SECTORAL CHANGE AND INTERREGIONAL MOBILITY: A SIMULATION MODEL OF REGIONAL DEMOECONOMIC DEVELOPMENT IN NORTH RHINE-WESTPHALIA

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FOREWORD

Declining rates of national population growth, continuing differential levels of regional economic activity, and shifts in the migration patterns of people and jobs are characteristic empirical aspects of many developed countries. In some regions they have combined to bring about relative (and in some cases absolute) population decline of highly urbanized areas; in others they have brought about rapid metropolitan growth.

Claus Schönebeck, a visitor to IIASA during the summer of 1981 and a research scholar at the University of Dortmund, analyzes the demographic changes that have evolved in the North Rhine-Westphalia region of the Federal Republic of Germany. To do this, he uses a multiregional simulation model that describes migration and investment decisions made by households and population groups taking into account the economic, technical, and social interconnections.

A list of recent publications in the Urban Change Series appears at the end of this paper.

Andrei Rogers
Chairman
Human Settlements
and Services Area

ABSTRACT

This paper describes a multiregional demoeconomic simulation model for the state of North Rhine-Westphalia in the Federal Republic of Germany. First, basic hypotheses of the model are discussed in the light of relevant theories and confronted with recent trends of regional development. Thereafter, the major submodels of the simulation model and the links between them are discussed in detail. The discussion focuses on two submodels simulating aging and migration of population and the locating behavior of industries.

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SECTORAL CHANGE AND INTERREGIONAL MOBILITY: A SIMULATION MODEL OF REGIONAL DEMOECONOMIC DEVELOPMENT IN NORTH RHINE-WESTPHALIA

1. INTRODUCTION

This paper reports the status of a research project conducted at the Institute of Urban and Regional Planning at the University of Dortmund. The project investigates the relationships between economic, technical, and social change and the development of regional and urban settlement systems within a framework of migration and investment decisions. Interregional and intraregional migration decisions made by households and population groups are analyzed. Also examined are the location and investment decisions of industry, services, and residential developers subject to the impacts of public programs and policies of infrastructure planning, housing construction, land-use planning, and industrial development.

Based on the assumption that the development of spatial systems depends significantly on

(1) horizontal (e.g., competitive) as well as vertical (e.g., hierarchical) spatial relationships

(2) functional dependencies between different activities such as working, shopping, housing, recreation

the decision was made to develop a hierarchical simulation model organized in three spatial levels:

(1) a macroanalytic model of demoeconomic development in 34 labor market regions in the state of North Rhine-Westphalia

(2) a microanalytic model of intraregional location and migration decisions in 30 zones of the urban region of Dortmund (Wegener 1980)

(3) a microanalytic model of land-use development in one or more districts of Dortmund (Tillmann 1981)

Information flow in the model is top-down through defined interfaces between model levels. The simulation of the model starts in 1970 and runs in two-year time periods until 1990.

In this paper, only the top level of the three-level model hierarchy, the model of regional development in North Rhine-Westphalia, will be discussed. The model simulates regional development in the state of North Rhine-Westphalia in the Federal Republic of Germany by using different scenarios of (1) economic change, (2) social, demographic, and technological change, and (3) the change of needs and values. The forecasting results include status information (e.g., sex and age composition of the regional population, employment by industries) and process information (e.g., migration and commuting flows of different population groups).

A clear distinction has been made between variables that are directly controlled by planners or politicians (instrument variables) and all other model variables. The explanation and prediction of the latter are based on hypotheses that are related to the process of aging and group-specific decision making. Decision making itself is based on attractiveness differentials between regions, including information delays and group-specific biases.

2. INTERREGIONAL COMPETITION: THEORY AND FACT

2.1 State of the Art

One of the problems regional and local planners in Europe are faced with is the question of agglomeration. Will agglomeration continue, slow down, stop, or even be followed by a phase of deglomeration? Surprisingly enough, recent empirical research leads to contradictory conclusions.

The Netherlands Economic Institute has been engaged in a series of studies that analyze the urbanization process in various countries in Europe (van den Berg and Klaassen 1978; Molle and Klaassen 1978; Klaassen et al. 1979). In these studies three succeeding stages of urban development have been identified:

(1) a phase of *urbanization* with high growth rates in the agglomeration core

(2) a phase of *suburbanization* as a process of relocating from the core to its surroundings

(3) a phase of *deurbanization* characterized by high losses of both the core area and its suburbanized periphery

Classifying the population trajectories of 115 European metropolitan areas, the authors conclude that, although suburbanization is still dominant today, there is a noticeable transition to deurbanization. Unless a powerful reurbanization policy is implemented, deurbanization may cause "garbage cities" or metropolitan ghost towns. However, the theoretical foundations of these studies seem to be weak and therefore lead to highly speculative conclusions.

The authors assume

(1) that for the phase of deurbanization it is typical for the development of large settlement systems to be dominated by residential preferences of households, in particular of households with a high income (Klaassen and Scimemi 1979)

(2) that footloose establishments, mostly of the tertiary or quarternary sector, tend to follow the migration decisions of households (Klaassen and Scimemi 1979)

(3) that spatial mobility of population and employment benefits medium-sized towns supposed to have the most favorable living conditions (van den Berg et al. 1979)

(4) that the shift of both population and employment from larger to medium-sized towns is a mutually reinforcing process (van den Berg et al. 1979)

In contrast, investigations comparing the locational quality of metropolitan areas and other types of regions conclude that the attraction of metropolitan areas will continue to grow. It is assumed that favorable labor market conditions attract migrants from less developed regions especially when overall unemployment is high; accordingly the disparities between metropolitan and rural regions tend to increase.

What are the main reasons for the attractiveness of highly urbanized areas for industry and services? Traditional argumentation emphasizes the quality and diversity of the labor force, good access to intermediate or final consumption markets, the infrastructure potential, opportunities for information exchange and personal contacts.

The current discussion stresses quality aspects of the infrastructure. Direct access to an international airport or to a political or decision-making center substantially adds to the attractivenss of a region, because such access offers opportunities in the competitive advantages of technical, organizational, and financial decision making (Ewers et al. 1979). Such high-level infrastructure seems to be most beneficial for international corporations with extensive investment in research and development (R & D). And, according to the growth pole theory, industries with R & D expenditures are key industries with respect to regional growth.

Furthermore, the spatial concentration of such corporations in the central business districts (CBDs) of large metropolitan regions is regarded as a comparative and thus self-reinforcing advantage. Especially for "headquarter" industries with a high demand for information, location in such areas provides the necessary direct and undisturbed access needed for decision-relevant information flows (Buttler et al. 1977). In particular, the theory of innovation diffusion stresses the point that spatial diffusion processes proceed stepwise in time, and each step is accompanied by information biases and losses.

If all these arguments hold true, the situation for all non-urbanized, peripheral regions is in fact hopeless; they would have the potential to compete with urban areas only if they succeeded in providing a high-level metropolitan infrastructure and attracting headquarter industries. But then, they would no longer be rural.

2.2 Demoeconomic Trends in North Rhine-Westphalia

Before drawing a conclusion to the previous discussion, it may be helpful to present some empirical evidence of recent demoeconomic trends in North Rhine-Westphalia. Theoretical and empirical considerations will then be evaluated together to establish the main hypotheses of the model approach presented here.

In North Rhine-Westphalia there are two large polycentric agglomeration areas comprising more than 50 percent of the total population of the area (Figure 1, top). One is the "Rhine corridor" extending along the river Rhine from Düsseldorf to Cologne and Bonn, and the other is the "Ruhr region", a conglomeration of industrial towns dominated by mining, iron, and steel industries that extend from Duisburg in the west to Dortmund/Hamm in the east.

The statistical comparison of the economic development of the Rhine corridor and the Ruhr region over a period of 20 years reveals that losses of workplaces in the Ruhr region are accompanied by gains of employment in the Rhine corridor.

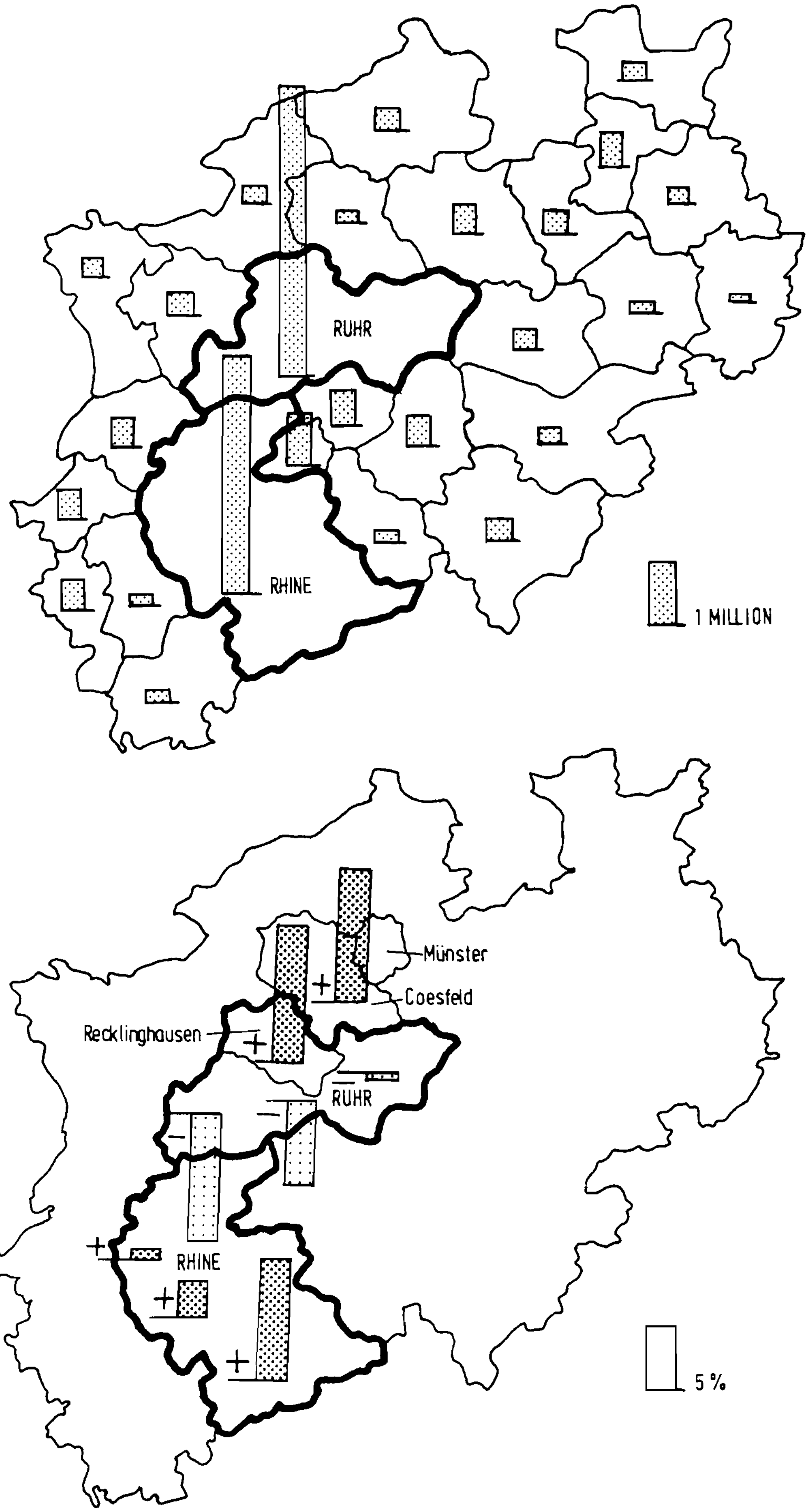

Figure 1. Population in North Rhine-Westphalia 1970 (top) and rates of change 1970-1979 (bottom).

The development of population follows the same path (Figure 1, bottom). Regions with high negative net migration are those with a large proportion of coal mining and steel manufacturing industries because of high unemployment; unattractive, highly polluted neighborhoods; and poor accessibility to recreation areas in the countryside. Additionally, as in most urban areas, birth rates are low. Regions with high positive net migration are those of the Rhine corridor (mainly because of attractive labor market conditions and a good supply of high-quality infrastructure) and all rural areas having good accessibility to more than one urban area (e.g., the Coesfeld region, which is close to the Ruhr region *and* to Münster).

So it can be concluded that neither the deurbanization hypothesis (Rhine *and* Ruhr should diminish) nor the urbanization hypothesis (Rhine *and* Ruhr should grow) fit reality; rather, demoeconomic trends comprise many different countercurrent as well as supplementary processes.

2.3 Basic Hypotheses of the Demoeconomic Model

Since demoeconomic trends are so diverse, a holistic understanding of the processes involved is important. This means that a model of demoeconomic processes must have the requisite level of complexity to grasp the variety of causes and effects inherent in reality. Moreover, such assumptions as "employment follows labor" or "labor follows employment" are not "social laws", but have to be modeled in a way that allows them to respond to changes in the surrounding environment.

With this in mind, the following basic hypotheses were formulated for the demoeconomic model:

(1) The development of a regional economy depends much on its present industrial mix. An above-average share of growing industries is a positive asset with at least medium-term effects. Conversely,a large share of declining or stagnating industries is a less fortunate precondition for the future development of a region.

(2) Regional economic development is also related to regional attractiveness differentials in terms of accessibility, the supply of business-oriented infrastructure, access to markets, financial aids and taxes, the labor market situation, and wage levels. Favorable conditions will, *ceteris paribus*, attract more investment-creating job opportunities. In contrast, unfavorable conditions may result in a slowdown of economic change and eventually in a loss of jobs.

(3) Regional populations change through aging and migration. While aging is a well-defined, steady process, migration flows are highly selective and unsteady in time. Migration can be seen as a kind of "voting" in favor of a place of destination to the detriment of a place of origin. The criteria by which populations evaluate the attractiveness of a region as a place of residence include accessibility, the supply of household-oriented infrastructure, the housing supply, the environmental quality, the labor market situation, and wage levels.

(4) Migration decisions of population and location decisions of enterprises are interrelated, although from different points of view. Both decisions are to some part based on the evaluation of regional labor markets. At times of high overall unemployment, job considerations become of primary importance for the migration decisions of workers, while at the same time the importance of labor market criteria for location decisions of industry decreases.

(5) Regional labor markets are highly segmented. Conditions for a specific market segment, say the labor market for computer engineers, may be quite different from overall conditions: computer engineers may be highly in demand, while overall unemployment is severe. Such imbalances may have a strong influence on both migration and location decisions.

3. MODEL STRUCTURE

Three dimensions of the model's structure are distinguished by spatial organization, the processing of time, and the model content. The following discussion will focus on the model content, therefore the first two dimensions are only summarized here (for details see Schönebeck and Wegener 1977; Wegener 1980).

North Rhine-Westphalia has been divided into 34 labor market (i.e., functional) regions for this study, following the regionalization of Klemmer and Kraemer (1975). Regional population ranges from 140,000 (Höxter) to 1,700,000 (Köln-Leverkusen). In addition, 13 external regions covering the rest of the FRG, the Benelux states, and some provinces of France have been defined.

The model is of the recursive-dynamic type operating with a two-year simulation period. Except for this implicit delay, explicit delays of the exponential or pipeline type are applied. As in all recursive models, a distinction can be made between *status* description parts of the model referring to a point in time and *process* description parts referring to a time interval. The subsequent discussion of the model content will follow this distinction.

3.1 Status Description

In the status description parts of the model, the attractiveness of the region, as perceived by different types of model actors, is determined. The attractiveness indicators are used later in various process description submodels to drive the decision behavior of migrants and locating industries.

The concept of attractiveness used here includes group-specific information on delays and biases. It is operationalized by the evaluation of amenities supplied in the regions themselves and of accessibility measures. The formal properties of attractiveness coincide with those of the additive model of the multiattribute utility theory (MAUT):

$$A_{ni} = \frac{1}{\sum_m w_{mn}} \sum_m w_{mn} v_{mn}(a_{mi}) \qquad (1)$$

where A_{ni} is the attractiveness of evaluation object i (which very often is a region) as seen by actor type n; a_{mi} is the m-th attribute of that evaluation object (e.g., the regional labor market), and w_{mn} and v_{mn} are group-specific importance weights and value or utility functions, respectively.

With a standardized weight structure, equation (1) simplifies to

$$A_{ni} = \sum_m w_{mn} v_{mn}(a_{mi}) \qquad (1a)$$

As indicated above, the attributes a_{mi} are either indicators of amenities supplied in region i

$$a_{mi} = f_m(b_{ki}) \qquad (2)$$

or accessibility measures

$$a_{mi} = \sum_j \frac{f_m(b_{kj}) e^{-\beta c_{ij}}}{\sum_j f_m(b_{kj}) e^{-\beta c_{ij}}} c_{ij} \qquad (2a)$$

where $f_m(b_{ki})$ is a generating function specifying how to calculate a_{mi} from the k-th variable b of region i; and c_{ij} is an indicator for travel time or cost between region i and j (Wegener 1980).

The following discussion will concentrate on the three most important attractiveness indicators calculated in the status description part: the indicators evaluating regional labor markets, market potentials, and housing.

3.1.1 Evaluation of Labor Markets

Job opportunities are a major factor driving interregional, i.e., long-distance, migration. At the same time, the availability of qualified workers is of prime importance for locating industries. Therefore, information on supply and demand on the regional labor market is a prerequisite for modeling spatial decision behavior of population and industry.

The analysis of regional labor market conditions involves three problems: the identification of homogeneous labor market segments, the forecasting of regional unemployment separately for each market segment, and the evaluation of labor market conditions for different population groups and industrial sectors.

For this model, a market segmentation of two skill levels for both male and female workers is considered appropriate.

The forecasts of labor demand in North Rhine-Westphalia made for each of these four market segments (two skills, male, and female) were based on research by the Battelle Institute Frankfurt (Blüm and Frenzel 1977). The Battelle reports provide detailed forecasts of labor demand by skill and sector for the Federal Republic of Germany until the year 1990.

On the labor supply side, the number and composition of the regional labor force is estimated using a top-down approach: first, labor force participation rates by age, sex, and skill for the whole of North Rhine-Westphalia are updated based again on the Battelle reports and on Weisshuhn (1978). Second, these rates are disaggregated by region, presently by multiple regression. The labor force participation rates are used to calculate the labor supply by market segment for each region. It is planned to replace this part of the model by a multistate labor force cohort-survival model simulating worker life cycles by sex and skill.

Next, regional unemployment can be estimated. This at first seems to be a trivial problem. That is true where the region is very large, e.g., a whole state or country, and commuting across its boundaries is negligible. In such a case

$$u^* = (S^* - D^*)/S^* \cdot 100 \tag{3}$$

where u^* is the unemployment rates in percent, S^* is the labor force, and D^* is the number of jobs.

However, on a smaller spatial scale, interregional commuting is neither balanced nor negligible. In general, urban areas have a surplus of jobs, whereas rural and suburbanized areas have a surplus of workers. Consequently, estimation of regional unemployment has to take account of interregional commuting:

$$u_i = (S_i - \sum_j T_{ij})/S_i \cdot 100 \tag{4}$$

where u_i is the unemployment rate in region i, and T_{ij} are home-to-work trips originating in i. Unfortunately, the work trip matrix $\underset{\sim}{T}$ is unknown. Estimating a work trip matrix with standard interaction modeling techniques does not help in this case, as the actual work trip origins W_i are not known. What is known is the labor force S_i in origin zones i, and by definition, it is also known that the actual number of work trips originating in i must be less or equal S_i.

For this special case, an entropy-maximizing approach with inequality constraints has been proposed by Jefferson and Scott (1979):

$$\text{Maximize} \quad T! \prod_{i,j} \left(\frac{R_{ij}^{T_{ij}}}{T_{ij}!} \right) \tag{5}$$

$$\text{subject to} \quad \sum_j T_{ij} \le S_i \qquad \text{for all } i \tag{5a}$$

$$\sum_i T_{ij} = D_j \qquad \text{for all } j \tag{5b}$$

$$T_{ij} \geq 0 \qquad \text{for all } i \text{ and } j \tag{5c}$$

where $T = \sum_i \sum_j T_{ij}$ and $R_{ij} = e^{-\beta c_{ij}}$ with c_{ij} as the distance between region i and j and β as a measure of distance sensitiveness and D_j is the number of jobs in j.

This approach agrees with the problem to be solved, because the number of work trips originating in i is less or equals the labor force in i, S_i, and the number of work trips ending in j equals the number of jobs in j, D_j.

Unfortunately, the algorithm documented by the authors produces inconsistent results when tested in a fictitious three-region example with the β-parameter being set to zero, i.e., setting all distances to unity. Under these circumstances, work trip origins should distribute over space in proportion to labor supply, resulting in equal unemployment rates u_i in all regions. However, as shown in Figure 2, the regional unemployment rates calculated by way of the Jefferson/ Scott algorithm vary considerably, whereas the expected result is obtained by a conventional attraction-constrained spatial interaction model.

To use an attraction-constrained interaction model in cases where the origins (supply) exceed the destinations (demand) has been suggested by Mayhew (1980):

$$\sum_j T_{ij} = S_i \sum_j B_j D_j e^{-\beta c_{ij}} \tag{6}$$

$$B_j = \left[\sum_i S_i e^{-\beta c_{ij}} \right]^{-1} \tag{6a}$$

Because in this model there is no constraint as in equation (5a), it may happen that some of the row totals $\sum_j T_{ij}$ may exceed S_i, the regional labor force. Other row totals may be less than the respective regional labor force.

I. DATA INPUT

Regions	c_{ij} R1	c_{ij} R2	c_{ij} R3		S_i		D_j	β
R1	2	3	4	R1	1000	R1	700	
R2	3	2	5	R2	600	R2	700	0.
R3	4	5	2	R3	800	R3	700	

II. ESTIMATION OF THE TRIP MATRIX T

a) with the Jefferson/Scott algorithm

	T_{ij} R1	T_{ij} R2	T_{ij} R3	$\sum_j T_{ij}$		S_i		u_i
R1	250	250	250	750	R1	1000	R1	25.0
R2	200	200	200	600	R2	600	R2	0.0
R3	250	250	250	750	R3	800	R3	6.25
$\sum_i T_{ij}$	700	700	700	2100		2400		12.5

b) with an attraction-constrained model

	R1	R2	R3	$\sum_j T_{ij}$		S_i		u_i
R1	$291.\bar{6}$	$291.\bar{6}$	$291.\bar{6}$	875	R1	1000	R1	12.5
R2	175	175	175	525	R2	600	R2	12.5
R3	$233.\bar{3}$	$233.\bar{3}$	$233.\bar{3}$	700	R3	800	R3	12.5
$\sum_i T_{ij}$	700	700	700	2100		2400		12.5

Figure 2. Sample calculation: trip matrix.

The idea is to use the information contained in these differences to estimate regional unemployment directly. The rationale behind this estimation is that these differences express the spatial immobility of labor, namely its failure to respond to the spatial distribution of job opportunities, resulting in different regional unemployment levels:

(1) A positive difference indicates that there are more job opportunities accessible from the region than there are potential workers, i.e., unemployment will be relatively low.

(2) A negative difference indicates that there are less job opportunities accessible from the region than there are potential workers, i.e., unemployment will be relatively high.

Assuming a linear relationship between the ratio of job opportunities to potential workers in a region and actual regional unemployment, the statistical estimation of regional unemployment rates is straightforward. In a forecasting context, the resulting unemployment rates may have to be adjusted to comply with the statewide unemployment rate predicted for North Rhine-Westphalia as a whole and, related to it, to comply with some specific upper and lower bounds (see Figure 3).

Given regional labor demand D_i, regional labor supply S_i, and the regional unemployment rate u_i, the actual work trip matrix can be calculated as supplementary information for the evaluation of the labor market. For this purpose, the number of workers living in i is calculated as

$$W_i = (100 - u_i)/100 \; S_i \tag{7}$$

where

$$\sum_i W_i = \sum_j D_j \tag{7a}$$

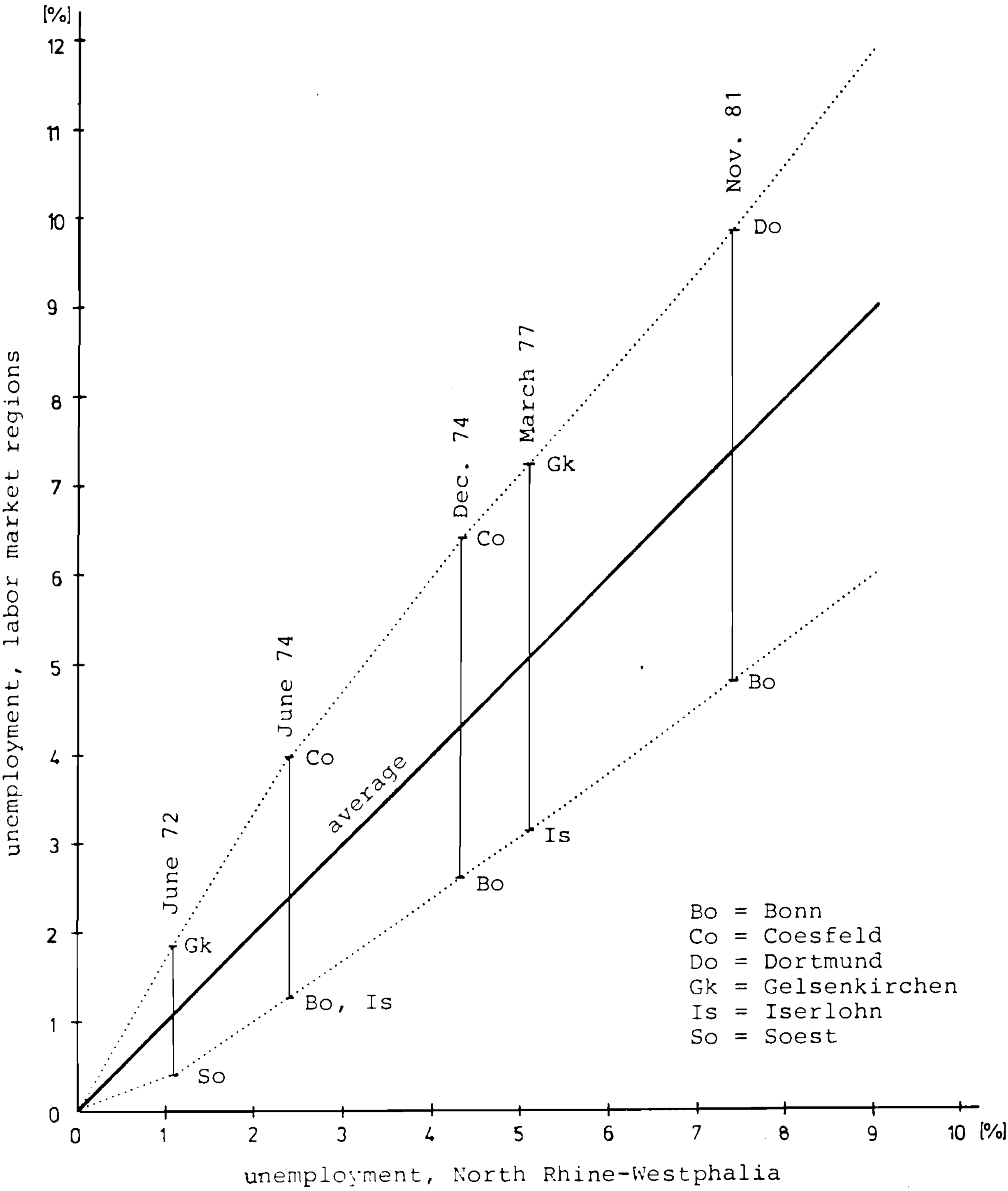

Figure 3. Regional differences in unemployment.

Taking W_i and D_j as the marginal vectors of a doubly constrained spatial interaction model, the work trip matrix $\underset{\sim}{T}$ is estimated by means of the RAS method (Stone 1962; Hübler 1979). In this way, all four labor market segments are analyzed, one after the other.

The criteria used in the model to evaluate regional labor markets are different for each type of model actor depending on its specific preference system. Both workers and employers address the level of regional unemployment as well as the composition of the labor market by skill levels, but obviously for quite different reasons. For the employers, also the number of workers commuting out to adjacent regions is of interest as a potential labor force which might be easily attracted by job opportunities in their home region.

3.1.2 Evaluation of Market Potentials

Access to markets is an important locational factor for industry. The markets of different industries are as different as their production programs. And because there is a continuous change in production caused by new technologies and changing demand patterns, markets change too. Consequently, it is necessary to define the sector-specificity and time-dependence of markets.

For each sector two separate markets exist: an *input* market comprising purchases from other sectors and an *output* market comprising sales to other sectors and to final demand.

Formally, a market can be represented by an input-output matrix containing exchange rates between industrial sectors. High exchange rates signal a high mutual interdependency between sectors. A group of industries connected by strong intersectoral links is sometimes called an industrial complex.

Because of transfers of goods and services between regions, the evaluation of a regional economy with respect to its markets cannot be restricted to its own boundaries, but has to include exchange relationships with other regions as well.

For this purpose, two market potentials can be calculated for each sector s in each region i: $U_{si}(t)$ is the regional market potential with respect to inputs (purchases), and $V_{si}(t)$ is the regional market potential with respect to outputs (sales):

$$U_{si}(t) = \sum_{s'} a_{s's} \sum_{j} \left(E_{s'j}(t) e^{-\beta^u_{s'} c_{ij}} \right) \tag{8}$$

$$V_{si}(t) = \sum_{s'} a_{ss'} \sum_{j} \left(E_{s'j}(t) e^{-\beta^v_{s'} c_{ij}} \right) \tag{8a}$$

where $E_{s'j}$ is the number of jobs of sector s' in region j, $a_{ss'}$ are input-output coefficients expressing trade relationships between sectors s and s' and the $e^{-\beta_s c_{ij}}$ are sector-specific deterrence functions.* In these equations, all regional economic structures are weighted with a sector-specific set of input-output coefficients. Spatial discounting is introduced by the definition of sector-specific spatial deterrence functions.

Two different sets of β-parameters, β^u and β^v, are needed for input and output markets. In the absence of regional input-output matrices, a national input-output matrix will have to be used, although regional peculiarities will not be represented in such a matrix.

The two market potentials are interpreted in the same way: high values of $U_{si}(t)$ or $V_{si}(t)$ indicate good access to input or output markets, respectively, low values indicate that the region is remote from its relevant markets.

To illustrate the model, a three-region, three-sector example is presented in Figure 4. Part I gives the data input with the matrix $\underset{\sim}{E}$ containing sectoral employment by region, the input-output matrix $\underset{\sim}{a}$, and the distance matrix $\underset{\sim}{c}$. For the sake of simplicity all β-parameters are set to one. The main diagonal of the input-output matrix is set to zero; i.e., intra-sectoral relationships are neglected.

I. DATA INPUT

$E_{s'j}$ Regions

		R1	R2	R3
Sectors	S1	500	300	200
	S2	100	500	1500
	S3	600	400	600
		1200	1200	2300

$a_{ss'}$

	S1	S2	S3
S1	0.	.7	.2
S2	.25	0.	.25
S3	.3	.25	0.

c_{ij} and $\beta_s^u = \beta_s^v$

	R1	R2	R3	$\beta_s^u=\beta_s^v$
R1	2	3	4	1
R2	3	2	5	1
R3	4	5	2	1

II. JOB POTENTIALS

$V''_{s'i}$

	R1	R2	R3
S1	86.27	66.84	38.25
S2	65.9	82.75	208.2
S3	112.1	88.05	94.89

III. REGIONAL OUTPUT MARKET POTENTIALS FOR SECTOR 1

$$\underset{V_{1i}}{\begin{bmatrix} 68.55 & 75.54 & 164.72 \end{bmatrix}} \leftarrow \underset{a_{1s'}}{\begin{bmatrix} 0. & .7 & .2 \end{bmatrix}} \underset{V''_{s'i}}{\begin{bmatrix} 86.27 & 66.84 & 38.25 \\ 65.9 & 82.75 & 208.2 \\ 112.1 & 88.05 & 94.89 \end{bmatrix}}$$

IV. DISCUSSION

68.55	R1	Below-average market potentials because of a low share of sector 2
75.54	R2	
164.72	R3	Above average market potentials because of a high share of sector 2
102.94	All regions	Average value

Figure 4. Sample calculation: market potentials.

For space limitations, only the regional output markets for sector 1 are described. Reconsidering equation (8a), it has been defined that weighting of the job matrix $\underset{\sim}{E}$ two times (by means of spatial discount factors and input-output coefficients) yields the matrix of regional output market potentials $\underset{\sim}{V}$. To facilitate the understanding of Figure 4, the two weighting steps are calculated one after the other. Step II calculates job potentials defined as follows:

$$V''_{s',i}(t) = \sum_j \left(E_{s',j}(t) e^{-\beta^V_{s'} c_{ij}} \right) \qquad (8b)$$

Multiplication of the resulting matrix $\underset{\sim}{V}''$ with the row vector of input-output coefficients of sector 1 in step III yields the regional output market potentials V_{1i}. In step IV the regional values are evaluated by comparing them with the average value.

3.1.3 Evaluation of Housing

The attractiveness of a region as a place to live is evaluated as a function of its location, its supply of household-oriented infrastructure (transport, education, recreation, and health care), its housing supply, and its environmental quality.

The *location* of the region is measured in terms of its relative accessibility to the other regions of North Rhine-Westphalia, to the remaining parts of the Federal Republic of Germany, to the Benelux states, and to the northeastern provinces of France. Regional jobs $E_j(t)$ are used as potential variables of the accessibility function of the type shown in equation (2a):

$$a_i = \sum_j \frac{E_j e^{-\beta c_{ij}}}{\sum_j E_j e^{-\beta c_{ij}}} c_{ij} \qquad (9)$$

This accessibility measure is dimensioned in the same way as the distance measure c_{ij}, i.e., a low value indicates good access to employment in neighboring regions.

The supply of the household-oriented *infrastructure* is represented by transport facilities (autobahn access, express train departures, airports), educational facilities (universities, graduate, and professional schools), recreation facilities (parks and woodlands, lakes, and waterways), health care facilities (hospital beds per capita).

The *housing supply* of the region (e.g., in terms of the average flat size, and the proportion of flats equipped with bath and toilet) is evaluated in relation to regional demand for housing.

The *environmental quality* of the region is evaluated in terms of the share of polluting industries.

3.2 Process Description

In the process description part of the model, all changes of model variables between two points in time, t and t+1, are simulated. Starting from the state of the modeled system at time t, the process description produces a new status at time t+1.

The process description consists of four submodels, which describe the demographic development, the economic development, changes of the housing stock, and public planning programs. The following discussion deals only with the first two submodels, which are the core of the whole model.

3.2.1 The Demographic Submodel

The demographic submodel combines a model describing the aging process of regional population stocks with a model explaining and predicting migration. The distinction between aging and migration reflects the different character of the two processes. Aging is a *steady* process, basically determined by the initial population distribution. Migration is a basically *unsteady* process caused by changing regional attractiveness differentials. The two processes, however, are closely interrelated. Aging changes the preferences and needs of people, resulting in different propensities to migrate during their lifetime. Migration alters the regional population stocks in number as well as in composition.

The following three subsections give a description of the aging submodel, the migration submodel, and the links between them.

3.2.1.1 Aging

The aging submodel serves to project the population of each region classified by age, sex, and nationality by one simulation period including childbearing and death. The aging submodel uses cohort-survival techniques adapted to five-year age groups, and is based on a time-invariant life table, but dynamic, age-specific, and regionalized fertility estimates. Extensions planned are, for instance, the inclusion of transitions of foreign population to native by naturalization.

The aging submodel distinguishes three kinds of transitions

(1) changing the age group, i.e., transitions from age group a to age group a+1

(2) births, i.e., transitions into age group 1

(3) deaths, i.e., transitions out of any age group a

First. Modeling the transitions from age group a to age group a+1 is straightforward if the length of the simulation period agrees with the width of the age groups, i.e., after one period all survivors of age group a have changed to the following age group a+1. However, where the length of the simulation period is less than the number of years constituting one age group, there is no "correct" solution for calculating these transitions.

At first glance, it seems to be a good approximation to estimate the yearly number of transitions $C_a^{sn}(t,t+1)$ from five-year age group a to a+1 as one-fifth of the population stock $P_a^{sn}(t)$ of age group a. Subscripts s and n indicate sex and nationality, respectively. For a simulation period of Δt years, this yields

$$C_a^{sn}(t,t+1) = \Delta t \; P_a^{sn}(t)/5 \qquad a = 1,\ldots,19 \qquad (10)$$

This approximation assumes a flat distribution of one-year age groups within the five-year age groups. Unfortunately, the shape of population pyramids in reality is not smooth enough to make this assumption acceptable. Empirical tests revealed that a much better approximation is obtained by averaging between the origin and the destination age groups (Wegener 1981):

$$C_a^{sn}(t,t+1) = \Delta t \left(P_a^{sn}(t) + P_{a+1}^{sn}(t)\right)/10 \qquad a = 1,\ldots,19 \qquad (10a)$$

Equation (10) is preferred only where $P_a^{sn}(t)$ is analyzed to be a "peak" or a "dip" compared with its adjacent age groups $P_{a-1}^{sn}(t)$ and $P_{a+1}^{sn}(t)$.

With these transitions the population stock in t is updated by means of the following three equations:

$$P_1^{sn}(t+1) = P_1^{sn}(t) - C_1^{sn}(t,t+1) \qquad (11)$$

$$P_a^{sn}(t+1) = P_a^{sn}(t) + C_{a-1}^{sn}(t,t+1) - C_a^{sn}(t,t+1) \qquad a = 2,\ldots,19 \qquad (11a)$$

$$P_{20}^{sn}(t+1) = P_{20}^{sn}(t) + C_{19}^{sn}(t,t+1) \qquad (11b)$$

Second. To compute the number of survivors between time t and t+1, age- and sex-specific survival rates p_a^s are used (cf. Willekens and Rogers 1978). They are computed on a yearly basis so that

$$P_a^{sn}(t+1) = (p_a^s)^{\Delta t} \; P_a^{sn}(t) \qquad a = 1,\ldots,20 \qquad (12)$$

Third. The number of newborn babies surviving the first simulation period is estimated on the basis of

(1) periodically updated, age-specific fertility estimates $f_a^n(t,t+1)$ for each female age group between 16 and 50 years for the whole of North Rhine-Westphalia

(2) a constant h describing the proportion of boys among the newborn babies

(3) the survival rate for age group 1, P_1^s

The updated fertility estimates $f_a^n(t,t+1)$ are regionalized by a multiple regression model leading to modified fertility rates $g_{ai}^n(t,t+1)$ for each region i. Then

$$C_{0i}^{1n}(t,t+1) = \sum_{a=3}^{10} \left(g_{ai}^n(t,t+1)\,h\,(p_1^s)^{1/\sqrt{2}\Delta t} \; P_{ai}^{2n}(t) \right) \qquad (13)$$

$$C_{0i}^{2n}(t,t+1) = \sum_{a=3}^{10} \left(g_{ai}^n(t,t+1)\,(1-h)\,(p_1^s)^{1/\sqrt{2}\Delta t} \; P_{ai}^{2n}(t) \right) \qquad (13a)$$

are newborn male and female babies, respectively, of nationality n in region i having survived the first simulation period, where s = 1 indicates male and s = 2 female. The multiplication of the exponent Δt of the survival rate by $1/\sqrt{2}$ takes account of the fact that births are distributed evenly over the period, i.e., the number of newborn babies increases cumulatively (cf. Wegener 1981).

In a final step, the newborn babies are added to the first age group of either sex:

$$P_{1i}^{sn}(t+1) = P_{1i}^{sn}(t) + C_{0i}^{sn}(t,t+1) \qquad (14)$$

3.2.1.2 Migration

The migration submodel predicts migration flows by age, sex, and nationality between the 34 labor market regions in North Rhine-Westphalia plus migration into and out of North Rhine-Westphalia. In accordance with Lee (1966) migration is viewed within a framework of factors associated with the area of origin, the area of destination, intervening obstacles, and the migrants themselves. In particular assumptions of the migration submodel correspond to the concept of place utility (Wolpert 1965), which is summarized as follows (Shaw 1975:110):

> Place utility considerations have to do with subjective evaluations on the behalf of individuals of composites of utilities to be derived from the individual's place of origin in contrast to utilities to be derived from alternative places of residence. Although we might expect the individual to locate himself at the place of highest utility, it is suggested that whether in fact the individual does so will be a function of two factors. The first concerns the individual's ability to adjust to the utility profile offered at his place of residence if it should devaluate either by contrast or actually. The second concerns the information available (and its perceived accuracy) on the utilities to be had elsewhere.

Below, an overview of the migration submodel is provided, describing its output and variable structure and its different modeling steps.

The migration submodel results in 24 matrices of dimension 35 × 35 per period, representing migration flows between the 34 labor market regions plus inmigrations to and outmigrations from North Rhine-Westphalia for six age groups (0-15, 16-20, 21-35, 36-50, 51-65, 65+ years) by sex and nationality (cf. Gatzweiler 1975). Children belonging to age group 0-15 are assumed to migrate with their parents. Forecasting group-specific migration flows for the 5 × 2 × 2 adult age groups proceeds through the following four modeling steps.

First. The general propensity to migrate, i.e., the total interregional migration volume and the total number of migrations into and out of North Rhine-Westphalia, are determined. It is assumed that temporal variations in the propensity to migrate of different age groups depend on two complementary factors:

(1) Job security. It is assumed that high unemployment rates correspond to a low level of spatial mobility (Bartels and Liaw 1981). Strong empirical evidence in favor of this assumption can be found in data of North Rhine-Westphalia for the period 1970-1979 (see Figure 5). The index in Figure 5 denotes migrations per capita in percent of 1970 migrations.

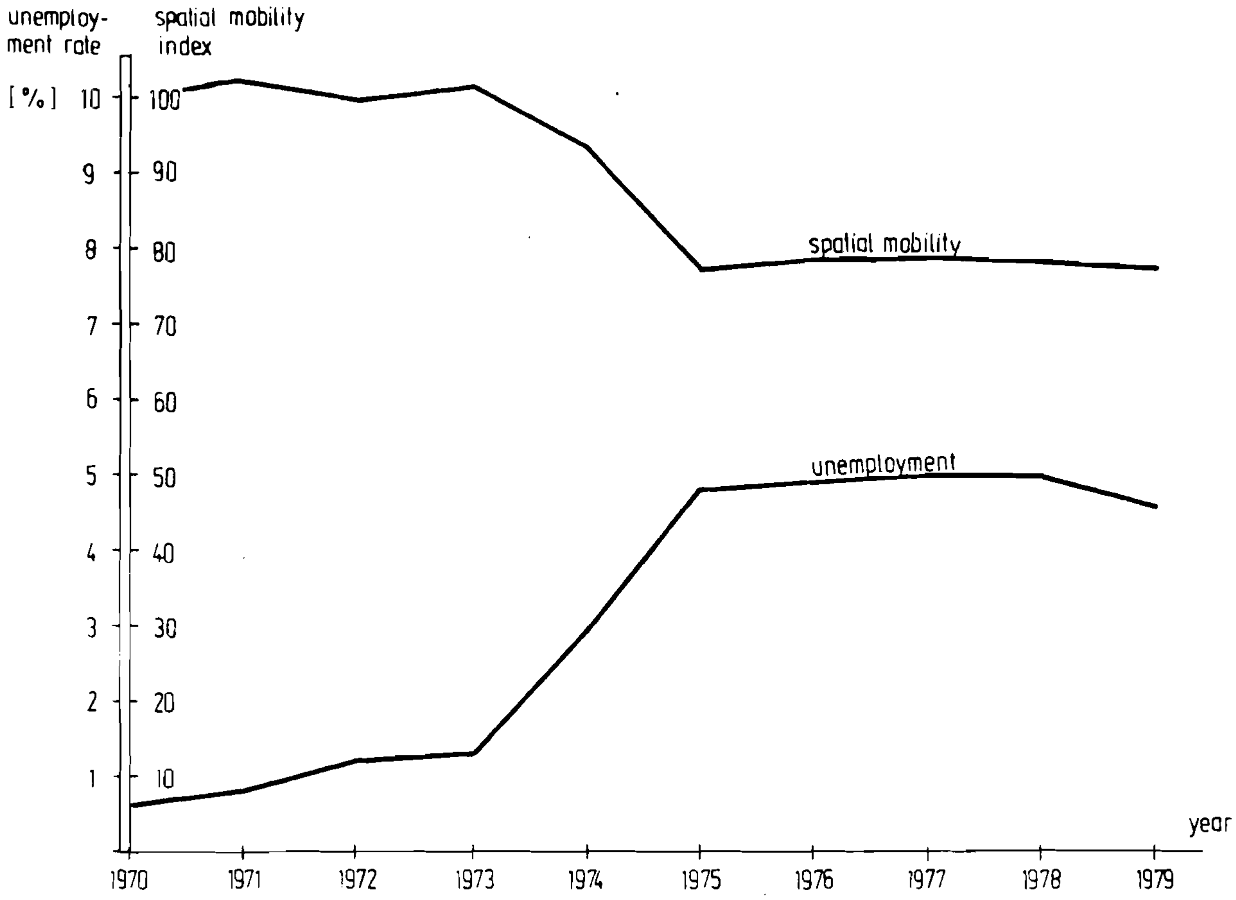

Figure 5. Spatial mobility as a function of unemployment.

(2) Regional diversity. It is assumed that spatial mobility decreases with the convergence of living conditions in the regions. Spatial convergence reduces the chance of improving one's living conditions by changing the place of residence; consequently, the stimulus to migrate becomes less.

The variance of the regional attractiveness indicators is taken to be an appropriate measure of regional diversity. So mobility rates $m^*_{gsn}(t,t+1)$ of age group g, sex s, and nationality n are determined as a function of the general unemployment rate $u^*(t)$ and the variance $v_{gsn}(t)$ of the attractiveness indicators $A_{gsni}(t)$:

$$m^*_{gsn}(t,t+1) = f_{gsn}\left(u^*(t),\ v_{gsn}(t)\right) \tag{15}$$

The mobility rates are expressed as multiples of the mobility of the first simulation period. Thus

$$M^*_{gsn}(t,t+1) = m^*_{gsn}(t,t+1)\ M^*_{gsn}(1,2) \tag{15a}$$

is the total interregional migration volume at time t+1. Total inmigration and outmigration from North Rhine-Westphalia are presently exogenously specified.

Second. Migrations out of each region are estimated as a proportion of total interregional migration. It is assumed that the regional differences in the propensity to migrate depend on the following factors:

(1) Regional attractiveness. It is assumed that less attractive regions have relatively more outmigration than attractive ones. This is the traditional push hypothesis.

(2) Home ownership. It is assumed that home owners are less inclined to migrate than tenants (Deutschman 1972).

The attractiveness of a region for migration consists of two subsets of attributes, the first one expressing the *housing situation* (location, public services, retail and private services, housing supply, recreational facilities, environmental quality), the second one expressing the *labor market situation* (labor supply and demand, wage level). Figure 6 shows these attributes in more detail. The weighting between these two subsets is done dynamically in response to the statewide labor market situation to take account of the fact that at times of high unemployment migration decisions are basically determined by job considerations.

Based on these hypotheses, the equation for regional outmigration is

$$M^o_{gsni}(t,t+1) = \frac{\left(P_{gsni}(t) - k\,H_{gsni}(t)\right)\left(100 - A_{gsni}(t)\right)}{\sum_i \left(P_{gsni}(t) - k\,H_{gsni}(t)\right)\left(100 - A_{gsni}(t)\right)}\,M^*_{gsn}(t,t+1) \qquad (16)$$

where $M^o_{gsni}(t,t+1)$ is the number of migrants of age group g, sex s, and nationality n leaving region i during this period, $P_{gsni}(t)$ and $H_{gsni}(t)$ are population and home-owning population, respectively. The transformation $100 - A_{gsni}(t)$ ensures the inverse relationship between the regional attractiveness $A_{gsni}(t)$ and the level of outmigration $\left(0 \le A_{gsni}(t) \le 100\right)$. The parameter k expresses the different propensities to migrate of tenants and home owners.

<u>Third</u>. The migration origins thus established are distributed by a production-constrained spatial interaction model stated as follows:

$$M_{gsnij}(t,t+1) = B_i D_j(t)\ A_{gsnj}(t) e^{-\beta c_{ij}}\ M^o_{gsni}(t,t+1) \qquad (17)$$

$$B_i = \left[\sum_j D_j(t)\ A_{gsnj}(t) e^{-\beta c_{ij}}\right]^{-1} \qquad (17a)$$

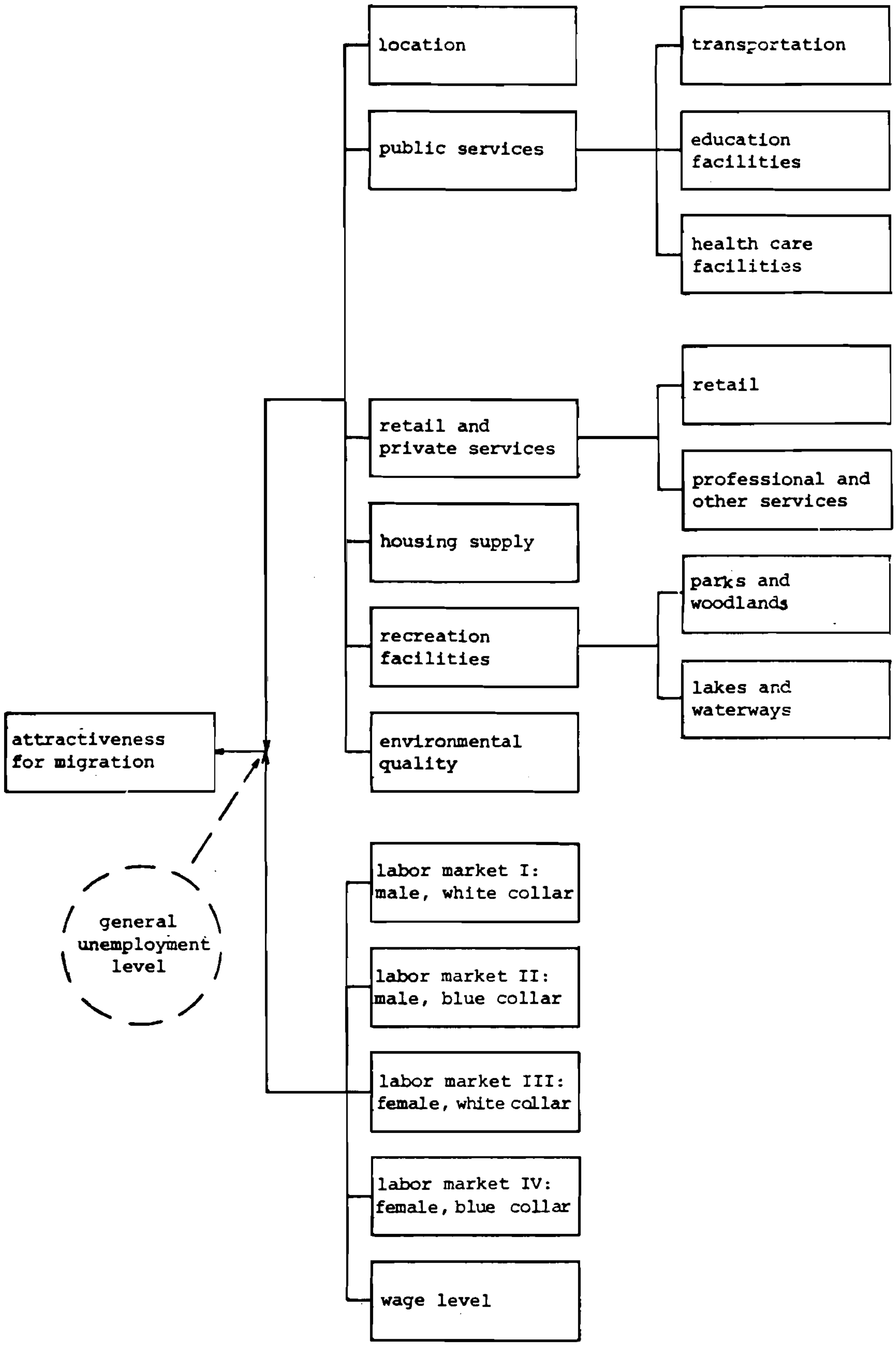

Figure 6. Attractiveness for migration.

where $M_{gsnij}(t,t+1)$ are migration flows of population group gsn from region i to region j between t and t+1. $D_j(t)$ denotes jobs in j. The A_{gsnj} are group-specific attractiveness indicators.

Note that the attractiveness indicators are used in equation (17) as pull or attractor variables and in equation (16), with a negative sign, as push or deterrence variables. In both cases the same aggregate of regional attributes calculated in the status description is used. It consists of two subsets: attributes expressing the labor market situation (cf. section 3.1.1), and attributes expressing the housing situation (cf. section 3.1.3).

Weighting between these two subsets is done dynamically in response to the general unemployment rate in North Rhine-Westphalia as a whole to take account of the fact that at times of high unemployment job considerations become of primary importance for migration decisions. After determining interregional migrations, the number of children migrating with their parents is estimated for parent age groups, and migrations into and out of North Rhine-Westphalia are distributed to regions in proportion to interregional migration.

Fourth. All changes of the regional population age structures caused by migration are executed. For this purpose, the interregional migration flows have to be split up to correspond to the five-year age structure of the population, taking account of the different migration propensities of each age group.

To achieve this, two matrices are defined: $M^t_{asnj}(t,t+1)$ as the number of inmigrants to region j for each five-year age group a, and $M^f_{asni}(t,t+1)$ as the number of outmigrants from region i for each five-year age group a.

The two matrices are computed for each of the six migration age groups g separately. For each region i, sex s, and nationality n, the share w_{asni} of each five-year age group a belonging to migration age group g is calculated and weighted with its specific migration rate m_{asn} (cf. Castro and Rogers 1979; Rogers and Castro 1981):

$$w_{asni} = \frac{m_{a'sn} P_{a'sni}}{\sum_{a' \in G} m_{a'sn} P_{a'sni}} \tag{18}$$

where {G} is the set of age groups a' belonging to g. The w_{asni} serve to split the migration flows:

$$M^t_{asnj}(t,t+1) = \sum_i w_{asni} M_{gsnij}(t,t+1) \tag{19}$$

$$M^f_{asni}(t,t+1) = \sum_j w_{asni} M_{gsnij}(t,t+1) \tag{19a}$$

Note that in both equations (19) and (19a) the split factors w_{asni} of the origin region are used to maintain consistency of the population age structures. With the two matrices determined, the population age structures are updated as follows:

$$P_{asni}(t+1) = P_{asni}(t) + M^t_{asnj}(t,t+1) - M^f_{asni}(t,t+1) \tag{20}$$

3.2.1.3 Linking Aging and Migration

The aging and migration submodels as well as all transitions within the aging submodel are processed sequentially. When compared with the multistate projection technique (Rogers 1975; Willekens and Rogers 1978; Rogers 1981), this sequential type of model needs some justification.

There are four kinds of transitions occurring in the aging and migration submodels:

- aging, i.e., transitions from age group a to age group a+1
- births, i.e., transitions into age group 1

- deaths, i.e., transitions out of any age group a
- migrations, i.e., transitions from region i to region j

Since each kind of transition occurs in a continuous stream over the whole projection interval, all transitions should be treated simultaneously in a projection model. This is done by the multistate projection model.

Processing the four kinds of transitions sequentially in a projection model has many advantages in terms of model organization, computing time, and computer storage space. However, the sequential model at the same time creates some problems. Depending on the sequence in which they are processed, the transitions are executed for different populations at risk, and this will of course affect the results. To minimize such distortions, the sequential model used here divides the simulation period into four equal subperiods. Starting with a population age structure status at t, the following sequence of steps is performed (see Figure 7):

(1) aging the population and deaths from t to t+0.25
(2) calculating births and aging them from t to t+0.5
(3) aging the population and deaths from t+0.25 to t+0.5
(4) updating the population at t+0.5 by births from t to t+0.5
(5) calculating migrations from t to t+1
(6) updating the population at t+0.5 by migrations from t to t+1
(7) aging the population and deaths from t+0.5 to t+0.75
(8) calculating births and aging them from t+0.5 to t+1
(9) aging the population and deaths from t+0.75 to t+1
(10) updating the population at t+1 by births from t+0.5 to t+1

The equivalence of both the multistate and sequential models has been tested with data of Slovenia and the rest of Yugoslavia for 1961 published in Rogers (1975) and Willekens and Rogers (1978) consisting of female five-year age structures, the number of births, deaths by age in each region, and the

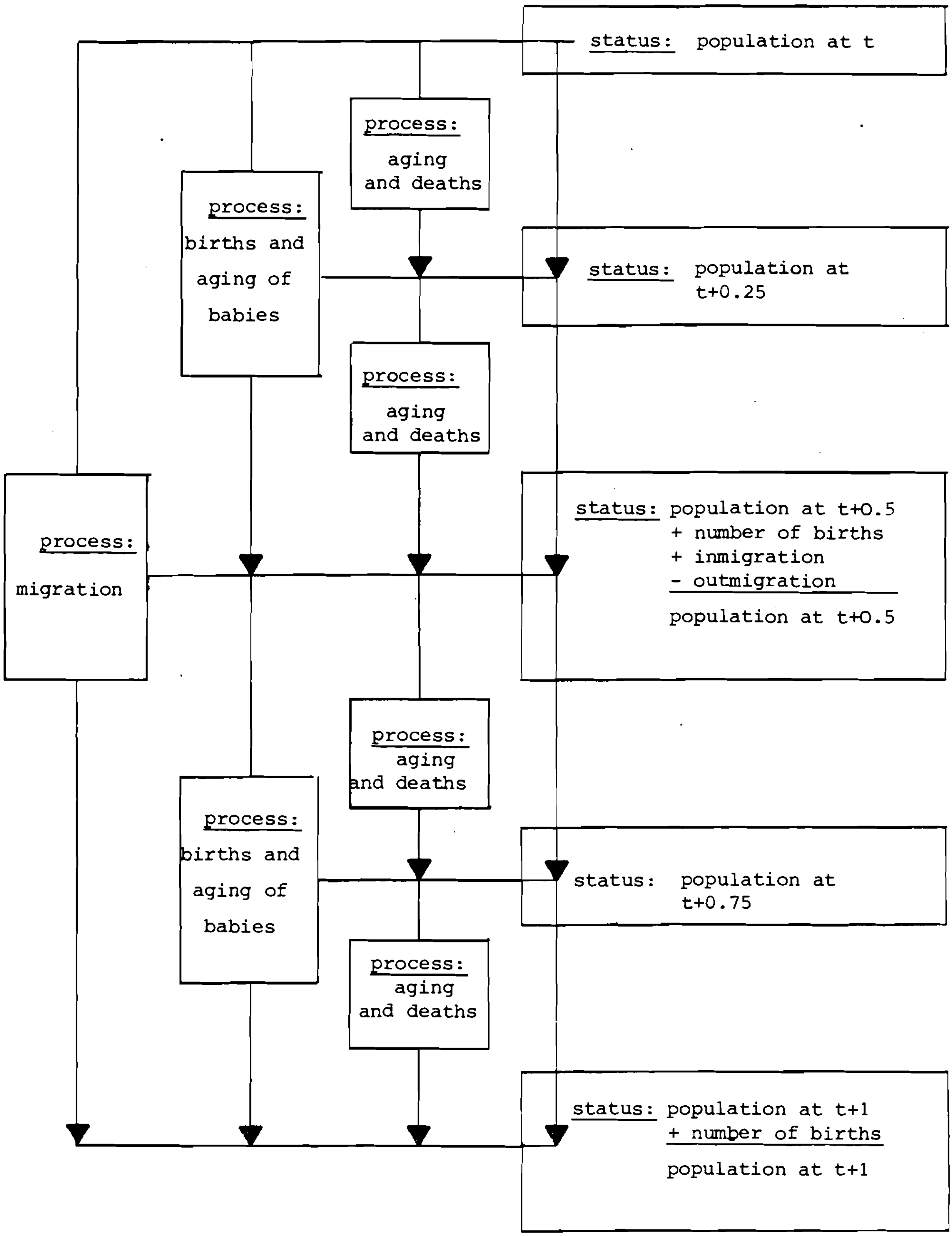

Figure 7. Aging and migration: the sequential model.

number of migrants by age between the two regions. The data input is listed in the Appendix.

The results of running the multistate projection model from this initial status in eight five-year intervals to the year 2001 as given in Willekens and Rogers (1978:67) are listed on the left-hand side of Figure 8. The sequential model was run with the same data in 40 one-year projection intervals. The results are listed on the right-hand side of Figure 8. The computer program used for this simulation is listed in the Appendix.

The comparison between the two projections shows that the deviations of mean ages and regional shares are less than 0.2 percent, and of total population levels less than 0.5 percent. It may be concluded, therefore, that both models are equivalent for practical purposes.

3.2.2 The Economic Submodel

The economic submodel predicts employment by 40 industrial sectors for each of the 34 labor market regions of North Rhine-Westphalia on the basis of sectoral employment forecasts for the whole state.

The development of regional employment is assumed to be basically determined by changes in the economic structure (i.e., the sectoral composition of the economy) and changes in the relative locational quality of competing regions.

This argument corresponds to the assumptions of shift/share analysis. This technique has been developed primarily as a comparative-static method used to examine economic development processes. In the shift/share analysis, two factors are identified: one isolates the effects of the sectoral composition of the regional economy on regional development, the other describes the relative attractiveness of the region as a location. The two factors are called the "structural" and "locational" factor.

year 2001

population

age	total	slovenia	r.yugos.
0	1211954.	81001.	1130953.
5	1105366.	77972.	1027895.
10	1070516.	76680.	993837.
15	1044993.	76582.	968411.
20	1022211.	77190.	945022.
25	974547.	75638.	898909.
30	910599.	72104.	833496.
35	883050.	70384.	812666.
40	825835.	67731.	758104.
45	918360.	74725.	844135.
50	806298.	69342.	736956.
55	599763.	56291.	543472.
60	657485.	56672.	600814.
65	632777.	54501.	578276.
70	501906.	45936.	455970.
75	330384.	31869.	298515.
80	131943.	11951.	119997.
85	145656.	9124.	136532.
total	13774651.	1085692.	12688959.

age	total	slovenia	r.yugos.
0	1170960.	81228.	1089733.
5	1097717.	77558.	1020159.
10	1096941.	77536.	1019406.
15	1055717.	76251.	979466.
20	991507.	75722.	915785.
25	937391.	73160.	864231.
30	914766.	71848.	842918.
35	914085.	71641.	842444.
40	895290.	71626.	823664.
45	828583.	70156.	758427.
50	749130.	64318.	684812.
55	721676.	61846.	659830.
60	699116.	61052.	638063.
65	624057.	55878.	568179.
70	432178.	39737.	392442.
75	316611.	29982.	286629.
80	134400.	12848.	121552.
85	148798.	9114.	139685.
total	13728918.	1081499.	12647419.

percentage distribution

age	total	slovenia	r.yugos.
0	8.7984	7.4607	8.9129
5	8.0233	7.1818	8.1007
10	7.7717	7.0628	7.8323
15	7.5863	7.0537	7.6319
20	7.4210	7.1097	7.4476
25	7.0749	6.9658	7.0842
30	6.6107	6.6413	6.6081
35	6.4107	6.4829	6.4045
40	5.9953	6.2385	5.9745
45	6.6707	6.8827	6.6525
50	5.8535	6.3869	5.8079
55	4.3541	5.1848	4.2830
60	4.7732	5.2199	4.7349
65	4.5938	5.0199	4.5573
70	3.6437	4.2310	3.5934
75	2.3985	2.9354	2.3526
80	0.9579	1.1007	0.9457
85	1.0574	0.8404	1.0760
m.ag	34.8823	36.8393	34.7148
sha		7.8818	92.1182

age	total	slovenia	r.yugos.
0	8.5291	7.5107	8.6162
5	7.9957	7.1714	8.0661
10	7.9900	7.1693	8.0602
15	7.6897	7.0505	7.7444
20	7.2220	7.0016	7.2409
25	6.8279	6.7647	6.8333
30	6.6631	6.6434	6.6647
35	6.6581	6.6242	6.6610
40	6.5212	6.6228	6.5125
45	6.0353	6.4869	5.9967
50	5.4566	5.9471	5.4146
55	5.2566	5.7185	5.2171
60	5.0923	5.6452	5.0450
65	4.5456	5.1667	4.4924
70	3.1479	3.6742	3.1029
75	2.3062	2.7723	2.2663
80	0.9790	1.1880	0.9611
85	1.0838	0.8427	1.1045
m.ag	34.9242	36.7863	34.7650
sha		7.8775	92.1225

Figure 8. Aging and migration: results of the multistate model (left) and of the sequential model (right).

The structural and locational factors of sectors s and region i for a past period t-1 to t are stated as follows, respectively (Birg et al. 1975):

$$q_{si}(t-1,t) = \frac{E'_{si}(t)}{E_{si}(t-1)} \tag{21}$$

$$r_{si}(t-1,t) = \frac{E_{si}(t)}{E'_{si}(t)} \tag{21a}$$

In these formulations, $E_{si}(t)$ is employment of sector s in region i at time t. $E'_{si}(t)$ is a fictitious employment level of sector s in region i that might have been expected if the sector had developed in the region in exactly the same way as in the whole economy, i.e., in this case in the whole of North Rhine-Westphalia:

$$E'_{si}(t) = \frac{E^*_s(t)}{E^*_s(t-1)} E_{si}(t-1) \tag{22}$$

where $E^*_s(t)$ is total employment of sector s in North Rhine-Westphalia at time t.

Using shift/share analysis for forecasting regional employment implies the crucial assumption that the locational factors observed in the calibration period will stay the same in the forecasting period. This assumption is made in most known applications (e.g., Klemmer 1973), in other applications the locational factors are held constant after extreme values have been corrected (e.g., Birg et al. 1975). Neither procedure seems to be very satisfactory.

In the model presented in this paper, an approach was adopted that makes the best use of the trend information contained in the results of the shift/share analysis, but at the same time takes account of developments that are likely to modify these trends. This is accomplished by combining effects of the shift/share analysis with a causal model relating changes of the locational factor to changes in the locational attractiveness of the regions.

To begin, for each sector s and region i two fictitious employment levels for time t+1 are calculated. One, $E'_{si}(t+1)$ in analogy with equation (22), is the employment level to be expected if all regions developed like the sectoral forecast for the whole state, i.e., irrespective of their individual previous development:

$$E'_{si}(t+1) = \frac{E^*_s(t+1)}{E^*_s(t)} E_{si}(t) \tag{23}$$

The other, $E''_{si}(t+1)$, is the employment level that might be expected if all regions continued to grow or decline at the same rate as in the previous period, provided that were possible under the sectoral forecast for North Rhine-Westphalia, i.e., if the pattern of, or relations between, regional rates of change stayed the same:

$$E''_{si}(t+1) = \frac{\frac{E_{si}(t)}{E_{si}(t-1)} E_{si}(t)}{\sum_i \frac{E_{si}(t)}{E_{si}(t-1)} E_{si}(t)} E^*_s(t+1) \tag{24}$$

Obviously, neither of the two projections is realistic as there is variation between regional rates of development, and this variation changes over time.

The model proceeds by dividing the rate of change of the trend projection $E''_{si}(t+1)$ with the help of the "ahistoric" projection $E'_{si}(t+1)$ into two multiplicative components, the structural factor and the locational factor:

$$q_{si}(t,t+1) = \frac{E'_{si}(t+1)}{E_{si}(t)} \tag{25}$$

$$r_{si}(t,t+1) = \frac{E''_{si}(t+1)}{E'_{si}(t+1)} \qquad (25a)$$

The structural factor $q_{si}(t,t+1)$ is that proportion of the rate of change of employment which is attributable to normal sectoral development, and $r_{si}(t,t+1)$ is the residual attributable to location, i.e., the locational factor.

Multiplication of the structural and locational factors and rearranging yields the employment forecast of the trend model:

$$E''_{si}(t+1) = q_{si}(t,t+1)r_{si}(t,t+1)E_{si}(t) \qquad (26)$$

In this forecasting equation, the locational factor $r_{si}(t,t+1)$ is crucial. It is valid only if the relative locational attractiveness of the region as observed in the previous period has remained the same. It can be argued that during a simulation period of only two years the locational preferences of industry as well as the attributes of regions do not change too much. However, over a number of simulation periods major infrastructure investments (or the lack of them), for example, may considerably change the attractiveness of a region compared with its previous attractiveness trend. It seems necessary, therefore, to periodically review the locational factors produced by the trend model in the light of the changes of the regional attractiveness occurring during the simulation.

The attractiveness of a region as a location for enterprises of a certain industry is represented in the model by attributes such as location, business-serving infrastructure, availability of financial aids, access to markets, labor supply and labor demand, and wage levels (see Figure 9). Similarly, as with the attractiveness for migration (cf. section 3.2.1.2), the two sets of attributes shown in Figure 9 are weighted dynamically in response to the general labor market situation in the whole state to take account of the fact that the relative importance of labor market considerations for industrial location decisions depends a great deal on the scarcity of labor.

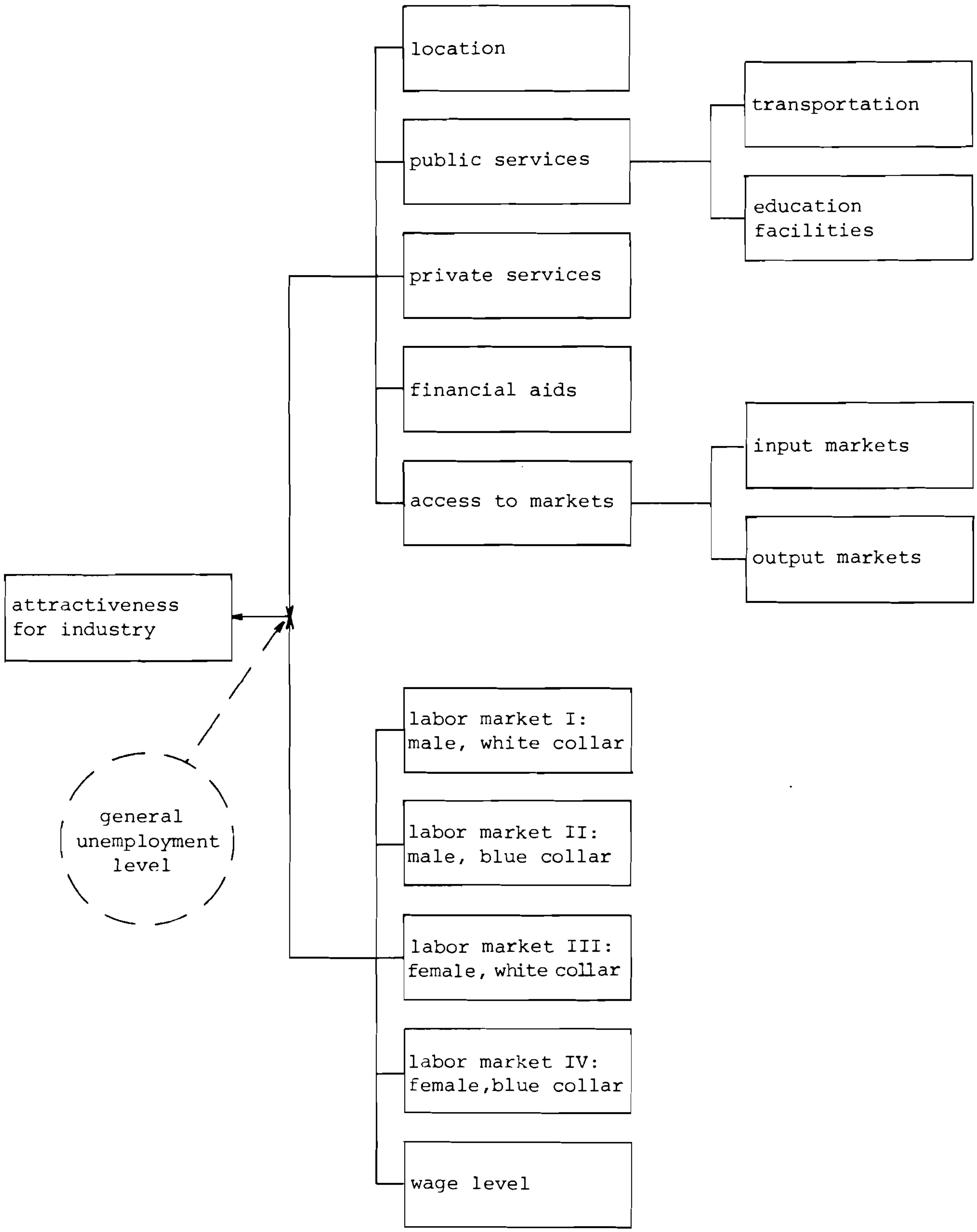

Figure 9. Attractiveness for industry.

Two alternative models are now investigated for reviewing the locational factors in each simulation period. In the first alternative, the locational factors are replaced by new locational factors $r'_{si}(t,t+1)$ estimated as a function of the current attractiveness $A_{si}(t)$ of the region i for sector s at time t:

$$r'_{si}(t,t+1) = f_s\left(A_{si}(t)\right) \tag{27}$$

The shape of the sector-specific transformation function f_s is an S-curve similar to Figure 10. By specifying upper and lower bounds r_s^{max} and r_s^{min} for f_s, the resulting $r'_{si}(t,t+1)$ are forced to more or less vary around one. For reasons of symmetry, the lower bound is computed as the reciprocal of the upper bound (Birg et al. 1975):

$$r_s^{min} = 1/r_s^{max} \tag{28}$$

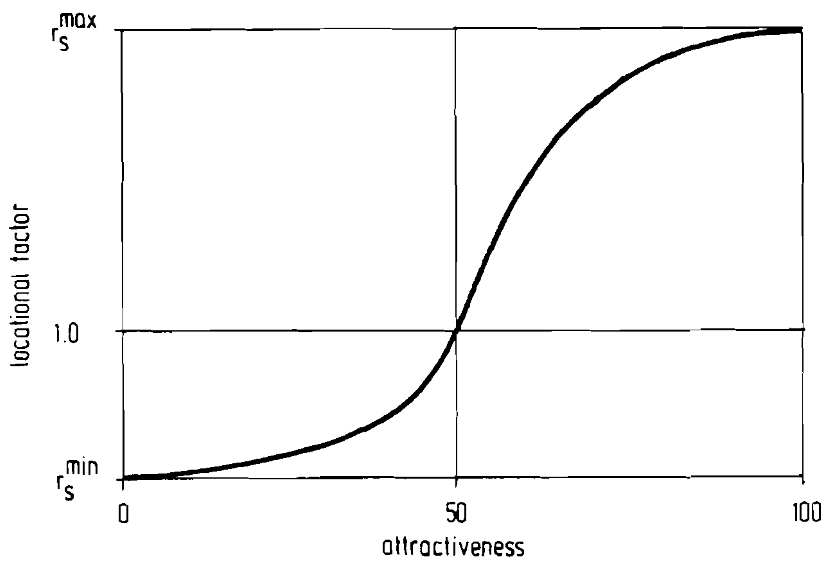

Figure 10. Locational factors as a function of attractiveness.

By specifying a wider or narrower domain for the transformation function f_s, different assumptions about the degree of dependence on locational attractiveness of industries can be introduced in the model. In the extreme case, both upper and lower bounds can be set to one indicating that there is no relation between locational attractiveness and the location decisions of that industry. This makes sense, for instance, in the case of the mining industry, which is completely dependent upon the existence of mineral deposits that do not figure in the attractiveness measure, or where locational decisions are entirely determined by political considerations and not on the market place.

An inherent weakness of the above model is that it does not utilize the information which may be contained in the locational factors of the previous period. Therefore, an alternative model was conceived using both the trend information contained in $r_{si}(t,t+1)$ and the current information on regional attractiveness contained in $A_{si}(t)$. Combining a trend model with a causal model raises the question of how to avoid double counting. If the $A_{si}(t)$ coincides with the attractiveness trend expressed by the $r_{si}(t,t+1)$, no modification of the locational factors should be made at all. To overcome this difficulty, the following procedure is used. A fictitious attractiveness $A'_{si}(t)$ is introduced describing the level of attractiveness the region might have reached if everything in it had developed in line with the previous attractiveness trend. This fictitious attractiveness is determined by extrapolating smoothed prior attractiveness values by one period. It may be considered as a kind of level of expectation. If the actual attractiveness $A_{si}(t)$ exceeds this level of expectation, the locational factor is increased by a certain margin; if $A_{si}(t)$ is less than the expected attractiveness, the locational factor is reduced:

$$r'_{si}(t,t+1) = r_{si}(t,t+1) + f_s\left(A_{si}(t) - A'_{si}(t)\right) \quad (29)$$

Again, as in the first transformation model, all estimated new locational factors are forced to vary around one by exogenously specified upper and lower bounds.

The second transformation model seems appropriate for all industrial sectors which in the past displayed a clear empirical relationship between the locational factor and attractiveness.

With all locational factors being reviewed, the final employment forecasting equation is

$$E_{si}(t+1) = q_{si}(t,t+1)r'_{si}(t,t+1)E_{si}(t) \tag{30}$$

4. CONCLUSION

In this paper the demoeconomic development of a region has been analyzed as being a highly dynamic and selective process. From this it is concluded that multiregional demoeconomic models must have a requisite level of complexity in order to grasp the variety of causes and effects inherent in real-world processes. But, however desirable, the implementation of a comprehensive modeling approach must overcome a number of serious difficulties: one difficulty lies in the limited availability of disaggregated regional data. Another difficulty is more fundamental and is related to the fragmentary character of theories and hypotheses on the development of regional settlement structures.

Seen in this framework, the simulation model presented in this paper is an ambitious undertaking, but at the same time is only a very modest and preliminary step towards a holistic and integrated approach.

The model is presently operational in an early version. Its data base is complete, and most of the parameters have been estimated. This version of the model is used as a research tool to test the validity and consistency of a number of hypotheses on long-term regional development. Although these tests are being continued, already now many encouraging results have been obtained. It is planned to report on them in the near future.

Future work will focus on testing the validity of the assumptions incorporated in the model by using different sets of regional data. The eventual aim is to use the model not only as a research tool, but also as a planning tool for forecasting medium and long-term effects of alternative regional policies.

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APPENDIX

```
      DIMENSION AG(18,2),BI(18,2),DE(18,2),TR(18,2),TRI(18,2),SAG(18),
     *PAG(18,2),PSU(18),SUM(2),BA(2),RS(2),DA(2)
C
C     POPULATION PROJECTION
C
C-----------------------------------------------------------------------
C     READ AJ AND NP, AJ - NUMBER OF YEARS PER PERIOD,
C                     NP - NUMBER OF PERIODS
C-----------------------------------------------------------------------
      READ (8,8000) AJ,NP
 8000 FORMAT(10X,F6.0,I6)
      READ (8,8010) AG,BI,DE,TR
 8010 FORMAT(10X,9F6.0)
C-----------------------------------------------------------------------
C     COMPUTING AGE-SPECIFIC FERTILITY, SURVIVAL, AND MIGRATION RATES
C-------------------------------------------------------------------------
      DO 100 J=1,2
      DO 100 I=1,18
      BI(I,J) = BI(I,J)/AG(I,J)
      DE(I,J) = 1.-DE(I,J)/AG(I,J)
      TR(I,J) = TR(I,J)/AG(I,J)
/    /

  100 CONTINUE
C---------------------------------------------------------------------------
C     POPULATION PROJECTION OVER NP PERIODS OF AJ YEARS
C---------------------------------------------------------------------------
      DO 200 IP=1,NP
      CALL AGING(AG,DE,AJ)
      CALL BIRTH(AG,BI,DE,BA,AJ)
      CALL AGING(AG,DE,AJ)
      DO 210 J=1,2
      AG(1,J) = AG(1,J)+BA(J)
  210 CONTINUE
      CALL MIGRAT(AG,TR,AJ)
      CALL AGING(AG,DE,AJ)
      CALL BIRTH(AG,BI,DE,BA,AJ)
      CALL AGING(AG,DE,AJ)
      DO 220 J=1,2
      AG(1,J) = AG(1,J)+BA(J)
  220 CONTINUE
  200 CONTINUE
C---------------------------------------------------------------------------
C     OUTPUT SPECIFICATIONS
C---------------------------------------------------------------------------

        ⋮

      STOP
      END
C
C
C
      SUBROUTINE BIRTH(AG,BI,DE,BA,AJ)
C
C     COMPUTING BIRTH AND AGING NEW-BORN BABIES FOR HALF A PERIOD
C
      DIMENSION AG(18,2),BI(18,2),BA(2),DE(18,2)
C
      DO 100 J=1,2
      BA(J) = 0.
      DO 100 I=1,18
      BA(J) = BA(J)+AG(I,J)*BI(I,J)*0.5*AJ
  100 CONTINUE
      DO 110 J=1,2
      BA(J) = BA(J)*DE(1,J)**(0.5*0.7071*AJ)
  110 CONTINUE
      RETURN
      END
```

```
C
C
C
      SUBROUTINE AGING(AG,DE,AJ)
C
C     AGING REGIONAL POPULATION FOR A QUARTER OF A PERIOD
C
      DIMENSION AG(18,2),DE(18,2),GW(18,2),IV(18,2)
C
      DO 100 J=1,2
      DO 110 I=1,18
      IV(I,J) = 1
  110 CONTINUE
      DO 100 I=2,17
      H = AG(I,J)
      IF (H.GT.AG(I-1,J).AND.H.GT.AG(I+1,J)) GOTO 10
      IF (H.LT.AG(I-1,J).AND.H.LT.AG(I+1,J)) GOTO 10
      GOTO 100
   10 IV(I,J) = 0
  100 CONTINUE
      DO 120 J=1,2
/    /

      DO 120 I=1,18
      AG(I,J) = AG(I,J)*DE(I,J)**(0.25*AJ)
  120 CONTINUE
      DO 130 J=1,2
      DO 130 I=1,17
      IF (IV(I,J)) 20,20,30
   20 GW(I,J) = AG(I,J)*0.2*0.25*AJ
      GOTO 130
   30 GW(I,J) = (AG(I,J)+AG(I+1,J))*0.1*0.25*AJ
  130 CONTINUE
      DO 140 J=1,2
      AG(1,J) = AG(1,J)-GW(1,J)
      DO 150 I=2,17
      AG(I,J) = AG(I,J)+GW(I-1,J)-GW(I,J)
  150 CONTINUE
      AG(18,J) = AG(18,J)+GW(17,J)
  140 CONTINUE
      RETURN
      END
C
C
C
      SUBROUTINE MIGRAT(AG,TR,AJ)
/    /

C
C     COMPUTING MIGRATION FOR ONE PERIOD
C
      DIMENSION AG(18,2),TR(18,2),TRI(18,2)
C
      DO 100 J=1,2
      DO 100 I=1,18
      TRI(I,J) = AG(I,J)*TR(I,J)*AJ
  100 CONTINUE
      DO 110 I=1,18
      AG(I,1) = AG(I,1)+TRI(I,2)-TRI(I,1)
      AG(I,2) = AG(I,2)+TRI(I,1)-TRI(I,2)
  110 CONTINUE
      RETURN
      END
```

00010	AJ	NF	1	40									
00020	POP	SL1	67800	74100	70700	60100	62900	66500	67100	62900	39500		Population of Slovenia
00030	POP	SL2	47900	51300	46100	39600	29500	21700	14400	7100	3600		
00040	POP	YU1	847900	905200	808100	617400	725500	774000	728400	633300	392400		Population of Rest of Yugoslavia
00050	POP	YU2	437100	453800	389300	325800	230600	180000	120900	61200	39300		
00060	BIR	SL1	0	0	5	953	4444	4204	2758	1438	308		Births in Slovenia
00070	BIR	SL2	34	15	0	0	0	0	0	0	0		
00080	BIR	YU1	0	0	54	16335	63828	57477	32261	14903	4729		Births in Rest of Yugoslavia
00090	BIR	YU2	940	324	0	0	0	0	0	0	0		
00100	DEA	SL1	417	32	21	31	47	45	67	77	76		Deaths in Slovenia
00110	DEA	SL2	171	268	369	513	763	1036	1088	1041	733		
00120	DEA	YU1	19051	606	386	534	885	1227	1277	1313	1127		Deaths in Rest of Yugoslavia
00130	DEA	YU2	1700	2896	3743	5492	6407	8652	8715	6843	5639		
00140	MIG	SY1	192	170	105	310	451	368	252	111	40		Migrants from Slovenia to Rest of Yugoslavia
00150	MIG	SY2	26	34	29	35	28	19	16	5	4		
00160	MIG	YS1	231	150	127	419	680	392	255	143	72		Migrants from Rest of Yugoslavia to Slovenia
00170	MIG	YS2	41	59	80	66	36	14	12	12	3		

Source: Willekens, F., and A. Rogers (1978) *Spatial Population Analysis: Methods and Computer Programs*. RR-78-18. Laxenburg, Austria: International Institute for Applied Systems Analysis. Page 201.

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