 2 and 4 show constrained hedonic price indexes (hedonic indexes where attribute coefficients are constant across all time periods and time dummies are used to generate the index). The indexes are reported for the market segmented by land use. We did not estimate separate indexes for mixed-use and industrial land uses as there are not sufficient transactions in very quarter to estimate the model.

The general form of the constrained hedonic price index model appears below. Equation (12) is similar to Equation (2) but for a series of time dummies for each quarter during the period of analysis.

$$lnP(x) = X\beta + S\ D_t + e \qquad (12)$$

There is significant volatility in the individual price indexes and with respect to the non-residential uses dramatic increases in price during 1996, 1998 and 1999. Prices are measured in real terms (PLN, new Polish zloties) adjusted for inflation.

After 1995, commercial values are influenced by high demand for retail locations (e.g., for hypermarkets, fast food outlets and gas stations), distribution sites and office sites. There are a few transactions beginning in about 1996 at prices in excess of $200 per square meter for commercial parcels. While prices in general are increasing, these seem to be extreme values. Research into individual transactions indicated that these prices were typically paid by global firms seeking well-located parcels to establish competitive advantage near the urban core. We removed 'geographic outliers' and extreme prices from the data and recomputed the indexes with minimal effect. While these transactions were unusual, they were the result of arms length negotiations and were part of the overall movement of commercial and mixed-use property values.

Semivariograms

As noted earlier, we plotted semivariograms for the residuals in each of the regression models reported above. We report only those for the time tranches (Periods 1, 2 and 3). A point in the empirical semivariograms in Figure 3a or 3b is the difference between the variance and covariance in the residual in the land price gradient model computed for properties within a given region. For example, in the first plot in Figure 3b, the first point to the right of the y axis measures the spatial autocorrelation for properties within +/- 200 meters of the separation distance h which is 333 meters. The points for the empirical semivariogram are computed for 30 values of h ranging from h=333 meters to h=10,000 meters. Since we are considering only isotropic spatial correlation, each point is determined without regard for the direction separating properties. The semivariogams in Figure 3a assume a maximum distance of five kilometers while 3b assumes ten kilometers.

Again, Figure 3a shows plots of isotropic empirical semivariograms for the residuals of estimations of land price gradient models for the Cracow market. We do not show the plots for the log price (the dependent variable in the same models) as they are virtually indistinguishable. This suggests that the land price gradient model does little to reduce the extent of spatial autocorrelation in log price. In each figure, there are plots for Periods 1, 2 and 3 during the time period from which our data is available. However, across time there does appear to be differences in the shape of the function although in all cases, gamma increases as distance increases. Second, during Period 1, log price and the residuals appear to be spatially auto-correlated for a distance of about 2 and 1/2 kilometers. During Period 2, the semivariogram appears to be increase throughout the region. During Period 3, there appears to be autocorrelation over distances of about one kilometer. In the plots shown, we used a maximum distance of five kilometers. In Figure 3b, we show the semivariograms where the maximum distance is 10 kilometers. The results appear much similar across time periods although there is individual variation in the measures for the range (θ_2), sill (θ_0 +

θ_1) and nugget (θ_0). The values for the range, sill and nugget are reported beside each plot in Figure 3a and 3b.

Estimation of Spatial Regressions: Introduction

In Table 4, we report OLS estimations of land value functions by time period and land use type. We estimated the same functional form in all cases for consistency and comparability.

$$LnP = a + b_1 * DIST + b_2 * LAREA + b_3 * MONTHS + b_4 * SEW + e \qquad (13)$$

The dependant variable is the log of the real unit price of each land sale where unit price is the real price per square meter in the new Polish currency using a 1993 base year. The distance from the lot's center to the center of old Cracow is the variable *DIST*. *LAREA* is the log of the area of the lot. It is assumed that larger lots might bring a discount on the per square meter price, all other things being equal. *SEW* is a measure of access to the sewer system. *MONTHS* is simply an ordinal measure of the number of months that have passed during the sample period thus creating a trend variable. Appendix A includes a description of all of the variables employed in the estimations. The results of the OLS models are included in the top two panels of Table 4. Note that the fit of the model declines between Periods 1 and 2 (the adjusted R^2 falls from 0.344 to 0.213) and then stays about the same in Period 3 (Adjusted R^2 = 0.215). This decline in fit is consistent with the results of other intertemporal studies of land price gradients where OLS land price gradient estimations have been reported. We report in detail the results of the spatial regressions in the lower two panels. Note that these results are for the model depicted in Equation (11)

Spatial Land Value Functions by Time Period

The spatial regression results for the three time periods appear in the third panel in Table 4. The measure *?* varies in size from less than 1% to in excess of 9%. The coefficients are highly significant in most cases and the coefficient on the distance variable is relatively stable across time periods. The coefficient on *MONTHS* varies reflecting the overall negative real growth (-1.5% per month) during Period 1, positive but insignificant real growth during Period 2 and positive real growth (2.7% per month) during Period 3. Access to infrastructure is valued based on the significant and positive coefficient on the measure for access to sewer lines during the first two periods. We include the variable for the size of the lot in the model as there one would expect larger lots to sell for less per square meter. The variable is significant in all cases but of the expected sign in Periods 1 and 3.

Spatial Land Value Functions by Type of Land Use

We turn to the third panel in Table 4, which presents the results of estimations of the spatial regressions of the land value function by type of commercial land uses (multi-family, industrial, mixed use and commercial). The key measure ? varies in size from less than 2 % to in excess of 11%. The coefficients are highly significant in most cases. The coefficient on the distance variable varies by type of land use. For multi-family and mixed uses, the estimated coefficient is -0.0003. For industrial uses and commercial uses the coefficient is -0.0002. Mixed land uses are combinations of commercial (office and/or retail) uses and multi-family residential uses. This result suggests that accessibility is most important for medium to high density residential uses (multi-family and mixed uses which include multi-family). There appears to be less variation in land price as a function of distance to the city center for industrial or commercial uses. This is particularly interesting for commercial uses as the transactions are dispersed throughout the city. See Figure 1.

The coefficient on the lot area variable is negative and highly significant for multi-family and commercial land uses. It is significant and positive for mixed uses and insignificant for industrial uses. The coefficient on *MONTHS* is highly significant in all cases but varies reflecting relative price performance of each of the land uses. Real growth rates per month range from 1.2% for multi-family land uses to 2.4% for mixed uses. Access to infrastructure (sewer services) is not significant for any land use. In comparing these results to the OLS results, this suggests that for particular land use types access to infrastructure is spatial and that the spatial regression approach captures some of these effects. Note that there are numerous other infrastructure variables in our data set and access to telephone services and other types of infrastructure prove important as well in unreported OLS models. Since the measures of the quality of infrastructure services tend to be highly correlated, we chose not to report the results of every case nor include more than one infrastructure variable in our final model.

Conclusions

In this study we report the estimation of land price gradients incorporating spatial regression techniques. Most studies that have examined land price data in an urban setting have not used spatial regression techniques. We report the price performance of different commercial land uses during the 1990s in Cracow, Poland, estimate OSL land price gradients and explore the extent to which there is spatial autocorrelation. We report plots of semivariograms for three different time windows during the '90s.

Finally we employ spatial regression techniques to re-estimate the land price gradients. We use the 'nearest neighbor' approach to specifying the weight matrix employed in the maximum likelihood estimation.

Perhaps most important, the use of spatial regression techniques allows us to more carefully estimate land price gradients for this market during this period of economic transformation. The land price gradient is derived from fundamental trade-offs that occur in the land market in a market economy. Thus the transition to a viable land market seems to have been rapid in Cracow as the estimated land price gradients behave as one would expect in a mature market economy.

There is dramatic real growth in land prices during 1996, 1998 and 1999 particular for transactions involving commercial land uses. This reflects the 'globalization' of the land market in Cracow as international retailers and developers became willing to pay 'global' prices for well-located parcels for the development of hyper-markets, gas stations and similar high volume retail oriented uses.

Our plots of semivariograms indicate spatial autocorrelation in the residuals of the land price gradient models up to distances of about 2 ½ to 5 kilometers. There is a lot of volatility on the plots reflecting the high variability in the underlying data. Our tests of spatial autocorrelation, which we don't report confirm these results and are robust to alternative choice of the parameters used to define the 'nearest neighbor' weight matrix *W*. This same matrix is used in the maximum likelihood estimates of the spatial regression models.

The measure *?* ranges in value from less than 1% to more than 11%. In some cases the use of spatial regression techniques is clearly justified. The results of our estimations show that land prices decline between 2/10ths and 3/10ths of 1% for each kilometer from the city center. While these numbers are small, they are consistent with prior results in other urban centers thought those results have generally not been from the analysis of transactional inter-temporal data. The size of the parcel tends to reduce the transaction price although this result does not arise in all cases. Access to infrastructure is also valued but not consistently.

The variability in the underlying data evidenced by the high standard deviation for some land use types for some years in Table 2 made detection of spatial relationships mode difficult. Part of this volatility is likely a function of the nature of the marketplace. However, some no doubt arises from variation in the expected development program that may not be captured by the extant zoning code. It is that zoning code that we have used to define land use. Unfortunately, it does not accurately define the anticipated rather it defines a range of densities. It may be spatial autocorrelation in the densities of these anticipated development schemes that we are capturing in this paper.

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Figure 1 – Commercial Land Transactions in Cracow

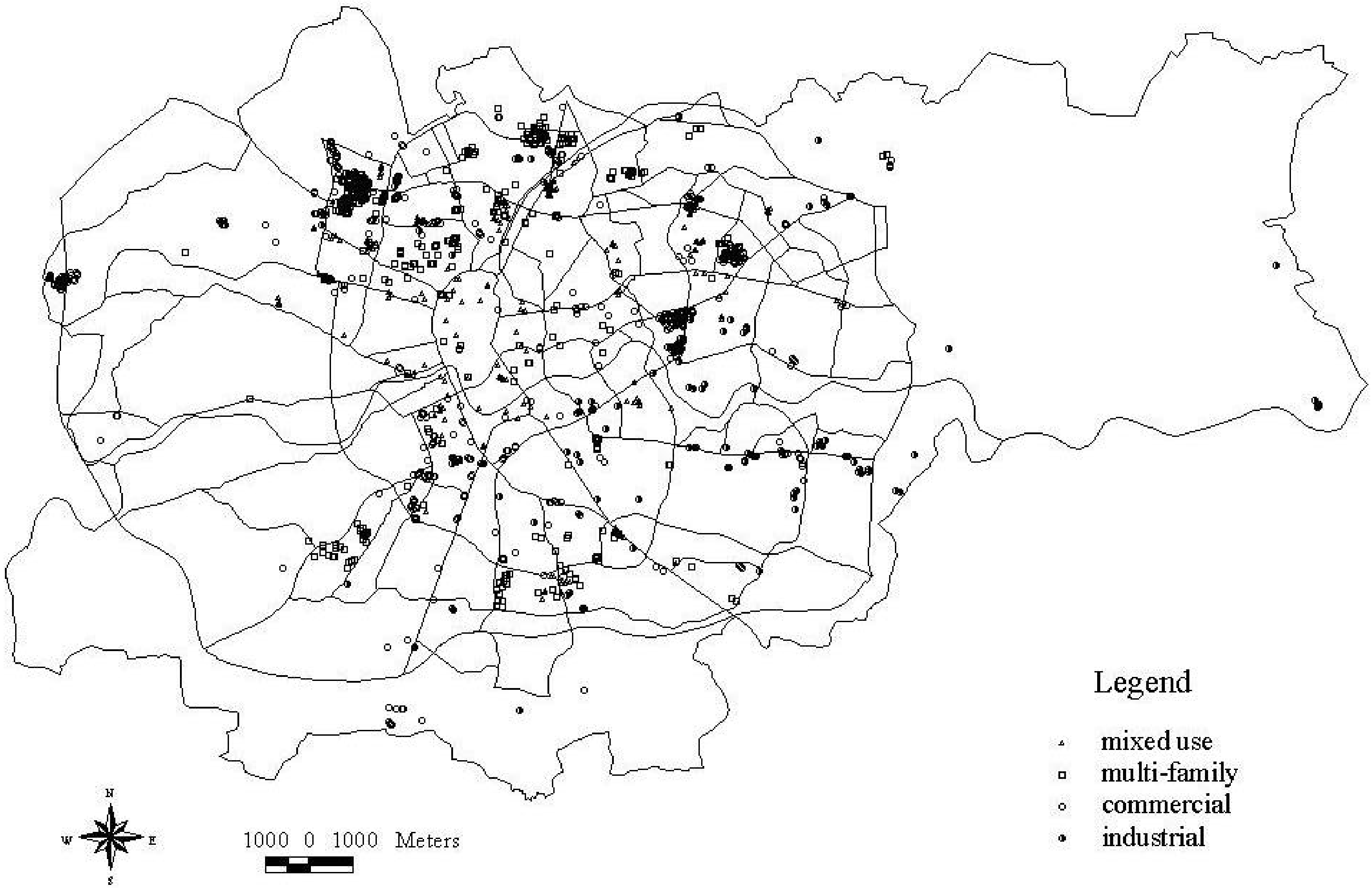


Figure 2: Constrained Hedonic Commerical Land Price Indexes for Cracow: 1993:1 to 1999:3

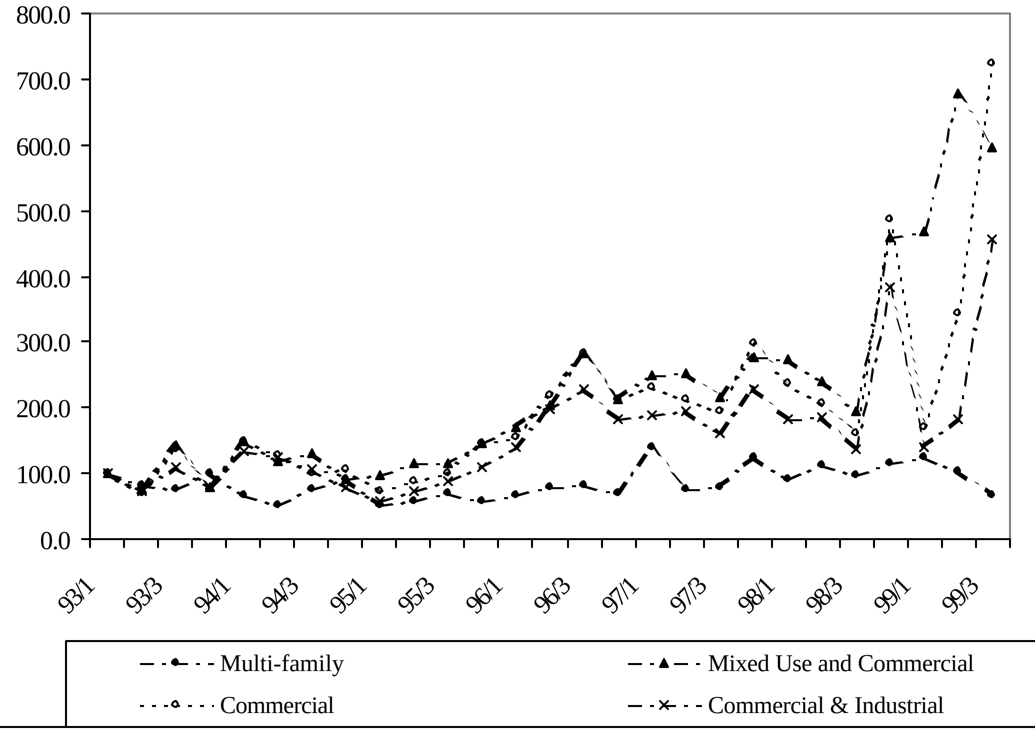
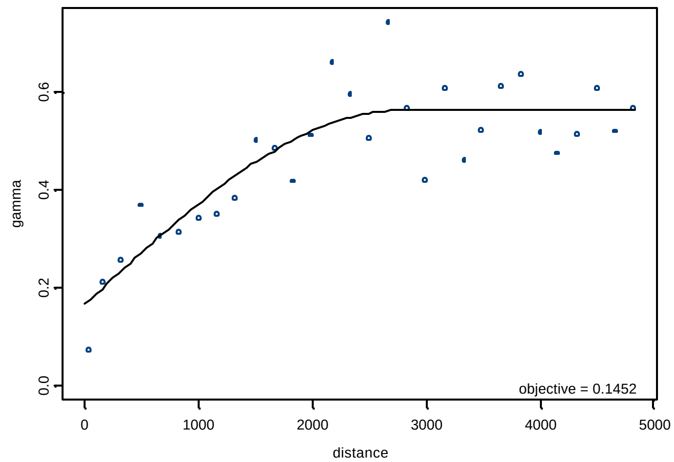
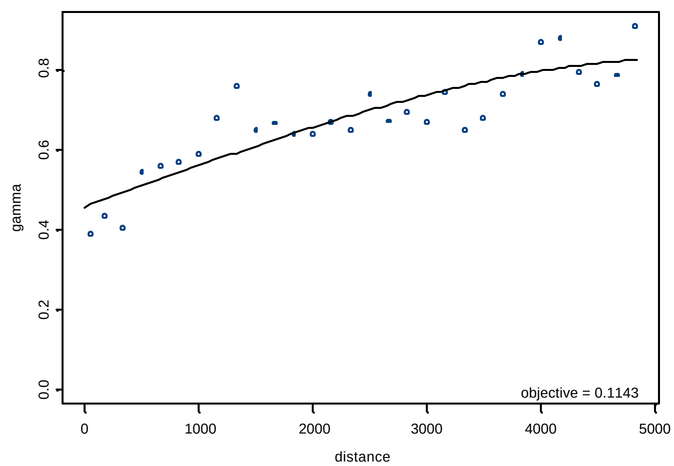


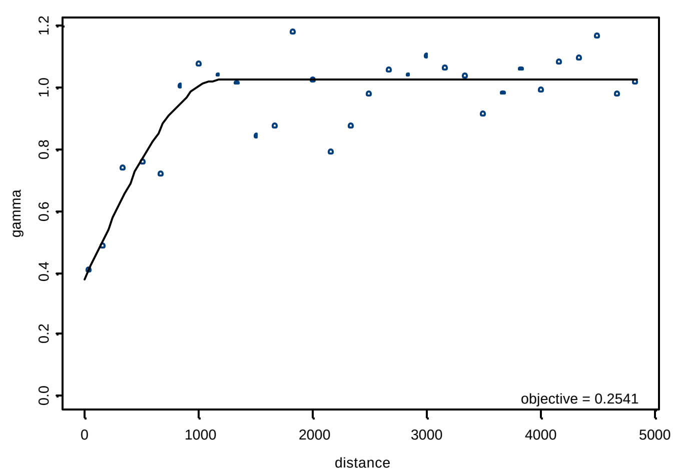
Figure 3a – Semivariograms - Periods 1, 2 and 3



$\theta_0 = 0.16$
$\theta_0 + \theta_1 = 0.57$
$\theta_2 = 2727.38$

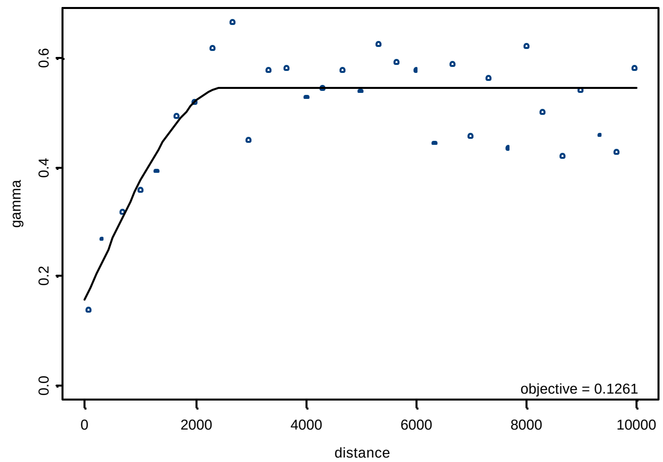


$\theta_0 = 0.45$
$\theta_0 + \theta_1 = 0.82$
$\theta_2 = 5344.30$

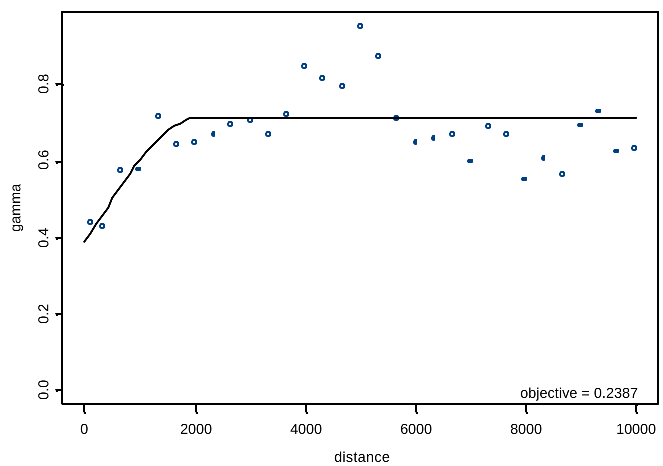


$\theta_0 = 0.38$
$\theta_0 + \theta_1 = 1.02$
$\theta_2 = 1165.67$

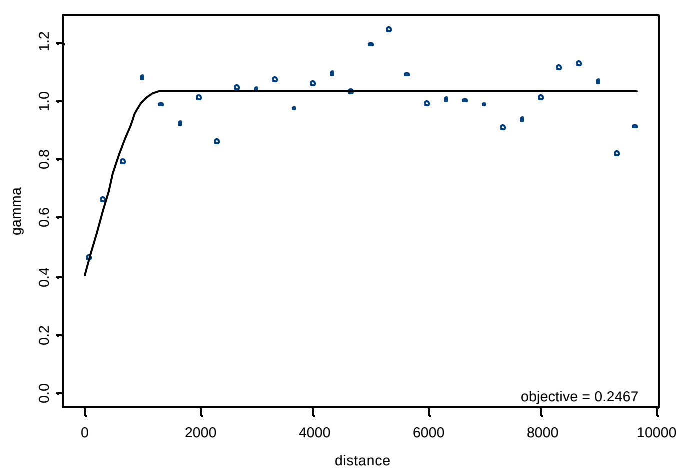
Figure 3b - Semivariograms - Periods 1, 2 and 3



$\theta_0 = 0.16$
$\theta_0 + \theta_1 = 0.55$
$\theta_2 = 2552.42$



$\theta_0 = 0.39$
$\theta_0 + \theta_1 = 0.72$
$\theta_2 = 2103.47$



$\theta_0 = 0.40$
$\theta_0 + \theta_1 = 1.03$
$\theta_2 = 1248.68$

Table 1

Economic Data for Poland

Year	Real GDP Growth	CPI Index	Nominal Wage Index	Nominal Rent Index	Public Transportation Cost Index
1990	-11.6	58	-	-	-
1991	-7.2	100	100	100	100
1992	2.6	143	140	160	160
1993	3.8	193	189	214	236
1994	5.2	255	253	279	317
1995	7	326	334	426	403
1996	6.1	391	421	554	512
1997	6.9	450	514	709	624
1998	4.8	504	596	879	731
1999	3.9	590	668	1056	855

Source: OECD and Cracow Real Estate Institute

Table 2
Vacant Land Transactions in Cracow, 1993-1999 - Median, Mean, s and N by Year

Year	Price in $/Sq. Meter	Multi-family	Industrial	Mixed Use	Commercial
1993	Median	20.09	6.28	29.73	8.90
	Mean	24.99	6.28	29.73	10.50
	s	(19.79)	(3.90)	(16.42)	(8.23)
	N	58	21	2	45
1994	Median	16.28	6.4	14.08	11.42
	Mean	20.99	14.28	15.03	16.57
	s	(15.49)	(29.77)	(8.39)	(21.44)
	N	47	14	26	34
1995	Median	19.28	5.07	13.91	12.29
	Mean	19.68	6.28	22.71	14.18
	s	(11.06)	(4.12)	(30.97)	(9.77)
	N	57	34	70	111
1996	Median	18.59	14.84	23.94	22.07
	Mean	26.39	26.58	41.26	32.01
	s	(22.33)	(51.28)	(65.80)	(38.66)
	N	88	29	83	178
1997	Median	19.00	8.93	25.67	21.38
	Mean	39.88	9.86	50.49	37.46
	s	(65.52)	(7.12)	(67.50)	(53.55)
	N	102	33	60	154
1998	Median	19.96	8.60	26.10	25.38
	Mean	44.07	12.52	54.04	42.96
	s	(65.26)	(12.14)	(73.78)	(50.67)
	N	88	16	64	95
1999	Median	23.93	14.21	85.37	38.74
	Mean	28.37	21.40	127.51	151.92
	s	(23.57)	(16.08)	(132.23)	(234.45)
	N	31	9	21	7

Table 3
Constrained Hedonic Indexes for Cracow Land Prices by Type of Land Use

Quarter N	Multi-family 471	Mixed Use & Commercial 944	Commercial 623	Commercial & Industrial 769
1993/1	100.0	100.0	100.0	100.0
1993/2	80.8	75.1	70.2	71.9
1993/3	76.9	142.9	138.2	109.4
1993/4	101.0	79.6	76.4	78.0
1994/1	65.4	148.1	148.8	135.2
1994/2	51.7	119.3	129.0	124.9
1994/3	75.5	130.4	100.1	106.8
1994/4	92.7	92.1	106.8	80.2
1995/1	50.4	98.0	71.8	56.6
1995/2	57.6	115.1	87.4	71.8
1995/3	71.0	115.4	100.1	86.9
1995/4	58.0	146.1	145.0	109.1
1996/1	67.4	171.6	156.0	139.6
1996/2	77.9	204.8	218.4	198.7
1996/3	83.4	283.4	281.4	229.0
1996/4	69.2	211.6	212.6	181.4
1997/1	140.0	248.8	232.0	188.3
1997/2	75.1	251.5	211.5	194.6
1997/3	77.8	215.9	193.4	160.8
1997/4	124.6	276.0	298.9	228.4
1998/1	92.4	275.3	237.3	181.5
1998/2	111.3	239.3	207.7	185.7
1998/3	95.9	193.5	160.0	135.9
1998/4	115.7	460.7	487.0	382.0
1999/1	125.5	468.1	170.1	140.8
1999/2	103.7	679.4	342.8	182.8
1999/3	66.2	595.3	724.7	456.4

Table 4 - Summary of Regression Results by Type of Land Use by Time Period*

	Constant	Distance	Log Area	Months	Sewer	Adjusted R^2	F-Statistic	Residual Standard Error	N
	C	***DIST***	***LAREA***	***MONTHS***	***SEW***				
Months 1-27	4.306	-0.0002	-0.185	-0.016	0.191	0.344	38.7	0.710	300
	0.398**	0.000**	0.040**	0.005**	0.091**				
Months 28-54	2.316	-0.0002	0.002	0.030	0.067	0.213	50.43	0.818	751
	0.273**	0.000**	0.026	0.0041**	0.036**				
Months 55-81	2.758	-0.0002	-0.054	0.027	0.083	0.215	31.21	0.993	460
	0.641**	0.000**	0.028*	0.008**	0.047*				
Multi-family	4.668	-0.0003	-0.132	0.008	0.010	0.283	45.83	0.767	470
	0.248**	0.000**	0.025**	0.002**	0.038				
Industrial	3.142	-0.0002	-0.126	0.013	0.137	0.406	24.56	0.708	149
	0.435**	0.000**	0.053**	0.003**	0.069**				
Mixed Use	2.244	-0.0003	0.083	0.027	0.039	0.257	27.29	0.885	326
	0.387**	0.000**	0.040**	0.003**	0.054				
Commercial	2.421	-0.0001	-0.025	0.024	0.095	0.211	41.3	0.892	624
	0.286**	0.000**	0.029	0.002**	0.050*				
	Constant	**Distance**	**Log Area**	**Months**	**Sewer**	**rho**	**Log-likelihood**	**Residual Standard Error**	**N**
	C	***DIST***	***LAREA***	***MONTHS***	***SEW***				
Months 1-27	4.061	-0.0002	-0.152	-0.015	0.209	0.096	-724.5	0.649	300
	0.394**	0.000**	0.036**	0.005**	0.097**				
Months 28-54	2.636	-0.0003	0.034	0.002	0.067	0.022	-2325	0.801	751
	0.273**	0.000**	0.004**	0.026	0.036**				
Months 55-81	2.939	-0.0003	-0.063	0.027	0.060	0.008	-1405	0.984	460
	0.643**	0.000**	0.030**	0.008**	0.047				
Multi-family	4.354	-0.0003	-0.119	0.012	0.039	0.017	-1294	0.723	470
	0.248**	0.000**	0.026**	0.002**	0.038				
Industrial	2.554	-0.0002	-0.062	0.017	0.097	0.116	-303.7	0.627	149
	0.446**	0.000**	0.049	0.003**	0.060				
Mixed Use	2.455	-0.0003	0.106	0.024	0.017	0.025	-888	0.849	326
	0.391**	0.000**	0.040**	0.003**	0.054				
Commercial	2.956	-0.0002	-0.076	0.022	0.031	0.017	-1895	0.833	624
	0.291**	0.000**	0.029**	0.002**	0.050				

Standard Errors reported below (**95% confidence, * 90% confidence)

APPENDIX A VARIABLE DEFINITIONS

Distance Linear distance from the lot's center to the center of Cracow as measured by X Y coordinates

Log Price Natural log of unit price (UP) expressed in real terms, January 1993 new zloties (new Polish currency units, PLN). Unit price is the price per square meter (P / AREA).

Log Area Natural log of total area of transferred land lot given in square meters.

Months Date of transaction recorded in notary deed (of conveyance) and converted into ordinal variable by using sequential month numbering from 1 (January 1993) to 81 (September 1999).

Land Uses Classification of multi-family, residential, mixed-use, commercial and industrial land coded as follows:

Multi-family

- medium high density residential multifamily with FAR 0.85 – 1.2
- high density residential multifamily with floor-to-area (FAR) ratio 1.2 – 1.6

Mixed Use

- compact low density mixed use with FAR 1.0 – 1.5
- medium density mixed use with FAR 1.2 – 1.7
- high density mixed use with FAR 1.4 – 1.9

Commercial Classification for parcels zoned commercial (commercial services – Official Zoning Classification UC).

Industrial Classification for parcels zoned industrial (manufacturing and technological processing and support - Official Zoning Classification ***PS***).

Sewer (SEW) Access to sewage system,
SEW is coded as follows:

0 - status unknown
1 - no access
2 - access over longer distance
3 - access over shorter distance
4 - access point on the lot
5 - installation ready for use