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WORKER AND WORKPLACE HETEROGENEITY, TRANSPORT ACCESS, AND RESIDENTIAL LOCATION: A HISTORICAL PERSPECTIVE ON STOCKHOLM

By

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Worker and Workplace Heterogeneity, Transport Access, and Residential Location: A Historical Perspective on Stockholm

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Abstract

Most analyses of urban transportation and residential location ignore the effects of labor force experience or individual skills upon the location of the worksite; they also ignore the potential effect of these factors upon the tradeoff between housing and community costs.

This paper, in contrast, analyzes the spatial distribution of worksites by industry, occupation, and educational requirements within a large metropolitan area. In a parallel fashion, we investigate the spatial distribution of the residential sites of workers, differentiated in a similar manner.

We use this spatially disaggregated information to analyze regularities in commuting and transport behavior. We also develop alternative measures of regional homogeneity, more descriptive alternatives to ratios of jobs to income and similar summary statistics measuring regional "balance."

I. Introduction

Most studies of the role of transportation in residential location assume that an individual´s human capital and labor force experience are of no relevance to the location of his or her worksite and to the tradeoff between commuting and housing costs. Recent models often assume a polycentric metropolitan area and do recognize non-central workplace concentrations, but concentrations are undifferentiated by industry or occupation. Traditional traffic models rely upon the number of jobs and workers in different subareas, distance costs, income and sometimes age and family type to explain an observed commuting pattern. It is implicitly assumed that all workers are is equally attracted to in all kinds of jobs and that, moreover, all workers have the same chance of getting any job.

This paper presents an analysis of the spatial differentiation of industry and occupation within a large metropolitan area. We analyze the spatial distribution of workplaces, differentiated by industry and occupation, over time. Using data on the spatial distribution of employment by industry and occupation for the Stockholm metropolitan area, we investigate trends in the spatial pattern of employment from 1970-1990. In a parallel fashion, we also investigate changes in the spatial distribution of the residential sites of workers, differentiated by occupation and industry, and also by education level during the same period.

These data also permit a cross-sectional comparison of the joint residential and workplace distribution of workers in metropolitan Stockholm using more detailed data for 1990. This latter analysis indicates the importance of spatial differentiation by industrial types and human capital in understanding commuting patterns.

All these comparisons are made using entropy measures which explicitly indicate the importance of the disaggregated perspective.

Finally, the paper provides data linking the residential and workplace location of the various subgroups to commuting and transport behavior.

The basic aim of the paper is to find out if disaggregated data support the common, but implicit, assumption that job diversity and differences in human capital and labor force experience do not influence commuting. The paper also develops and illustrates alternative desciptive measures of regional balance or regional homogeneity. Currently the most widely used measure of intra regional "balance" is the ratio of jobs to population. We illustrate the use of equally simple, but more meaningful alternative measures.

II. The Stockholm Metropolitan Region

The Stockholm Metropolitan Region is built on a series of islands emanating from a medieval center dating from the twelfth century. Figure 1 indicates the major arterials providing access to the historic center of the region. The transport system depicted in Figure 1 is consistent with a single concentrated worksite located in the inner city. This is the historical pattern of the city´s development. Both the number of jobs and the number of workers living in the region has increased during the last

decades. As is shown in Table 1, there are more jobs than workers, and net commuting into the region more than doubled in two decades.

Table 1. Number of jobs and workers (thousands) in the Stockholm Region 1970-1990

	Year		
	1970	**1980**	**1990**
Jobs	685	804	951
Workers	665	781	909
Net commuting	20	23	42

The increasing employment has gone hand in hand with a restructuring of employment by industry, occupation and educational level. The largest changes in industrial composition are the decline of manufacturing (including heavy and light industry) and the increase of health care and social care.

The occupational structure has shifted from administrative work (managers, accountants, cashiers, etc.) and goods handling work (farmers, craftsmen and workers in manufacturing, etc.) towards knowledge work (technical scientific work and other knowledge-based work such as legal services and journalism.) and other service work (nurses, policemen, barbers, etc).

The educational level of workers has increased substantially. The fraction of workers with low education (11 years or less) has decreased from 74 to 55 percent, and the fraction with high education (at least 15 years) has almost doubled, from 8 to 15 percent.

The expansion and restructuring of the labor market has been accompanied by a significant dispersion of both residents and jobs.

Figure 2 provides an overview of the distribution of jobs over subareas during the past quarter century. The region is divided into fourteen zones representing subareas used by the Regional Planning Authorities.

As the figure indicates, 46 percent of regional employment was concentrated in the inner city of Stockholm in 1970. By 1990, this concentration had been reduced to 34 percent, and there had been systematic increases in employment shares at non central locations.

Figure 3 indicates the distribution of worker residences during the same period. As expected, the residential distribution is considerably less centralized. Nevertheless, the same pattern of decentralization is apparent in the data. The population share of the inner city share declined from 18 to 15 percent during the 1970-1990 period, and the population share in the southern part of the city declined from 24 to 15 percent. The population shares of the inner suburbs remained roughly constant, while the shares of the outer suburbs increased substantially -- but from a relatively small base.

Clearly the spatial patterns of both workplaces and residence places have become less differentiated over time. Worksites are less concentrated in particular central locations, and residence sites are less segregated from worksites.

The dispersion of jobs and workers has changed the commuting pattern. Between 1971 and 1987 the share of all commuting directed towards the inner city decreased from 47 to 39 per cent. Table 2 shows the pattern of worktrips summarized by destination into three categories: worktrips to the same zone as that of residece; worktrips to the inner city; worktrips to other destinations. The table also reports variations by residence zone, industry, sex, occupation and education.

Tabel 2. Pattern of worktrips by destination for different areas (the numbers within brackets initiate rusch hour travel time by car to the inner city/Stockholm in) 1975-1990

	1975			1980			1990		
	Percent of residents working in								
Residential area	the inner city	the same area	other areas	the inner city	the same area	other areas	the inner city	the same area	other areas
Norrtälje (90)	3,3	85,7	10,9	4,3	83,9	11,8	5,3	82,1	12,6
Södertälje (57)	8,0	76,1	15,8	8,1	75,8	16,2	8,5	74,9	16,6
Stockholm-inner (-)	-	71,5	28,5	-	69,2	30,8	-	66,9	33,1
Nynäshamn (72)	7,2	68,9	23,9	7,4	69,1	23,6	8,2	65,2	26,6
Sigtuna (53)	13,3	59,0	27,8	12,3	58,2	29,5	13,5	59,3	27,3
Vaxholm (57)	27,4	43,8	28,9	25,6	45,3	29,0	18,1	50,7	31,2
Österåker (55)	27,4	43,8	28,9	25,6	45,3	29,0	20,8	48,0	31,2
Haninge (42)	30,3	38,8	30,9	31,3	39,2	29,6	24,8	46,6	28,6
Nacka (31)	39,6	41,1	19,3	38,1	40,3	21,6	35,3	44,4	20,3
Lidingö (28)	44,1	38,8	17,0	44,6	37,2	18,1	38,6	43,2	18,3
Järfälla (40)	25,6	35,0	39,4	25,7	35,9	38,4	20,2	42,0	37,7
Ekerö (46)	28,9	37,9	33,2	28,7	36,8	34,5	25,4	41,4	33,2
Sollentuna (46)	33,8	30,5	35,7	32,0	31,4	36,6	24,7	41,2	34,1
Danderyd (38)	42,0	31,4	26,6	40,3	32,5	27,2	34,8	38,9	26,3
Täby (44)	38,3	30,9	30,8	36,9	30,7	32,4	30,2	38,7	31,1
Stockholm-söder (32)	47,7	36,0	16,2	45,8	35,4	18,8	42,4	37,5	20,1
Stockholm-väst (32)	38,0	36,4	25,6	37,1	36,0	26,9	34,9	37,4	27,7
Upplands Väsby (43)	21,3	43,6	35,2	19,9	44,7	35,3	19,2	36,0	44,8
Värmdö (42)	20,7	54,3	25,0	24,3	48,4	27,3	30,9	35,2	33,9
Tyresö (41)	38,5	28,5	33,0	38,4	27,7	34,0	32,4	35,1	32,6
Sundbyberg (26)	27,0	27,6	45,4	28,4	26,8	44,8	27,8	32,7	39,5
Botkyrka (52)	30,4	27,9	41,7	28,6	31,2	40,2	25,0	30,7	44,3
Huddinge (40)	33,7	28,7	37,7	32,8	29,2	38,0	29,1	30,0	40,9
Upplands-Bro (46)	21,5	35,6	42,9	20,2	34,2	45,6	23,7	28,8	47,5
Solna (22)	36,7	37,6	25,7	36,5	36,2	27,4	38,4	28,4	33,2
Vallentuna (57)	27,0	34,9	38,1	26,3	34,5	39,2	24,5	23,6	51,9

Table 3. Pattern of worktrips by destination för different categories 1990. Percent of residents working in

Industry	Manufacturing	45,8	14,5	39,7	100
	Local services	50,1	23,7	26,2	100
	Nat/reg services	35,3	38,1	26,6	100
	Public adm	37,9	38,0	24,1	100
	Education/research	51,9	19,4	28,7	100
	Health- &social care	58,0	13,2	28,7	100
	Other	47,3	19,4	33,3	100
Education	Low	49,1	22,8	28,1	100
	Medium	42,0	26,6	31,4	100
	High	40,3	27,8	32,1	100
Occupation	Knowledge	42,2	24,5	33,2	100
	Administration	37,6	38,7	23,7	100
	Service	49,7	21,6	28,7	100
	Goods handling	49,3	15,8	35,0	100
Sex	Men	41,3	24,3	34,4	100
	Women	49,8	25,0	25,1	100
Total		**45,6**	**24,7**	**29,7**	**100**

The fraction of residents working and living in the same subarea is highest in the inner city and in municipalities most distant from the inner city. The latter are also characterized by the lowest fractions of people commuting to the inner city. As expected, commuting to the inner city is most common in closeby municipalities. There is also a clear downward trend for the fraction commuting to the inner city.

The commuting pattern doesn't vary as much among different categories of workers as it does between subareas. However there are some clear differences. By way of example, the commuting distance tend to be shorter for those employed in in the healthcare industry than in public administration and also for those with lower levels of education. Women are also more likely than men to work where they live.[1]

We will begin our analysis by asking a series of questions about the internal homogeneity of worksites and residence places. For these and for all other calculations, we rely upon a partition of the metropolitan region into 26 zones or sub areas. 23 of these correspond to the suburban towns surrounding the central city[1]. The central city itself is divided into three parts: the CBD or inner city, the western portion, and the southern part. Figure 4 shows the rush hour travelling time by car from each suburban town to the inner city.

We have detailed information about the occupational and industrial structure of jobs in each of these 26 zones, as well as information on the sex and educational level of employees. We have similar information of the characteristics of residents of each of these areas.

[1] Except for the municipalities of Botkyrka and Salem which have been grouped together

III. Quantitative Measures of Heterogeneity

Entropy measures are natural quantitative indicators of the heterogenety or homogeneity of populations. These measures can be applied to describe the residential segregation of different types of workers, for example, or the clustering of employment by industry within a geographical area. Depending upon the specifie focus of interest, the entropy measure can be formulated in a variety of ways.

A most basic measure is the extent to which different geographical areas - be they residence places or workplaces - are homogeneous with respect to some characteristic or set of categories. An index of heterogenity based on entropy concepts can be computed from counts of individuals (eg, residents or workers) by category in each of the geographical areas. For example, let N_{ij} denote the number of individuals in category i associated with subarea j. $N_{.j}$ is the total number of individuals in subarea j, and $N_{..}$ is the grand total. Consider the following index of spacial heterogeneity.

$$I_j = \sum_i \frac{N_{ij}}{N_{.j}} \ln\left(\frac{N_{ij}}{N_{.j}} / \frac{N_{i.}}{N_{..}} \right) \qquad (1)$$

Equation (1) indicates how the mix with respect to category i in area j differs from the mix at the regional level. If the mix in area j is identical to the mix for the region as a whole, then the expression in brackets in equation (1) is equal to 1, and $I_j=0$.

Let $\bar{I}$ be the weighted average of the index of heterogeneity of the individual sub areas

$$\bar{I} = \sum_j \frac{N_{.j}}{N_{..}} I_j \qquad (2)$$

The value of $\bar{I}$ equals zero when the distribution of categories within each subarea is the same and is equal to the distribution of categories at the regional level.

Inserting (1) into (2) yields, after some manipulation,

$$\bar{I} = \sum_i \frac{N_{i.}}{N_{..}} \ln\left(1 / \frac{N_{i.}}{N_{..}} \right) - \sum_j \frac{N_{.j}}{N_{..}} \left\{ \left(\sum_i \frac{N_{ij}}{N_{.j}} \ln\left(1 / \frac{N_{ij}}{N_{.j}} \right) \right\} \right. \qquad (3)$$

$$= E(i) - \sum_j \frac{N_{.j}}{N_{..}} E(j)$$

$$= E(i) - \bar{E}(j)$$

The first term on the right hand side is the entropy of the distribution over categories at the regional level. The second term is a weighted average of the entropies of

each of the subareas in the region. The value of $\bar{I}$ equals zero if the entropy of each subarea is equal to the entropy of the region. The maximum value of $\bar{I}$ is obtained when the average entropy attains its minimum value. This suggests that a relative measure of heterogeneity or segregation (S) can be formed by dividing $\bar{I}$ by the first term of (3)

$$S=\bar{I}/E(i)=1-\bar{E}(j)/E(i) \qquad (4)$$

Table 4 summarizes trends in the spatial segregation of residences in the Stockholm region during the past three decades. Part A presents trends in residential location by occupation and industry. Part B presents trends in residential location by sex and level of education. The categories are the same as those introduced in section II above. They include five occupational categories, seven industries, and three educational categories.

For each classification, the table presents the average entropy level (based on the 26 geographical areas described earlier) and the maximum entropy level for the region as a whole. The table also reports the index of segregation for each classification.

Table 4. Trends in Heterogeneity by Residential Location

A. Have residential areas become more similar by occupational and industrial mix over time?

	Year		
Occupation:	**1970**	**1980**	**1990**
Average entropy $\overline{E_i}$	1,339	1,321	1,263
Maximum entropy E_i	1,361	1,342	1,281
Relative reduction S	1,62%	1,54%	1,45%
Industry:			
Average entropy $\overline{E_i}$	1,821	1,840	1,815
Maximum entropy E_i	1,850	1,862	1,834
Relative reduction S	1,53%	1,17%	1,06%
Occupation and industry:			
Average entropy	2,930	2,958	2,933
Maximum entropy	2,974	2,997	2,968
Relative reduction	1,49%	1,29%	1,17%

B. Have residential areas become more differentiated by sex and education level?

Sex:			
Average entropy $\overline{E_i}$	0,680	0,692	0,693
Maximum entropy E_i	0,685	0,692	0,693
Relative reduction S	0,64%	0,12%	0,06%
Education:			
Average entropy $\overline{E_i}$	0,720	0,795	0,952
Maximum entropy E_i	0,733	0,815	0,980
Relative reduction S	1,86%	2,53%	2,83%
Sex and education:			
Average entropy	1,389	1,479	1,643
Maximum entropy	1,408	1,501	1,672
Relative reduction	1,39%	1,53%	1,73%

The table indicates that the levels of residential segregation by occupation and industry are low, and they have been declining steadily in the past three decades. The maximum entropy of occupation and industry is declining (as the region is becoming more specialized), but the average entropy has declined more rapidly, and residential segregation has declined.

The table indicates that there is essentially no residential segregation by sex. In contrast, segregation by level of education has increased rather substantially. The maximum entropy of education has increased (as levels of schooling have become more equalized), but the average entropy has increased more rapidly - - hence residential segregation by education level has increased.

Table 5 presents comparable information on the spatial segregation of workplaces.

Table 5. Trends in Heterogeneity by Workplace

A. Have workplaces become more similar by occupational and industrial mix?

	Year		
Occupation:	**1970**	**1980**	**1990**
Average entropy $\overline{E_i}$	1,328	1,308	1,263
Maximum entropy E_i	1,361	1,344	1,292
Relative reduction S	2,41%	2,67%	2,17%
Industry:			
Average entropy $\overline{E_i}$	1,784	1,780	1,737
Maximum entropy E_i	1,849	1,865	1,827
Relative reduction S	3,50%	4,56%	4,96%
Occupation and industry:			
Average entropy	2,877	2,891	2,845
Maximum entropy	2,972	3,008	2,957
Relative reduction	3,20%	3,89%	3,83%

B. Have these areas become more differentiated by sex and education?

Sex:			
Average entropy $\overline{E_i}$	0,683	0,690	0,669
Maximum entropy E_i	0,685	0,693	0,693
Relative reduction S	0,36%	0,33%	0,53%
Education:			
Average entropy $\overline{E_i}$	0,725	0,816	0,969
Maximum entropy E_i	0,731	0,825	0,982
Relative reduction S	0,80%	1,08%	1,30%
Sex and education:			
Average entropy	1,393	1,497	1,655
Maximum entropy	1,406	1,511	1,674
Relative reduction	0,91%	0,92%	1,12%

Part A presents trends in workplace heterogeneity by occupation and industry. The 26 geographical areas have become more similar according to the occupational mix of employment. In contrast, the industrial composition of the subareas has become more differentiated - - as industries have become more segregated through their location decision.

In contrast, part B of the table reports that there is only a small tendency for employment in these areas to be differentiated by sex. There is a stronger tendency for employment segregation by level of education, and this tendency is increasing over time.

Table 6 compares the concentration of residence sites and work sites within the region.

Table 6. Residential and employment entropies within the region

	Year		
	1970	**1980**	**1990**
A. By residence			
Entropy $\overline{E_i}$	2.689	2.880	2.925
Maximum E_i	3.258	3.258	3.258
Relative reduction S	17,5%	11,6%	10.2%
B. By workplace			
Entropy $\overline{E_i}$	2.161	2.449	2.540
Maximum E_i	3.258	3.258	3.258
Relative reductio S	33,7%	24,8%	22.1%

If residence places or workplaces were equally dispersed throughout the region, the corresponding entropy level would be 3.258 (i e 26 ln [1/26]). The concentration of residences in 1970 reduced the entropy of residence sites to 2.689, a reduction of 17.59 percent. The concentration of workplaces in 1970 reduced the entropy of workplaces to 2.161 or by 33.7 percent. Over time, the decentralization of residential population and employment has led to increases in both residential and employment entropy. This dispersion has been most rapid and pronounced for employment locations. Nevertheless in 1990, residential sites were still much more widely dispersed throughout the metropolitan area than employment sites were.

In summary, when compared to the distribution of population, the distribution of employment has decentralized more rapidly. But the relative segregation of employment sites, by the characteristics of workers, is substantially higher than the

segregation of the residences chosen by workers classified according to the same criteria.

Table A1 in the appendix presents the disaggregated data which form the basis for these trends. It reports the entropies of education, industry and occupation separately for residences and workplaces for 1970, 1980 and 1990. Higher entries in this table are associated with larger deviations from the regional average of the distribution of education, industry and occupation respectively. The table indicates that there is a strong persistence over time in the geographical areas which are outliers in each of these dimensions.

Table 7 summarizes the geographical areas which were most atypical and also those which were the most typical in 1990.

Table 7. Most atypical geographical areas in workplace and residence place distribution, 1990

	Workplace	**Residence**
Occupation	Norrtälje	Täby
	Värmdö	Sollentuna
	Södertälje	Sundbyberg
	Sigtuna	Solna
	Nynäshamn	Västerort
Industry	Sigtuna	Lidingö
	Vaxholm	Täby
	Huddinge	Sollentuna
	Danderyd	Sundbyberg
	Värmdö	Söderort
Education	Norrtälje	Täby
	Nynäshamn	Nacka
	Värmdö	Västerort
	Haninge	Vaxholm
	Danderyd	Sollentuna

The analysis so far has concentrated on geographical areas and has analyzed the extent to which locational patterns vary by geographical area. In a parallel fashion, one might concentrate on demographic or individual characteristics and analyze the extent to which the spatial dispension of each category deviates from the regional average. Consider the following index of demographic heterogeneity.

$$J_i = \sum_j \frac{N_{ij}}{N_{i.}} \ln\left(\frac{N_{ij}}{N_{i.}} / \frac{N_{.j}}{N_{..}}\right) \qquad (5)$$

Equation (5) indicates how the distribution of a given category i varies with respect to the geographical areas. It investigates the spatial segregation of a category of individuals rather than the spatial segreagation of geographical areas.

The weighted average of the index over individual categories is

$$\bar{J} = \sum_i \frac{N_{i.}}{N_{..}} J_i \qquad (6)$$

It is easy to show that $\bar{J} = \bar{I}$, which is not surprising since the same information is used in both cases concerning the distribution of employment by categories and subareas. However, it is important to notice that the relative segregation will differ. If expression (6) is rearranged we get the following expression corresponding to (3).

$$\bar{J} = \sum_j \frac{N_{.j}}{N_{..}} \ln\left(1 \frac{N_{.j}}{N_{..}}\right) - \sum_i \frac{N_{i.}}{N_{..}} \left\{ \sum_j \frac{N_{ij}}{N_{i.}} \ln\left(1 / \frac{N_{ij}}{N_{i.}}\right) \right\}$$

$$= E(j) - \sum \frac{N_{i.}}{N_{..}} E_{i.}$$

$$= E(j) - \bar{E}(i)$$

Note that the second term on the right hand side of (7) is identical to the second term on the right hand side of (3) and hence $\bar{E}(i) = \bar{E}(j)$ Since the first term in (7) differs from the first term in (3), the measure of segregation will differ

$$S = \bar{J} / E(j) = 1 - \bar{E}(i) / E(j) \neq 1 - \bar{E}(j) / E(i) \qquad (8)$$

This is because the absolute segregation is related to the entropy of the regional distribution over categories in (3) and over subareas in (7).

Table 8 reports the spatial distribution of the various categories of education, occupation, and industry over workplaces and residence placers during thirty year period, 1960-1990.

Table 8. Segregation for various categories of education, occupation and industry. Worksites and residence sites 1970-1990

		Worksites			Residence sites		
A.	**Education**	**1970**	**1980**	**1990**	**1970**	**1980**	**1990**
	Low	0,002	0,004	0,009	0,004	0,008	0,020
	Medium	0,011	0,012	0,010	0,015	0,018	0,009
	High	0,033	0,038	0,030	0,100	0,108	0,092
	Average	0,006	0,009	0,013	0,014	0,021	0,028
	Rel reduction	0,008	0,011	0,013	0,019	0,025	0,028
B.	**Occupation**						
	Knowledge	0,009	0,008	0,009	0,021	0,021	0,019
	Administrative	0,068	0,075	0,063	0,026	0,016	0,009
	Services	0,003	0,006	0,005	0,002	0,001	0,0020
	Goods handing	0,060	0,088	0,087	0,048	0,067	0,087
	Average	0,033	0,036	0,028	0,022	0,021	0,018
	Rel reduction	0,024	0,027	0,022	0,016	0,015	0,014
C.	**Industry**	**1970**	**1980**	**1990**	**1970**	**1980**	**1990**
	Manufacturing	0,072	0,119	0,118	0,041	0,049	0,042
	Local service	0,009	0,016	0,019	0,005	0,006	0,020
	Nat. and reg serv	0,122	0,110	0,109	0,038	0,027	0,026
	Public adm	0,074	0,211	0,192	0,025	0,026	0,018
	Education, research	0,022	0,045	0,039	0,029	0,015	0,014
	Health- & social care	0,101	0,079	0,096	0,015	0,004	0,005
	Other	0,022	0,032	0,065	0,029	0,019	0,0159
	Average	0,065	0,085	0,091	0,028	0,022	0,019
	Rel reduction	0,035	0,046	0,050	0,015	0,012	0,011

The differences in the pattern of worksites of the group with the highest education are much larger than for the other two groups. The differences in the pattern of residence sites for the highly educated are still larger. The residential concentration of the hight education group is much more pronounced than for any other education group, or for any occupational or industrial concentration either.

Planners are familiar with concepts of "balance" between the residence and workplaces contained in geographical subareas, and the ratio of jobs to residences in a geograhical area is often used as a measure of this balance. The entropy measures discussed here suggest a more general measure of their balance:

$$\bar{J} = \sum_j \frac{N_{.j}}{N_{..}} \ln\left(1 \frac{N_{.j}}{N_{..}}\right) - \sum_i \frac{N_{i.}}{N_{..}} \left\{ \sum_j \frac{N_{ij}}{N_{i.}} \ln\left(1 / \frac{N_{ij}}{N_{i.}}\right) \right\} \qquad (7)$$

$$B_j = \sum_j \frac{N_{.j}}{N_{..}} \ln\left(\frac{N_{.j}}{N_{..}} / \frac{D_{.j}}{D_{..}}\right) \qquad (9)$$

where D.j is the number of workplaces in subarea j.

Analogously

$$B_i = \sum_j \frac{N_{ij}}{N_{i.}} \ln\left(\frac{N_{ij}}{N_{i.}} / \frac{D_{ij}}{D_{i.}}\right) \qquad (10)$$

where D_{ij} is the number of worksites in subarea j with employment in category i.

By analogy to equation (1), (2) and (3), it is possible to calculate the relative concentration of origin-destination combinations or commuting patterns for various categories. The following measure is a straightforward application of the previous reasoning.

$$C_i = \sum_m \sum_n \frac{N_{imn}}{N_{i..}} \ln\left(\frac{N_{imn}}{N_{i..}} / \frac{N_{.mn}}{N_{...}}\right) \qquad (11)$$

where N_{imn} is the number of workers of category i commuting between subareas m and n.

The weighted average over categories is

$$\overline{C} = \sum_i \frac{N_{i..}}{N_{...}} C_i \qquad (12)$$

and a measure of relative concentration is obtained by dividing $\overline{C}$ by

$$\sum_m \sum_n \frac{N_{mn.}}{N_{...}} \ln\left(1 / \frac{N_{mn.}}{N_{...}}\right) \qquad (13)$$

Calculations of this kind have been made both for one-way and for two-way classifications into categories of the employment. In the latter case we have simply defined new categories and used the same measures.

Table 9 presents information on the relative concentration of origin-destination (OD) combinations for various categories. Each measures the deviation of the OD pattern for a particular category from the OD pattern for all categories according to expressions (11) and (12).

Table 9. Relative concentration of commuting patterns for various categories of sex, education, occupation and industry 1990.

Sex	
Men	0,016
Woman	0,018
Average	0,017
Relative reduction	0,004
Education	
Low	0,027
Medium	0,019
High	0,125
Average	0,040
Relative reduction	0,009
Occupation	
Knowledge	0,035
Administration	0,076
Service	0,012
Goods handling	0,132
Average	0,046
Relative reduction	0,010
Industry	
Manufacturing	0,150
Local services	0,045
National/reg. services	0,125
Public administration	0,249
Education/research	0,106
Health/social care	0,157
Other	0,098
Average	0,126
Relative reduction	0,028

Note that there are quite substantial differences. For example, the worktrip pattern of highly educated workers is more than five times as concentrated as that of those with less education. These workers live in areas with higher concentrations of similar people and commute to areas with higher concentrations of more highly educated workers.

Particularly striking is the far more concentrated worktrip pattern of public sector employees.

Table 10 gives the same kind of information when employment is classified both according to industry and occupation and according to education and sex.

Table 10. Relative concentration of commuting patterns for cross-classifications of industry/occupation and education/sex

Industry	Knowledge	Adm	Service	Goods handling
Mannufacturing	0,25161	0,15402	0,14748	0,28499
Local services	0,21347	0,09442	0,06608	0,18159
Nat/reg services	0,20356	0,19724	0,11351	0,18082
Public adm	0,35040	0,32041	0,30923	1,53281
Education/research	0,13818	0,25888	0,21933	0,54626
Health/social care	0,18776	0,26919	0,18482	0,40265
Other	0,16489	0,13518	0,15799	0,24439
Average	0,18422			
Relative reduction	0,04034			

Education	Men	Women
Low	0,04670	0,04802
Medium	0,04020	0,04423
High	0,17562	0,12770
Average	0,06238	
Relative reduction	0,01366	

IV. Conclusion

The patterns of workplace location and residential location of workers are closely related. These two distributions give rise to the pattern of commuting and work trip behavior. This paper has provided a description of trends in these patterns over the past two decades, and an analysis of the joint distribution of workplace-residence place patterns (and hence commuting patterns) for 1990.

The paper emphasizes the linkage between the site specific demands for human capital in production (as measured by industry and occupation) and the consequent residential choices of those workers (disaggregated by sex and education, as well as industry and occupation). The analysis shows that the relative deconcentration of worksites has been accompanied by a modest increase in the segregation of workplaces by industry and occupation. In contrast, there has been a substantial desegregation of residence places by the occupation and industry of workers. Despite this, there has been an increasing segregation of the resident population by level of education. Particularly striking is the increase in the relative segregation of residences chosen by those with the highest levels of education. The analysis of these joint distributions for 1990 finds substantial differences in work trip patterns of workers, especially when classified by industry and education levels. The concentration of similar workers among particular origin-destination patterns is quite large, especially for certain types of workers, for example those working in the public sector.

Figure 1

The Stockholm Region: main roads and tracks 1994

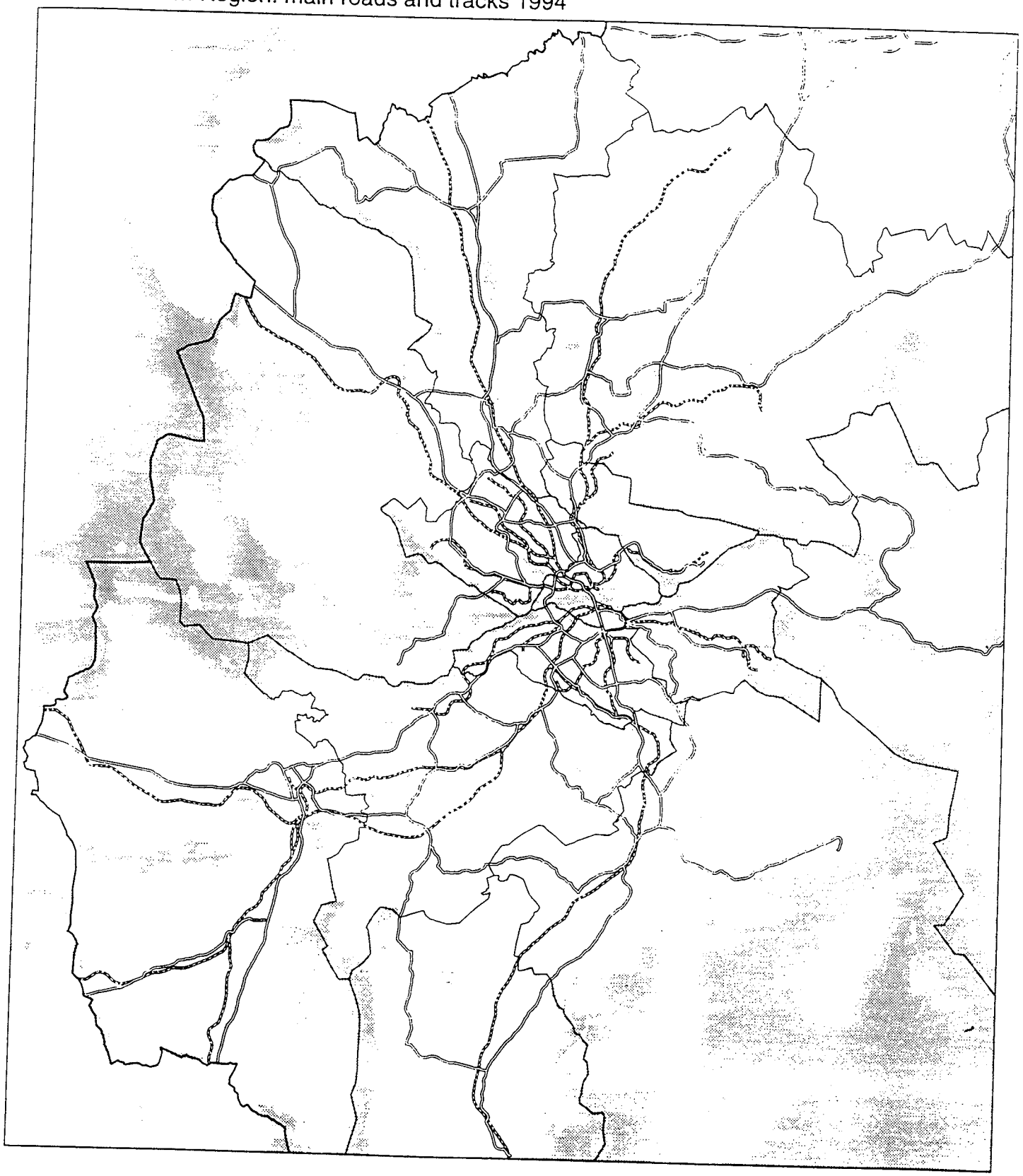

Figure 2

Employment in the Stockholm Region by work sites.
Percent 1970 (upper) and 1990 (lower)

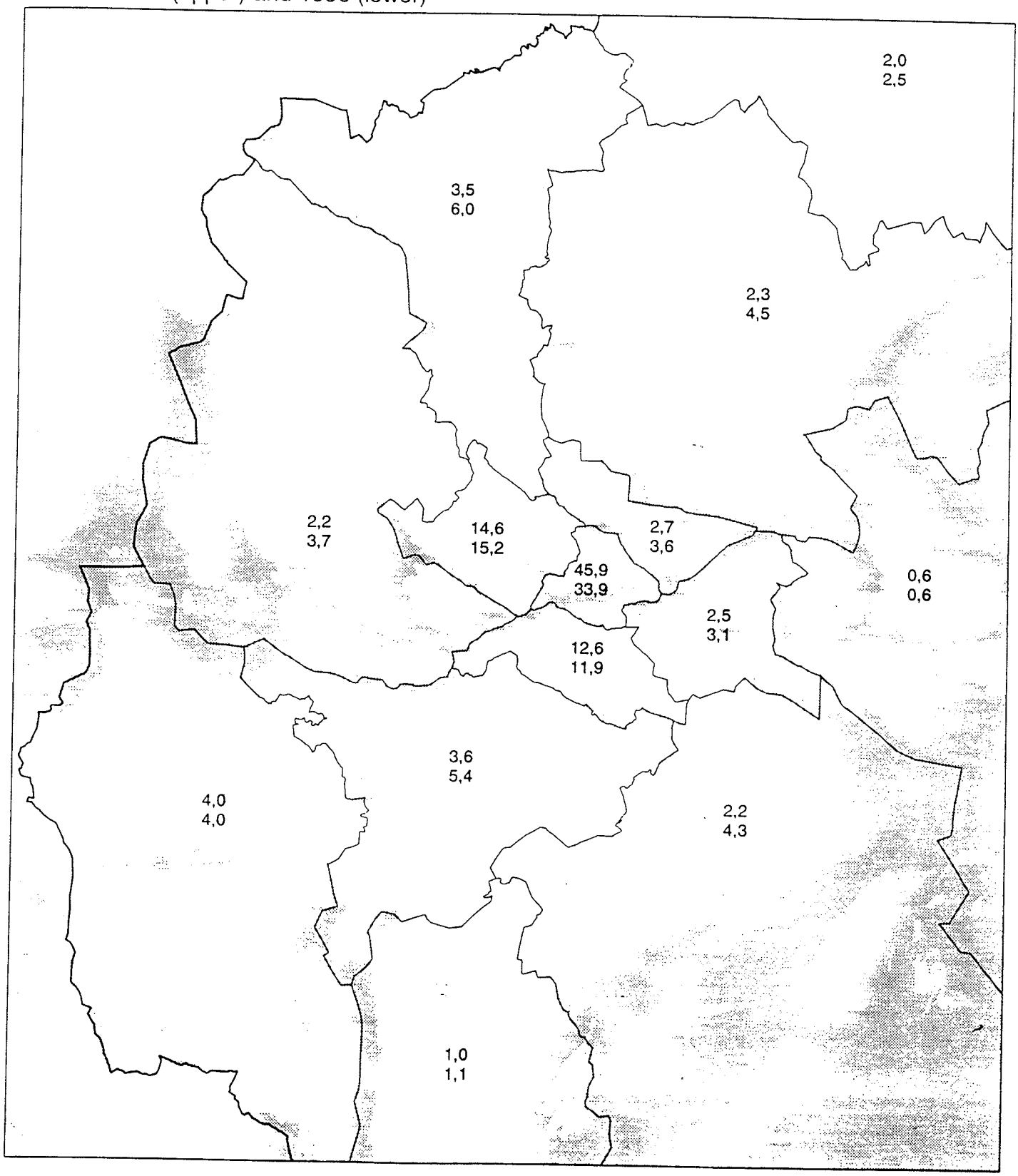

Figure 3

Employment in the Stockholm Region by residential areas.
Percent 1970 (upper) and 1990 (lower)

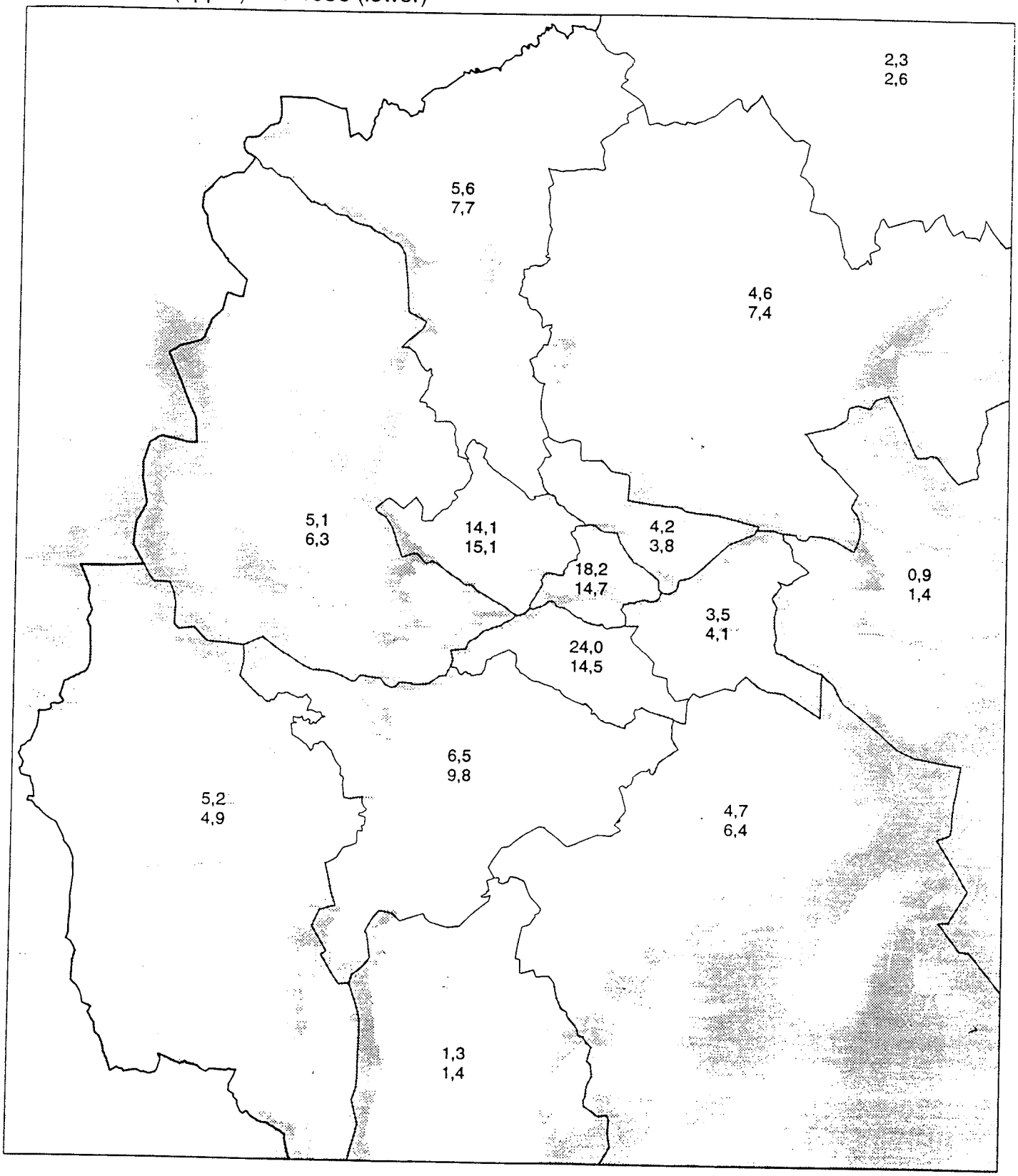

Figure 4

Suburban towns and rush hour travelling time by car to the inner city in minutes