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**Working Paper**

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Working Paper, No. 2009:2

**Provided in Cooperation with:**

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*Suggested Citation:* Li, Chuan-Zhong; Isacsson, Gunnar (2009) : Valuing urban accessibility and air quality in Sweden: A regional welfare analysis, Working Paper, No. 2009:2, Uppsala University, Department of Economics, Uppsala, <https://nbn-resolving.de/urn:nbn:se:uu:diva-100815>

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Working Paper 2009:2

*Department of Economics*

# Valuing urban accessibility and air quality in Sweden: A regional welfare analysis

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Working paper 2009:2  
March 2009  
ISSN 1653-6975

VALUING URBAN ACCESSIBILITY AND AIR QUALITY IN  
SWEDEN: A REGIONAL WELFARE ANALYSIS

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# Valuing urban accessibility and air quality in Sweden: A regional welfare analysis\*

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March 20, 2009

## Abstract

This paper is concerned with the implicit values of urban accessibility and air quality in Sweden. Based on the hedonic wage and rent theory, we construct an econometric model to compute such values, and illustrate their implications for regional sustainability analysis. It is shown that for most Swedish cities, welfare has increased from 1986 to 1998 due to improved air quality but the positive effect is partly offset by the deteriorated accessibility in some areas. The results also indicate that the values people place on urban accessibility and air quality vary considerably across regions.

Keywords: hedonic pricing, air quality, urban accessibility, welfare analysis

JEL-codes: D6, R10, Q51

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\*The authors would like to thank the seminar participants at the University of Dalarna and the Department of Economics SLU for valuable comments and suggestions. Financial support from the Swedish Road Administration and the Swedish Governmental Agency for Innovation Systems (VINNOVA) is gratefully acknowledged. The usual disclaimer applies.

# 1 Introduction

In recent years, the theory of green national accounting and sustainability measurement has been greatly advanced. In particular, exact welfare measures such as comprehensive income and inclusive wealth have been developed and the conditions under which such measures can indicate welfare changes are also identified (cf Weitzman 2001; Arrow et al., 2003; Hamilton and Atkinson, 2006; and Li and Löfgren, 2006). The idea is that if a welfare measure based on ideal prices and a comprehensive list of items increases over time, then social welfare is improving and the development is sustainable. Similarly, if the measure in one region is higher than others, then the residents in the region on average enjoy a higher level of welfare.

To construct empirical welfare measures, however, we need to value the various nonmarket goods and services that are relevant for human welfare. This may include, for example, the flow value of travel comfort and safety and the stock value of capital services such as air and water quality, minerals and other natural resources. Since such values are mostly lacking or are incomplete, they are in general not incorporated in the traditional national and regional accounting framework. In Sweden, efforts have been made to incorporate natural and environmental values in satellite national accounting. Skånberg (2001) estimates the negative external effects from reduction in natural resources such as metal ores, soil erosion and overfishing and pollution damages such as eutrophication and acidification, and subtracts these costs from the national GDP (they amount to some 2% of GDP). Ahlroth (2000) obtains a modified GDP by correcting for the impact of nitrogen and sulphur emissions, and finds the environmental cost to be about 1.6% of conventional GDP. In contrast, Gren and Svensson (2004) consider non-marketed values that have positive influences on utility, where natural capital is valued by the current and future ecosystem services. They find positive net welfare contributions from these assets but net negative trend over time, which indicates a non-sustainable use of the resources.

In most such studies, the underlying values of environmental pollution and ecosystem services are benefit-transferred from different valuation studies. In this paper, we attempt to assess the value of urban accessibility and air quality in

Sweden by a self-contained valuation study with certain aspects of spatial interdependence taken into account. We will also make inference on how these valuations contribute to regional welfare as well as the dynamics of such contributions. The valuation theory underlying our study is an integrated hedonic pricing model (Rosen, 1974; Roback, 1982; 1988). The idea is that individual consumers and firms are rational in making trade-offs between various attributes and the values of which are capitalized in wages and rents. For identical individuals, no matter where they chose to live and work, they should be indifferent between staying and moving. A person who lives along the western coast with enhanced scenic beauty, for example, may have to accept a lower wage or a higher housing price *ceteris parabus*; and a person who lives in Stockholm with access to more cultural activities may have to accept a higher living cost and more traffic noise. Similarly, a firm that chooses to locate its business in a certain city has to balance the market potential and factor costs in terms of wages and rents.

The Rosen-Roback hedonic pricing model has been applied in numerous studies during the past decades (see Gyourko et al. 1999 for a comprehensive review). The most recent application is the Berger et al. (2008) study on compensating differentials in labor and housing markets in Russia, where the authors found some disequilibrium features due to the drastic structural transitions in the country from 1994-1999. For Western countries with more stable political and economic systems, however, there are good reasons to retain the spatial equilibrium assumption as in Roback (1982; 1988). Using data for US cities over the period 1971-1988, Greenwood et al. (1991) tests for spatial equilibrium without finding any significant disequilibrium effects.

In this paper, we make the first attempt to apply the Rosen-Roback model to the case of Sweden. As compared to previous studies using the model, we attempt to highlight the following three features in our study. First, in addition to amenity measures, we also incorporate transport and business variables in the model which are important for firm establishment and consumer welfare (cf Krugman, 1991). Second, we adopt an endogenous econometric model to directly estimate the implicit values rather than estimate the wage and rent models separately and then combine them ex-post. Finally, since we have panel data covering a discrete time

period, we can perform a trend analysis on regional welfare rather than merely performing a static welfare comparison.

The remaining part of the paper is structured as follows: Section 2 presents the Rosen-Roback hedonic model with consumer and firm interactions concerning wages, rents, and other attributes such as transport, environmental and market potentials with neighbor cities. The implicit price formula will be derived with comparative static analyses. Section 3 describes the data material and presents summary statistics, and section 4 analyzes the data to derive the implicit prices. In section 5, we assess tentatively the effect of the implicit prices on regional welfare dynamics and section 6 sums up the study.

## 2 The hedonic value theory and the econometric model

Following Rosen (1972) and Roback (1982), we consider a number of  $m$  cities, each is described by a vector of attributes  $\mathbf{z}_i$ ,  $i = 1, 2, \dots, m$ , such as city size, environmental quality and accessibility. An individual worker  $j$  with characteristics  $\mathbf{s}_j$ ,  $j = 1, 2, \dots, n$ , receives a wage rate  $w_{ij}$  and pays a housing rent  $r_{ij}$ , if he lives and works in city  $i$ . By consuming housing services and other competitive goods, the individual can derive a maximum utility  $V(w_{ij}, r_{ij}; \mathbf{z}_i, \mathbf{s}_j)$  with given wage income. It is also assumed that both labor and housing markets are perfectly competitive and people can frictionlessly move from one city to another. Thus, by the no-arbitrage condition, an individual with characteristics  $\mathbf{s}_j$  would be indifferent on where he chooses to live and work. More precisely,

$$V(w_{ij}, r_{ij}; \mathbf{z}_i, \mathbf{s}_j) = V_j, \text{ for all } i = 1, 2, \dots, m, \text{ and } j = 1, 2, \dots, n \quad (1)$$

To start with, we assume identical individuals with the same characteristics across all  $j$  to derive the basic model, and later on to incorporate variation across individuals. Thus, we can rewrite (1) as

$$V(w_i, r_i; \mathbf{z}_i) = \bar{V}, \text{ for all } i = 1, 2, \dots, m \quad (2)$$

where  $w_i = w_{ij}$  and  $r_i = r_{ij}$  for all  $j = 1, 2, \dots, n$ . The marginal utility of income is assumed to be positive, i.e.  $V_w^i \equiv \partial V / \partial w_i > 0$ , and the own price effect is negative

i.e.  $V_r^i \equiv \partial V / \partial r_i < 0$ , for all  $i = 1, 2, \dots, m$ .

Firms are assumed to be identical and perfectly competitive, each producing a homogeneous composite good with a constant-returns-to scale technology using labor and housing services. All firms minimize the cost of producing a given amount of the good, including wage and land costs, resulting in a linear total cost function. Marginal and average (unit) costs would be equal in this model, which also equals the competitive world market good price (normalized to unity). Let the unit cost function for a representative firm be expressed by

$$C(w_i, r_i; \mathbf{z}_i) = 1, \text{ for all } i = 1, 2, \dots, m \quad (3)$$

The effects of wages and rents on the unit cost  $C$  are both positive such that  $C_w^i \equiv \partial C / \partial w_i > 0$  and  $C_r^i \equiv \partial C / \partial r_i > 0$ . By solving the equation system of (2) and (3), we can express the equilibrium wage and rent for each city  $i$  as functions of the city characteristics  $\mathbf{z}_i$ , respectively, by

$$\begin{aligned} w_i^* &= f_1(\mathbf{z}_i) \\ r_i^* &= f_2(\mathbf{z}_i) \end{aligned} \quad (4)$$

We are interested in the implicit price an individual would place on each attribute of  $\mathbf{z}_i$ . A total differentiation of (2) and (3) gives

$$\begin{aligned} V_w dw + V_r dr &= -V_z dz \\ C_w dw + C_r dr &= -C_z dz \end{aligned} \quad (5)$$

where  $z$  refers to a specific attribute in the vector  $\mathbf{z}$ , and which according to

Cramer's rule results in

$$\begin{aligned} \frac{dw}{dz} \Big|_{(*)} &= \frac{-V_z C_r + V_r C_z}{V_w C_r - C_w V_r} \\ \frac{dr}{dz} \Big|_{(*)} &= \frac{-V_w C_z + V_z C_w}{V_w C_r - C_w V_r} \end{aligned} \quad (6)$$

where  $\Big|_{(*)}$  denote that the derivatives are evaluated at the equilibrium wage  $w^*$  and rent  $r^*$ . The sign of the derivatives depends on how the attribute in  $\mathbf{z}_i$  affects



utility and the unit cost. Suppose that  $V_z < 0$  for a negative externality, and  $C_z < 0$  (cf. Brock, 1974) where increased allowable emission implies that the firm can save on factors of production and therefore cost decreases. Then,  $\frac{dw}{dz}|_{(*)} > 0$ , meaning that an individual would demand a wage compensation for the negative pollution effect. Under the same assumptions, it can be readily shown that  $\frac{dr}{dz}|_{(*)}$  may be positive or negative, indicating that pollution may either raise or lower housing prices. Note also that the sign of the wage effect would be reversed for an attribute that contributes positively to utility while increasing production cost. From (5), we can also solve for the marginal cost of a negative attribute  $z$  by

$$P_z \equiv -\frac{V_z}{V_w} = \left( \frac{dw}{dz} - h^c \frac{dr}{dz} \right) |_{(*)} \quad (7)$$

where  $h^c = -V_r/V_w$  is the demand for housing service according to Roy's identity. Note that the derivation above assumes that all individual are identical, and thus there can be only one equilibrium wage and rent in each city. With heterogenous individuals with different characteristics  $\mathbf{s}_j$ , the equation system in (4) should be extended to

$$\begin{aligned} w_{ij}^* &= f_1(\mathbf{z}_i, \mathbf{s}_j) \\ r_{ij}^* &= f_2(\mathbf{z}_i, \mathbf{s}_j) \end{aligned} \quad (8)$$

to allow a spectrum of wage and rent levels. In other words, there is a specific set of equations (4) to (7) for each "type" of individuals of the same characteristics  $\mathbf{s}_j$ .

In the literature, the models in (4) have mostly been estimated separately and then combined ex-post to calculate the implicit price/cost according to (7). In this paper, we formulate a unified econometric model to provide direct attribute variations, where both the wage and rent are used as endogenous variables. The advantage with the model is that the structural parameters may be estimated more efficiently. Furthermore, we include variables for urban accessibility and neighborhood income (related to market potential). We consider the following semi-translog model

$$\ln(w_{ij}) = \alpha + \beta \ln(r_{ij}) + g(\mathbf{z}_i, \mathbf{s}_j) + \varepsilon_{ij} \quad (9)$$

where  $g(\mathbf{z}_i, \mathbf{s}_j)$  is a function of city attributes  $\mathbf{z}_i$  and individual characteristics  $\mathbf{s}_j$ ,  $\alpha$  and  $\beta$  are parameters, and  $\varepsilon_{ij}$  is a stochastic component with a zero mean and

constant variance. By totally differentiating (9) with respect to  $w_{ij}$ ,  $r_{ij}$  and  $\mathbf{z}_i$ , and making some rearrangement, we obtain the following expected marginal cost of the attribute  $z_i$  for individual  $j$  as

$$\frac{dw_{ij}}{dz_i} - h_{ij}^c \frac{dr_{ij}}{dz_i} = w_{ij} \frac{\partial g(\mathbf{z}_i, \mathbf{s}_j, \gamma)}{\partial z_i} \quad (10)$$

where  $h_{ij}^c = \beta w_{ij}/r_{ij}$  can be interpreted as the individual's housing demand in city  $i$  with  $\beta$  as the budget share of housing cost, provided that the utility function is of a Cobb-Douglas type. It is seen that with the semi-translog specification, we can arrange terms in the regression model to build an exact expression for the implicit attribute values as shown in (10). A technical problem in estimating (9) is that the rent is also an endogenous variable, which render the simple OLS estimates inconsistent. Therefore, we employ an instrumental variable approach and estimate the system of equations within a three-stage-least squares framework, see section 4 for further discussion.

### 3 The data material

The data used in this paper originates from several sources of information covering most cities over the period from 1986 to 1998. Regional purchasing power, population density, housing price levels, and personal characteristics such as annual wage earnings, gender, age and education are obtained from labor market data based on administrative registers (RAMS) held by Statistics Sweden (Isacson, 2003). Travel time and generalized travel costs associated with different travel modes such as car and train are calculated using output from the simulation models EMMA/SAMPERS that the Swedish national road and rail administrations use in their planning process. In total, 288 cities according to the 1992 delineation are considered but in our analysis, some are deleted due to missing information on the environmental quality data. As in Isacson (2003), we use these two data sources to construct a reduced form measure of the market potential based, which is assumed to affect both the individuals' choice of residence and the firms' choice of plant location. Let  $Y_{ik}$  denote the purchasing power (the total sum of wage earnings) for city  $i$  from a neighbor city  $k$ ,  $i \neq k$ , and  $c_{ik}$  be generalized travel

cost between cities  $i$  and  $j$ , then this market potential measure is defined by  $MP_i = \sum_{k=1}^{n_i} (Y_{ik}/c_{ik})$ , where  $n_i$  is the number of neighbors to city  $i$ . The market potential may be regarded as a reduced form measure of the demand for labor in a specific city. Empirical models including this type of measure has a long history in regional economics (see Harris, 1954, for an early application). The empirical relationship between the market potential and wages have only more recently been given a more solid underpinning in the so-called 'new economic geography' (see, for example, Fujita et al. 1999, and Hanson, 2005, for a structural empirical model). The market potential for a city defined in this way, thus, increases in the purchasing power in the surrounding cities and decreases in the generalized travel cost to each city. According to the 'new economic geography' the market potential is a measure of the size of the market to firms. Hence, a higher market potential makes a city more attractive for firms' location since they can save on costs for transporting goods. Note that the generalized travel costs<sup>1</sup> used in our analysis are confined to work trips only, which are regarded as proxies of the overall travel cost.

An accessibility variable for each city is also constructed to measure the "degree of ease" for the working population to come from neighboring cities. More precisely, it is defined as the weighted inverse of generalized travel costs from the neighbor cities as  $ACC_i = \sum_{k=1}^{n_i} (l_k/c_{ik})$ , where  $l_k$  is the working population in a neighbor city  $k$ ,  $k = 1, 2, \dots, n_i$ . Since the accessibility measure is constructed for the working population, it may also be referred to as job-accessibility. The lower the travel cost and the higher the working population in the neighbors, *ceteris parabus*, the larger the accessibility measure. Presumably, a city with better accessibility is more attractive for firms to establish in, at least for the reason of abundant labor supplies. Furthermore, a high accessibility may be beneficial to individuals since it makes it easier for individuals to change jobs and it increases the probability of finding a new job if the individual has lost his job. In the empirical wage model we consider this measure as a kind of reduced form aggregate labor supply function. Clearly accessibility and market potential are likely to be highly correlated. We expect, however, that after conditioning on the market potential

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<sup>1</sup>Note that waiting time for train travel is not included in the calculations.

the effect of accessibility on wages are likely to be negative if our interpretation of the variable as a reduced form aggregate supply function is correct.

In our econometric analysis, we also use the neighborhood income variable  $NI_{it}$  defined as the weighted average of neighbor city incomes. The more accessible a neighbor city is to the city in concern, the larger weight its average per capita income has on the average neighborhood income. This variable is intended to capture certain spillover effects among cities. While the production function for firms are assumed to be of constant-return-to-scale, this variable is expected to explain possible divergences caused by potential positive spatial dependences.

Air quality data is obtained from the Swedish Environmental Institute which has conducted urban air quality measurement together with the local authorities since 1986. The measurements are normally made by one or more central receptors in the urban background somewhere distant from any direct emission sources such as a freeway or a heating plant. The measurement results can thus be regarded as some normal or representative air quality in the city, which is comparable across cities. From the beginning the program involved measurements of daily average concentration of nitrogen dioxide (NO<sub>2</sub>), sulphur dioxide (SO<sub>2</sub>) and soot, but it has been expanded in recent years to encompass VOC, PM<sub>10</sub>, PM<sub>2.5</sub>, NO<sub>2</sub> och SO<sub>2</sub> etc. also in rural areas though on a weekly or monthly basis (cf Persson and Sjöberg, 2003, for more details).

In this paper, we will use the measurement data during the winter season focusing on the emissions of NO<sub>2</sub>, SO<sub>2</sub> and soot, for which the data is available throughout the whole period from 1986 to 1998. It is worth mentioning that not all pollutants are measured over all cities each year so we have a problem of missing information for some observations. We therefore construct a pollution index ( $Pollution_i$ ) by averaging the concentration of the three pollutants in each city  $i$ , like Persson and Sjöberg (2003) along the lines suggested by Statistics Sweden. We do this to retain as many observations as possible. But using the simple average effectively amounts to assuming that the damage caused by each type of emission is considered as approximately equal by individuals. This may obviously be regarded as a strong restriction in the model.

The annual wage earnings  $w_{ij}$  for individual  $j$  in city  $i$  over the whole study

period is measured in real terms at the 1986 price level. It is calculated by deflating the nominal annual wage by the consumer price index (CPI) reported by Statistics Sweden. For the rent variable  $r_{ij}$ , we use the housing prices (deflated to 1986 prices) as a proxy. In theory, if the capital market is perfect, then the annual housing rent should be equal to the interest cost, i.e. the product of interest rate and housing price. This implies that the rent and its corresponding housing price differs only up to a scale factor. Moreover, we lack information on the individual's housing costs in the sample of individuals for whom we have the wage earnings data. We will therefore use the municipality average instead.

In the empirical model we control for the following individual characteristics: gender, age, and education. Gender is expressed as a dummy variable that takes the value 1 for a male and the value 0 for a female, and age is measured in years. The education variable is based on the highest education level a person has achieved and how many years each of the seven, mutually exclusive, levels involves on average. The average years of each level has been estimated from the Swedish-level-of-living-survey (cf Eriksson and Åberg, 1987). The education variable we use in the empirical model is, thus, the average years of education imputed from the estimate obtained in the Swedish-level-of-living-survey.

In our analysis, we also incorporate dummy variables indicating to which NUTS-2 region a given city belongs. In Sweden the NUTS 1-level is for the whole country, the NUTS 2-level divides Sweden into 8 distinct regions and the NUTS 3-level corresponds to the 20 provinces as shown the Appendix. It is expected that the regional dummies capture unobserved regional variables like: climate, scenic beauty and cultural amenities. These dummies are defined as follows:  $d_1 = 1$  (Stockholm) and  $d_1 = 0$  otherwise;  $d_2 = 1$  (Ostra Mellansverige: Mid-Eastern) and  $d_2 = 0$  otherwise;  $d_3 = 1$  (Smaland med Oarna: Smaland with island) and  $d_3 = 0$  otherwise;  $d_4 = 1$  (Sydsverige: Southern) and  $d_4 = 0$  otherwise;  $d_5 = 1$  (Vastsverige: Western) and  $d_5 = 0$  otherwise;  $d_6 = 1$  (Norra-Mellansverige: Mid-Northern) and  $d_6 = 0$  otherwise;  $d_7 = 1$  (Mellersta Norrland: Mid-Norrland) and  $d_7 = 0$  otherwise;  $d_8 = 1$  (Övre Norrland: Upper Norrland) and  $d_8 = 0$  otherwise.

Since the pollution, accessibility and housing price variables etc. are clustered at the city level we also use city (municipal) averages of the individual characteris-

Table 1: Descriptive statistics of the main variables

Variable	Explanation	1986	1990	1998
$w$	Annual wage earnings (SEK)	95825 (5949)	106225 (6692)	120055 (10343)
$r$	Housing price (SEK)	340548 (88666)	583581 (217483)	663576 (287776)
Pollution	Pollution index ( $\mu\text{g}/\text{m}^3$ )	14.7 (3.4)	10.6 (3.1)	9.7 (4.2)
NI	Neighborhood income (SEK)	99452 (3991)	110590 (4736)	126098 (6370)
ACC	Accessibility	5661 (3452)	6124 (4050)	5484 (3778)
POP	Working population	26404 (39380)	24231 (35854)	25856 (40060)
Male	Share of males	0.54 (0.03)	0.53 (0.03)	0.53 (0.03)
Age	Age (years)	39.7 (0.9)	39.7 (0.9)	41.8 (0.9)
Edu	Education (years)	10.6 (0.4)	11.0 (0.4)	11.6 (0.5)

tics in the analysis. Table 1 presents the descriptive statistics of the main variables over the period 1986-1998. Note that the averages of the individual characteristics are the average of the municipality averages of each variable; i.e. they are *not* weighted by the population in each municipality. The third through the fifth columns report the mean values and the standard deviations for three "representative" years: 1986, 1990 and 1998, i.e. the start, "middle" and the end of the study period. From the table, we can see that the average real annual labor income<sup>2</sup> per

<sup>2</sup>Note that the number is calculated by averaging the municipality-wise mean annual income without using the population levels across the municipalities as weights. Thus, it may differ somewhat from similar statistics reported elsewhere. The numbers here also differ a bit from Isacson (2003) due to the omission of observations due to missing values.

employed individual has increased by about 25% from SEK 95825 to 120055 over the period, whereas the air pollution index decreased by approximately 34% from 14.7 to 9.7  $\mu\text{g}/\text{m}^3$ . The dramatic improvement in the urban air quality is a result of reduced emissions from transport, industry and households. The average (real) housing price rises from about SEK 340,000 to 664,000 about 95%.

The neighborhood income variable  $NI$  has increased by approximately the same amount as the average earnings over the cities concerned, whereas the accessibility measure has decreased from 5661 to 5481 (a decrease by 3%). According to the definitions of these variables, the trends may depend on the rise in the generalized travel cost combined with a fall in the working population and a rise in wage earnings in the neighbor cities. The share of males in the population seems to remain constant, and the average age and education levels have increased to some extent. The working population has on average become about 2 years older accompanied with an improvement in the average years of schooling from 10.6 to 11.6 years.

## 4 Model estimation and results

As touched upon in section 2, we are interested in estimating the translog-like model in (9) in order to derive the implicit value (cost) of the different attributes. The averaged attribute values for each city  $i$  at year  $t$ ,  $\bar{\mathbf{z}}_{it}$ , ( $t = 1986, \dots, 1998$ ), encompass  $Pollution_{it}$ ,  $ACC_{it}$  as well as the region dummies  $d_k$ ,  $k = 2, 3, \dots, 8$ . The averaged values of personal characteristics  $\bar{\mathbf{s}}_i$  are  $Male_{it}$  (the share of males in the working population in city  $i$  and year  $t$ ),  $Age_{it}$ , and  $Edu_{it}$ . In addition, we will also include a time trend variable  $\tau_t$  - the number of years elapsed since 1986 to capture technological progress. Thus, the specific econometric model based on (9) becomes

$$\begin{aligned} \ln(\bar{w}_{it}) &= \alpha + \beta \ln(\bar{r}_{it}) + \gamma \ln(\bar{\mathbf{x}}_{it}) + \boldsymbol{\theta} \mathbf{d} + \lambda \tau_t + \varepsilon_{it}, & (11) \\ \text{for } i &= 1, 2, \dots, m, t = 1986, 1987, \dots, 1998 \end{aligned}$$

where  $\alpha$ ,  $\beta$ ,  $\gamma$ ,  $\boldsymbol{\theta}$  and  $\lambda$  are parameters or parameter vectors to be estimated. The vector  $\bar{\mathbf{x}}_i = [\bar{\mathbf{z}}_{it}, \bar{\mathbf{s}}_{it}]$  denotes the average city and individual attributes such as

*Pollution*, *ACC* and *Edu*, among others,  $\mathbf{d} = [d_2, d_3, \dots, d_8]$  is a vector of dummy variables for all regions excluding Stockholm (the reference region), and  $\varepsilon_{it}$  a stochastic component with a zero mean and constant variance.

A problem when estimating the model in (11) is that the housing price variable is also endogenous and it may be determined by wage earnings. A direct ordinary least square estimation will thus lead to biased and inconsistent results. It is possible to estimate the wage and rent equations separately, but the estimates will then be inefficient. Instead, we adopt a three-stage-least-squares estimation procedure to estimate the model (cf. Kmenta, 1997; Greene, 2003, 405-407). The first stage develops instrumented values for the two endogenous variables,  $\ln(w)$  and  $\ln(r)$ , with the fitted values based on a separable equation system. The next stage uses the instrumental endogenous variables and the other exogenous ones to estimate the structural model and calculate the covariance matrix of the residuals. The final stage performs a type of generalized least squares estimation using both the covariance matrix consistently estimated from stage 2 and the instrumental values from stage 1 in place of the right-hand-side endogenous variables.

From the estimated wage equation in Table 2, we can see that about 25% of wage earnings is devoted to housing services though with some caveats. Among other things, heating, electricity and water costs are not included. Thus, the share of income devoted to housing in Sweden is likely to be higher than suggested by the parameter estimate reported in Table 2. Anyhow, this will probably have but a minor effect on the rest of the estimates as the boat rises with the water. The coefficient associated with the  $\ln(\textit{Pollution})$  is positive (about 0.013) and statistically significant at the conventional level. The interpretation is that individuals who experience an increase in pollution concentration by 1% would on average require 0.013% higher wage earnings as a compensation. In other words, people would be willing to pay 1.3% of their wage earnings in order to avoid a doubling of the pollution concentration. The accessibility and neighborhood income variables seem to have larger effects than air quality on the wage rate. The signs on the accessibility and neighborhood income variables have the expected signs, since we interpret the former as a "good" in contrast to pollution as a "bad" to be "compensated".



The coefficient for the share of males is positive reflecting that men earn more than women on average. The time trend has a positive coefficient partly reflecting the effect of technological progress on wage earnings. It is also interesting to examine the role of region-specific dummies. Compared to the reference region, Stockholm (with  $d_1 = 1$ ), it is only individuals in the West-Coast region ( $d_5 = 1$ ) who receive lower wage earnings (*ceteris parabus*). One possible reason is that the region enjoys enhanced scenic beauty and thus a negative wage differential from Stockholm. In comparison, the regions Mid-Northern Sweden (Norra-Mellansverige) and the Mid-Norrland (Mellersta Norrland) require a higher wage compensation. Note that this is conditional on pollution, housing prices, accessibility etc so the higher wage earnings in these three regions as compared to Stockholm might suggest that relatively lower cultural amenities, for example, require a compensating wage differential. The insignificant difference between Mid-Eastern Sweden (Ostra-Mellansverige) and Stockholm is understandable due to its proximity to Stockholm. The lack of difference between Upper Norrland (Ovre-Norrland) and Stockholm is perhaps more surprising, since the two regions differ substantially in many respects. Taken at face value, the lack of difference suggests, however, that unobserved differences between Upper Norrland and Stockholm do not cause a compensating wage differential between the two regions.

Table 3 reports the jointly estimated semilog housing price model. It is seen that the pollution variable is absent. The variable was included in an initial run but deleted afterwards as the coefficient associated with it is not statistically significant. The Rosen-Roback theory does not indicate whether the coefficient should be positive, negative or zero, and its sign and magnitude is thus an empirical question. While increased pollution would lead to a downward shift in consumers (upward-sloping) indifference curve defined in terms of  $r$  and  $w$ , it would induce firms to shift up their iso-unit-cost curve if increased pollution allows them to produce the same amount cheaper. The two forces together would lead to a definite increase in the required wage rate but leave the equilibrium rent level ambiguous. In our case, it turns out to be not statistically different from zero. The results also indicate that increased city size (with the working population as a proxy), market potential, and general education levels are positively correlated with housing prices,

whereas the average age of the working population has a negative correlation. Thus reflecting a larger share of young workers in expanding cities where housing prices are higher. This could be due to the larger mobility of young workers. The dummies indicate that housing prices in all regions, except the West coast area, *ceteris paribus*, are lower than Stockholm. In this paper, we estimate the house price function to serve as an instrument for better estimating the valuation-related wage model. We are not interested in this equation as such, but the results obtained as a by-product make some sense and thus add some credibility to the model. Before closing this section, we also need to mention that the parameters estimates above may be sensitive to addition of new interaction terms between the different attributes. Fortunately, a sensitivity analysis indicates that the net marginal effects are rather stable when evaluated at the averaged values of the attributes.

Table 2: The estimated translog wage earnings model

Variable	Coefficient	Standard Error	T-value	P-value
constant	6.5709	0.5743	11.44	0.0000
$\ln(r)$	0.2456	0.0110	22.18	0.0000
$\ln(\text{Pollution})$	0.0132	0.0035	3.76	0.0000
$\ln(\text{ACC})$	-0.0280	0.0035	-7.86	0.0000
$\ln(\text{NI})$	0.2546	0.0510	4.99	0.0000
Male	1.0143	0.0720	14.09	0.0000
tao	0.0052	0.0009	5.65	0.0000
d5	-0.050	0.0063	-7.94	0.0000
d6	0.0316	0.0072	4.35	0.0000
d7	0.0179	0.0097	1.84	0.0650

## 5 Shadow prices and regional welfare analysis

With the parameter estimates of the semi-translog model (Table 2), we calculate the shadow prices for the pollution reduction, accessibility and the market potential

Table 3: The estimated translog housing price model

Variable	Coefficient	Standard Error	T-value	P-value
Constant	-9.7914	1.4351	-6.82	0.000
$\ln(w)$	1.0319	0.1262	8.17	0.000
$\ln(\text{Pop})$	0.0480	0.0084	5.66	0.000
$\ln(\text{Edu})$	3.5198	0.2297	15.32	0.000
$\ln(\text{age})$	-1.7267	0.2701	-6.39	0.000
$\ln(\text{Mp1})$	0.0923	0.0166	5.55	0.000
d2	-0.2512	0.0254	-9.89	0.000
d3	-0.1747	0.0216	-8.08	0.000
d4	-0.1847	0.0217	-8.49	0.000
d6	-0.2793	0.0227	-12.27	0.000
d7	-0.2862	0.0356	-8.03	0.000
d8	-0.1993	0.0433	-4.60	0.000

variables by using equation (10) for all the cities involved in the sample. In Table 4, we report the average shadow price (over cities and years) for a representative individual within each of the 20 provinces in Sweden.

The second column in Table 4 shows a representative person's annual willingness-to-accept compensation for an extra unit ( $\mu\text{g}/\text{m}^3$ ) of pollution concentration, and the third column the willingness-to-pay for a marginal improvement in accessibility. The numbers indicate that residents in the province of Jämtland value air quality higher than other provinces while those living in Norrbotten place a higher value on accessibility. The last two columns show the quantity change for the two variables over the study period 1986-1998. It is seen that air quality has improved most in Kronoberg but deteriorated most in Uppsala. Accessibility improves most in Västergötland province while it deteriorates most in Stockholm.

In addition to the two "hard" variables, we also include a third one, i.e. the elapsed time since 1986, which is expected to capture the role of technological progress or other time-related factors left outside of the model. The value of this variable is calculated in the same way as the other ones according to equation (10) by taking partial derivatives and point evaluations.

Table 4: Shadow prices and quantity changes

Province	$P_{Pollution}$	$P_{ACC}$	$\Delta Pollution$	$\Delta ACC$
Blekinge	128	0.56	-3.18	-619
Dalarna	84	0.57	-0.82	-2379
Gävleborg	136	0.62	-6.59	-284
Gotland	221	N/A	-11.75	N/A
Halland	208	0.42	-9.38	210
Jämtland	501	2.05	6.57	550
Jönköping	157	0.42	-8.93	-724
Kalmar	80	0.65	1.20	-599
Kronoberg	323	0.40	-11.72	-608
Norrbottn	131	6.07	-3.62	-63
Skåne	182	0.61	-6.81	126
Stockholm	166	0.19	-3.43	-2868
Uppsala	96	0.29	6.97	-177
Värmland	144	0.76	-7.34	-969
Västerbotten	100	2.73	-3.07	-153
Västernorrland	103	1.37	-2.91	-728
Västmanland	164	0.37	-3.91	-127
Västra Götaland	125	0.47	-5.09	864
Örebro	117	0.39	-4.02	-523
Östergötland	113	0.51	-6.32	-532

Now, let the shadow prices of the three quantities be denoted by  $P_i$ , and the corresponding change in quantities by  $\Delta X_i$ ,  $i = 1, 2, 3$ , respectively for *Pollution* (reduction), *ACC*, and  $\tau$ , the changes in welfare over the period, conditional on other things being equal, can be expressed a

$$\Delta W = \sum_{i=1}^3 P_i \Delta X_i \quad (12)$$

i.e. the value of changes evaluated at constant accounting prices. Strictly speaking, this linear-in-quantity welfare indicator is valid for "small projects" only, in which the change in quantity is infinitesimal. When the change is considered large, certain

capital gain and consumer surplus terms need be used for additional adjustment as shown in Weitzman (2001), Arrow et al. (2003), and Li and Löfgren (2007). Since the effects of these terms are presumably small, we simply use the "small project" evaluation formula here.

Table 5: Regional welfare changes

Province	Value Components			$\Delta W$
	Pollution	ACC	Time trend	
Blekinge	410	-351	513	632
Dalarna	68	-1368	509	-775
Gävleborg	898	-179	502	1300
Gotland	2605	-	454	-
Halland	1952	90	480	2552
Jämtland	-3299	1134	457	-1616
Jönköping	1410	-309	517	1669
Kalmar	-96	-394	504	62
Kronoberg	3785	-244	495	4108
Norrbottn	476	-386	477	672
Skåne	1244	78	534	1923
Stockholm	572	-569	554	650
Uppsala	-674	-52	509	-141
Värmland	1063	-739	530	908
Västerbotten	307	-420	506	426
Västernorrland	302	-1006	525	-135
Västmanland	642	-479	515	785
Västra Götaland	640	408	574	1612
Örebro	473	-204	519	858
Östergötland	718	-272	497	1025

Change in the value of the three components as well as their sum as a welfare indicator are shown in Table 5. From the table, it can be seen that for most provinces, the aggregated welfare change with regards to pollution, accessibility, and "technological progress" over time, is positive. In other words, the welfare

Table 6: Aggregated welfare at NUTS-2 level

NUTS-2 Region	Obs	Mean	Std Err	Min	Max
Mid-Norrland	10	-876	783	-1707	-45
Mid-Northern	11	627	918	-791	1397
Smaland with island	9	1854	1448	14	4179
Stockholm	3	650	80	558	704
Southern	12	1708	509	573	2025
Western	18	1926	464	1493	2634
Mid-Eastern	13	726	403	-217	1136
Upper-Norrland	9	590	141	393	783

level by 1998 in these provinces are higher than its 1986 level. The improvement is most pronounced in Kronoberg, where air quality is considerably higher at the end of the study period. In spite of the decreased accessibility, the net effect is highly positive. For Västra-Götaland, the change in all component values are positive, so people are better-off on all of three items. The change in Jämtland is, however, most negative, due to the adverse changes in air quality. It is worth mentioning that these results should not be exaggerated for several reasons. First, the pollution variable is treated implicitly as a "flow" variable with no long-lasting effect. If the improvement in air quality has a persistent beneficial effect, then the price of pollution reduction should be considerably higher. To take the long-run effect into account, however, we need information on the real discount rate over time as well as the rate that nature can assimilate the pollutants. Second, many capital stocks such as forests for carbon sequestration services are excluded from this study. This is also true of social and human capital stocks. When such aspects are considered, the rank of welfare change over provinces here may become rather different. Finally, we aggregate the city level data to NUTS-2 regional level at which all regions except Mid-Norrland experience (on average) a positive welfare change over the study period (Table 6). In comparison, it is the Western region that experiences the largest welfare improvement.

## 6 Concluding remarks

In this paper, we have studied the implicit value of urban air quality and accessibility for regional welfare measurement. With the Rosen-Roback theory as a basis, we have developed a structural econometric model with wage earnings and rents as endogenous variables. Two types of exogenous variables are included in the study: one group concerns the "determinants" of wages such as personal characteristics and the other group involves goods and amenities on which people spend their income for "consumption".

Based on city level data, we have estimated the model under alternative functional specifications using a three-stage-least-squares procedure. With the instrumental variables and covariance matrices obtained from the first two stages, we estimate the structural model in a generalized linear model framework. The terms involving wages and rents enter the model in such a way that a linearization with respect to an infinitesimal change in an attribute gives an exact formula for calculating the implicit, accounting or shadow price of the attribute. Moreover, the share of housing cost or the demand for housing factor is a part of our estimation results rather than being exogenously calculated as in Roback (1982).

Using the model estimates, we have calculated the implicit prices for three types of attributes, i.e. air quality, accessibility and the technological progress (with the time elapsed as a proxy) for all cities where we have observations in the dataset. Together with the changes in these variables over the study period 1986-1998, we compute the monetary value of them for each component as well as the sum of them. The sum here may be roughly interpreted as the change in welfare with respect to the change in these variables, provided that all other things are held constant. The results indicate that welfare improves most in the province Kronoberg over the period while Jämtland experiences the largest deterioration. On a more aggregate level, welfare increases in all regions except Mid-Norrland, with Western Sweden as the big winner.

It is worth mentioning that the welfare results reported here should be considered as quite tentative due to a number of caveats. First, we have not differentiated between utility and the money-metric measures when comparing welfare in this study (Weitzman, 2001; Li and Löfgren, 2007). Second, over a period of more than

a decade where air quality improvement is on average over 34%, we still value them in linear prices without taking into account possible consumer/producer surpluses, and the cost of air pollution reduction measures are not included. Third, the number of receptors for recording air quality in each city is rather limited and thus we have to use the measurement data as a proxy for the whole city. Even though the measurement is in accordance with the guidelines by the EPA for representativeness, no within-city air quality variation was available for this study. A similar problem also concerns the accessibility variable where the generalized travel costs have been assessed from models. In addition, our empirical framework for assessing the effects of accessibility have not been directly concerned with the potential endogeneity of these variables so the estimated effects of these variables should be interpreted cautiously. The results in Isacson (2003) suggest, however, that the effect of the market potential (related to the neighborhood income variable) on wage earnings obtained in a simple ordinary least squares regression survives in a dynamic panel data model with city level fixed effects. Hence, unobserved city attributes that are constant over time do not seem to be a source of bias for the effect of the market potential variable. Furthermore, better air quality models and data with larger spatial variation may lead to more precise value estimates. Finally, the list of goods and services for overall welfare measurement should be comprehensive including natural, social and human capital stocks. In this paper, however, we only limit our analysis to a few components. Therefore, the study is a partial welfare analysis, and the results should be interpreted with caution. In future research, more detailed data on environmental quality, travel time and costs, as well as other amenity attributes including within-city-variations should be collected (modelled) for valuation studies. For overall sustainability measurement, the type of partial welfare analysis presented here should be extended with similar studies involving other capital forms such as forests for ecosystem services, education and research for knowledge production, as well as resilience (Mäler et al, 2007) of integrated systems. Notwithstanding these caveats we believe that our analysis has demonstrated the usefulness of a rather simple hedonic pricing model in the context of regional welfare analysis applied to environmental and transportation issues.



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# Appendix

The Swedish NUTS2 regions and provinces

SE01 Stockholm

Stockholm

SE02 Mid-Eastern Sweden

Uppsala

Södermanland

Östergötland

Örebro

Västmanland

SE09 Smaland with island

Jönköping

Kronoberg

Kalmar

Gotland

SE04 Southern Sweden

Skåne

Blekinge

SE0A Western Sweden

Halland

Västra Götaland

SE06 Mid-Northern Sweden

Värmland

Dalarna

Gävleborg

SE07 Mid-Norrland

Västernorrland

Jämtland

SE08 Upper Norrland

Västerbotten

Norrbottn



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