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RURAL SETTLEMENT PATTERNS

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PREFACE

This paper identifies the forces that shape the settlement system in rural regions, describes the process of restructuring of the system, and presents a model simulating this process.

It synthesizes concepts from many sources and forms a basic framework for further research.

Rural settlement problems require more attention from reserchers and research institutions. In the majority of countries in the world a considerable share of the population still lives in rural areas. This creates serious economic, social, cultural, and institutional problems. At present, there is very little literature that throws light upon such problems, and suggests programs for developing the rural settlement to suit modern conditions.

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INTRODUCTION

Very little has been written on settlement systems in rural regions in comparison with the significant number of publications that have appeared on urban systems. The literature that exists is mainly devoted to the history of individual rural settlements and their spatial forms (geometry). Rural settlement patterns and their dynamics are rarely considered and most of the publications dealing with this subject are of a descriptive character. Little theoretical work has been done, especially with regard to modeling.

Since little relevant theory exists, it is not surprising that many of the policies and plans for rural areas have been made without a sound theoretical base. It is generally believed that central place theory can be used as the starting point for the theory and planning of settlement systems in rural regions and, in part, this is justifiable. Undoubtedly, several concepts of central place theory can be helpful when considering the problem. However, the theory as a whole does not explain the behavior of rural settlements. This is obvious since it has been developed to explain the size, number and distribution of towns. Farms are assumed to be uniformly distributed over space. Besides, it is static in nature and cannot provide an adequate basis for development planning.

Appeals for a theory of the development of settlement systems in rural regions appear at an opportune time. We are witnessing substantial changes in rural areas, which are multidimensional (demographic, economic, social , technological, organizational, etc.) and break the continuity of the previous development process.

The changes are spatially differentiated. Some villages are continuously increasing, undergoing industrialization and urbanization, and enjoying a growing range and level of services. Such villages are usually located within close proximity of large urban-industrial agglomerations. On the other hand, villages in remoter areas often suffer from continuous depopulation, decreasing job opportunities, a low level of services and become more and more unsuited to modern life. The process of natural adjustment is in fact a process of decline accompanied by undesirable economic and social conditions.

In the USA there are rural areas where population decline has been reversed. In some cases this occurred in the 1960s, but it was not until the 1970s that nonmetropolitan areas as a whole reached a turning point where they were not only retaining residents but also gaining population. The number of persons moving from metropolitan areas began to exceed the number of inmigrants from nonmetropolitan areas.

When attempting to formulate a theory of the settlement system in rural regions, one should be aware of the great variety of conditions that occur in the rural areas of the world. Rural areas in developing and developed countries can hardly be compared. Substantial differences also exist among developed countries. Take, for instance, rural areas in the USSR and Western Europe, or in Western Europe and the USA.

In this paper only rural areas in which villages form the basic pattern of the settlement will be considered. Such a pattern is common in most European countries, and originates from the medieval period, frequently also from a medieval scale of economy and mobility. In such areas, one can expect a further population decline, which will mostly affect small dispersed villages in remote areas with job opportunities, housing conditions and services below the recent requirement level.

Rural planners are now faced with the problem of devising programs for adjusting the settlement pattern to modern economic conditions. The theoretical work will help to determine: how the restructuring process might be accelerated to reduce the period in which the rural population experiences unsatisfactory living conditions and how the process may be directed to ensure the optimal use of scarce resources in rural areas.

There are added advantages to expressing theoretical concepts in the form of models. Dynamic simulation models that may be used to reproduce the development processes of the rural settlement pattern are presented in this paper. Such models allow different sets of projections about settlement system growth and behavior to be generated under alternative assumptions. Because of their dynamic nature they permit the long-term consequences of actions such as the establishment of key villages or the demolition of certain hamlets to be studied.

THEORETICAL FRAMEWORK

The settlement system in rural regions is being shaped by various forces. When trying to explain the development of the system, these forces and their interaction should be identified. In addition, the socioeconomic conditions in which the interaction occurs and which constitutes the environment of the system should be defined. Four types of interaction can be distinguished.

Interaction of Intrafarm Location Forces and External Forces

There is interaction between intrafarm location forces and external forces, i.e., village infrastructure, the market, and services (Whitby and Willis 1978, pp. 228-229).

The efficiency of farms depends to a large degree on their spatial structure, i.e., the distance between home and fields. The greater the distance, the higher are the farmer's inputs of time and materials. British farmers, for instance, spend about one-third of the total working time in movement. In the Netherlands, over half of the working hours of horses and tractors is spent transporting materials and production (Chisholm 1968, p.49) and, as a result, the more distant plots are cultivated less intensively. With each additional kilometer from the farmstead, there is a consequent reduction in output per hectare.

Farm efficiency may be considerably improved by the consolidation of holdings, i.e., amalgamation of scattered plots into compact holdings around farmsteads. The process of consolidation changes the spatial pattern of villages. New farms are built in the midst of their fields, villages become less concentrated and overcrowded, and occasionally rural slums are removed.

Hence, intrafarm location forces favor the dispersion of rural settlements, but this tendency is opposed by external forces. The provision of public utilities (water mains, sewage, electricity) requires infrastructural investment, which is very expensive. Investment inputs increase with the increase in spatial dimensions of settlements. The provision of infrastructural facilities then attracts farmers to the location and favors the concentration of farms. Farmers are therefore able to reduce their investment inputs.

The farms have recently become more involved in economic circulation and their production needs as well as the consumption needs of the rural population have increased. The satisfaction of these needs requires improved access to the market and services.

Services are economically efficient if the facilities operate on the proper scale. For each kind of service there exists a threshold value, defined as the minimum population needed to support the facility. The operational costs of the facility decrease with its size until the inflection point of the U-shaped cost curve is reached. Only larger villages have a population sufficient to meet the efficiency requirements.

The question arises as to which forces are stronger: intrafarm, or external? In recent years external forces have generally been stronger. Transactions with the nonfarm sector have grown rapidly in the last few decades and the demand for domestic requirements (food, technical and social services) has grown even more rapidly. At the same time, intrafarm location forces are weaker now than formerly. Modern farm equipment facilitates transportation between home and fields which is now a less weighty cost component. The location of farm buildings in the midst of the fields has also become less advantageous.

Summing up, the interplay between intrafarm location forces and external forces has resulted in a tendency for rural settlements to become concentrated in certain areas and to increase in size.

The Interplay between Villages

The interaction of villages results in spacing between them, which, according to classical central place theory, is regular. In Lösch's theory, the regularity is triangular. The triangular arrangement of production sites and hexagonal market areas represents an optimum, assuming that there exists an unbounded plain settled at a uniform density and equally accessible in all directions.

If the properties of the rural settlement pattern are to be examined, the assumption of uniformity must be relaxed and rural areas should be considered to be differentiated.

The basic question is: under which circumstances is the regular pattern of rural settlemets not be expected?

J.C. Hudson (1969) using the analogy of plant ecology, argues that in the first two phases of the development process, i.e., in colonization and spreading, the conditions necessary for regularity do not exist. In these phases, irregularities may occur. When the clone colonization is dominant, settlement clusters develop. Conditions of regularity occur in the third phase, with the increase of population density when dwellers compete for space. It is this competition which drives the settlement pattern towards regularity.

The regular pattern is also unlikely when farms vary greatly in size. In this case, settlement clusters develop around the large farms. Clustering is most frequently accompanied by an increase in the density of the farming population.

The increasing intensity of agriculture is yet another cause of irregularities in the rural settlement pattern. As the intensity increases, the size of rural settlements becomes more sensitive to distance from the regional market center.

R.M. Sarly (1972) established the relation between total cost at which the settlement is producing (representing the intensity), settlement size (radius), and distance from market. He found that in a less developed, unurbanized agricultural region with low total settlement costs, the rate of increase of the settlement radius away from the regional market center is slow. This results in small variation of the settlement sizes. On the other hand, in a highly developed urbanized agricultural region with high total settlement costs, the rate of increase of settlement radius with the distance from the market center is relatively high. As a consequence, the variation of settlement sizes is larger. The agricultural settlement production units situated close to the market center happen to be smaller, while those located further away, are larger.

Parallel to the processes that disturb the regular pattern of rural settlements, there are also processes that make the pattern more orderly over time. One of these is the process of farm abandonment, which has the effect of increasing farm size.

Classical central place theory does not take into account the hierarchy of the rural settlement. It assumes the existence of a basic uniform layer of rural population on which several layers of cities are superimposed (Beckmann 1958). This hierarchy is relevant only to cities.

The differentiation of rural areas is the basic assumption of this paper. However, is it possible to discover a hierarchical pattern in the differentiation?

H.C. Bos (1965, p. 89) has defined the conditions necessary for a hierarchy of urban-industial centers:

1. Agricultural production and population are spread over a given area.
2. Production from nonagricultural industries is characterized by indivisibilities leading to economies of scale.

3. Transportation of goods and services gives rise to transportation costs.

All three conditions are present in rural areas. Indivisibilities and scale economies occur also in agricuture, e.g., in irrigation systems, antierosion practices, technical services. In many villages the nonagricultural sector developed showing the same characteristics. Sufficient conditions are also present, among which organization of agricultural production may be included. Its influence can be seen clearly in the pattern of rural settlements in the USSR. S.A. Kovalev (1975) states that the principal system of rural settlements consists of a central settlement and a number of satellite settlements. On the lower levels, depending on the size and specialization of the agricultural enterprise, there are supplementary settlement units, e.g., narrowly specialized satellite settlements, branches of satellite settlements, seasonal settlements on distant pastures or cropland.

Hence, a hierarchy can be found in the pattern of rural settlements, although it has only a local, narrow range. It is incomplete and lacks uniformity since it has no primate village or rural town on a level higher than the local level.

The composition of goods and services offered by rural settlements of the same level contains some common items, as well as some specialized items. The specialization of settlements is revealed in such a composition. G. Rushton (1974) argues that in the case of the differentiation of composition in urban centers of the same level, the concept of a class of centers belonging to a level in a hierarchy loses all meaning, and from theoretical point of view, only a continuum remains. Whether or not his relates also to local hierarchies of rural settlements is open to discussion.

The Interaction Between Rural and Urban Settlements

The interrelations between villages and towns are numerous: migrations, economic transactions, provision of services, cultural impacts.

Nowadays a characteristic interaction occurs at the extremes of the urban hierarchy: around metropolitan centers and around small towns. Villages located immediately adjacent to metropolitan centers experience the highest rates of population growth. Simultaneously, their functions undergo changes and become more and more urban in character. In this way, villages are involved in the suburbanization process and the annexation of villages to metropolitan areas is the logical effect of this process.

The extent of the impact of small towns on villages depends on the socio-economic situation of these towns; some develop and expand, while others decline or stagnate. Many policies have been elaborated to stimulate their revitalization (Tweeten and Brinkman 1976, Bryce 1977).

In general, the role of small towns in the life and development of villages is decreasing. The functions that they previously performed have shifted upwards in the urban hierarchy and a process of disintegration at the lower levels of the hierarchy is now taking place. This is accompanied by reintegration, resulting in new hierarchical relations, during which the functions of small towns are taken over by medium-size towns.

The socioeconomic situation of the population in rural areas and in small towns may worsen in the processes of disintegration and reintegration. One way to counteract this tendency is to improve the accessibility of the populations of rural and small towns to employment and services in medium-size towns, which requires a considerable improvement of the rural transportation system. A recent simulation experiment (Domanski, 1979) showed that, under certain conditions and within certain limits, improvement of the accessibility to larger towns may give better results in terms of spatial equity than the interregional dispersion of investments, which creates new job opportunities and service facilities in less developed regions (Figure 1.)

The forces shaping the rural settlement pattern mentioned so far originate from and act within the national settlement system. They are set in motion, modified, strengthened, or weakened by the socioeconomic factors and conditions of the environment of the settlement system.

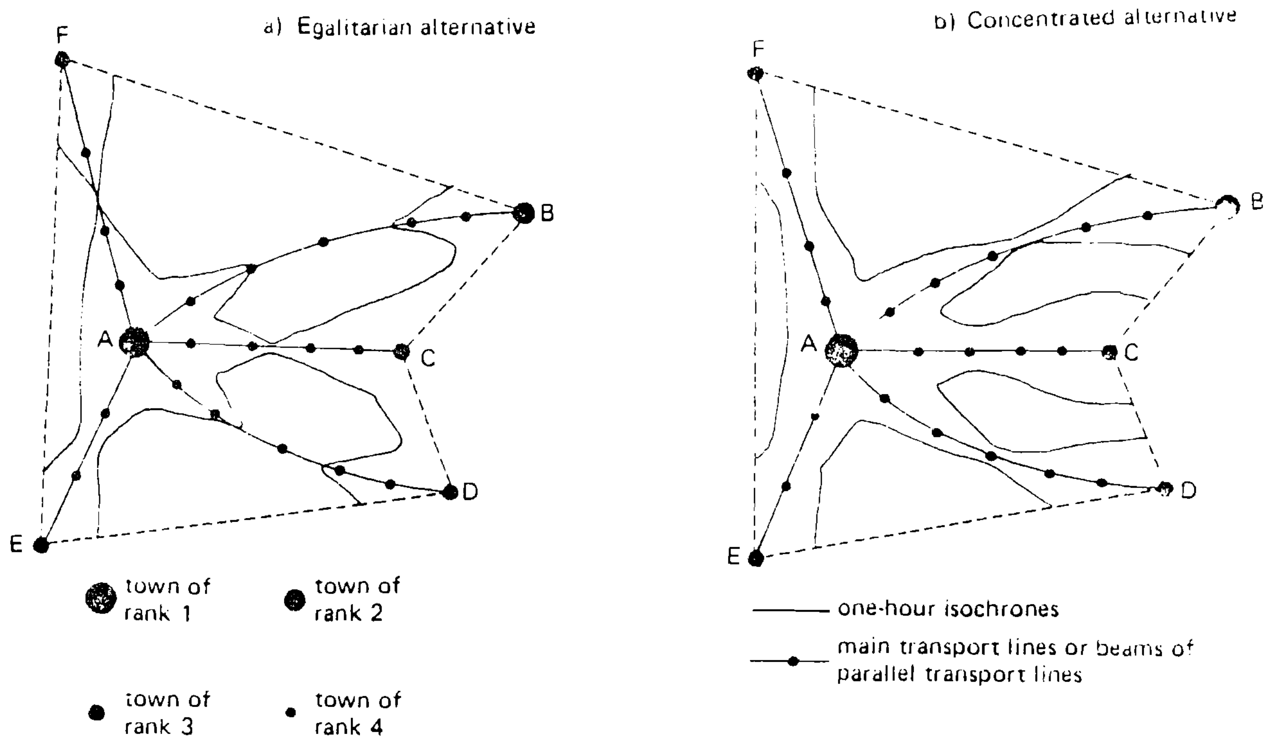

Figure 1. Areas accessible to regional centers within one hour.

The Interplay Between the Rural Economy and the Socioeconomic Environment

The socioeconomic environment, through its demand for agricultural products, exerts an influence on the level and structure of production in rural areas. It also influences industrial production, since some agricultural products must be processed at the source of supply.

Agricultural and industrial production naturally affect employment in rural areas and consequently the population and settlements. The sequence of interactions extends to both technical and social services, the development of which is shaped by agricultural and industrial development and population growth.

In addition to economic linkages, the interaction between the rural economy and the socioeconomic environment also influences important social and cultural phenomena, such as changes in the consumption pattern of the rural population and in its attitude towards employment in the agricultural sector.

POLICIES: KEY VILLAGES

Rural settlement patterns in European countries as well as in other parts of the world are characterized by great dispersion. There exist many small settlement units: villages, hamlets, single farms, which for the most part are poorly supplied with services, both technical and social. Low economic efficiency, related to the small scale of the facilities needed in such settlement units, is an obstacle to improving the provision of services.

Poor supply of services retards development of agricultural production and hinders improvement of the quality of life of the rural population. It is, therefore, a subject of deep concern to rural planners and policy makers.

This problem can be solved by selective development of rural settlements. A limited number of villages conveniently located, with regard to transportation links to neighboring villages, should be selected and the services frequently demanded by rural areas should be developed in these villages. In Great Britain, where this idea has been implemented, such villages are called key villages.

There are various forms of key villages (Woodruffe 1976). Besides villages-service centers, which are the most frequent form, there are villages associated with public investment in facilities (education, health) and with residential developments. Others are identified as possible growth points for industry. It is suggested (H.D. Clout 1972, p.142,146) that key villages have some typical set of facilities (e.g. water mains, electricity, sewerage, primary school, post office, general store, public house). As the resident population increases, the range of services provided widens (hairdresser, doctor, electrical goods shop, hardware store, secondary school etc.).

The remaining villages and hamlets will survive as commuter satellites around key villages or around not too distant towns. Those, however, with poor access and depreciated buildings face decline in the future. This will be a rather lengthy process with immense frictions, unless local and regional authorities can create a social climate fovoring the acceleration of decline.

Farmers living on large farms located in the midst of fields may remain there, at least for a longer time period. Who, then, will reside in key villages in such cases? These will be: farmers from smaller farms, employees connected with the nonagricultural sector in the villages, and employees commuting to towns. It is conceivable that some key villages will have fairly large service facilities and a relatively small population living on the spot. The facilities would then be supported by the population living in neighboring villages and hamlets. The rationale of such a pattern is that the places suitable for the location of services may be less suitable for housing purposes.

The planning problem consists in the rational selection of key villages and the determination of their sizes and service functions. Due to a large number of key villages and high capital requirements, the solutions deviating from the rational solutions would mean great losses.

The development of key villages will exert an influence upon small towns. Small towns serving rural areas may be chosen as key villages. Others will depend on nonagricultural sources of existence and on improvement of the accessibility to prospering towns.

Medium-size towns playing the role of regional or subregional centers will also be affected by the rationalization of the rural settlement pattern. They will have to assume the functions of declining small towns and meet the growing demands of the rural population. In doing so, they will tighten connections with rural areas and their distribution will therefore tend to be more uniform because of the accelerated growth of smaller regional and subregional centers.

CONDITIONS OF TRANSITION

The analysis presented above leads to the conclusion that the future pattern of settlements will undergo essential changes at the lower levels of the hierarchy. It would seem probable that the pattern may take a form similar to that presented in Figure 2. The restructured hierarchy diverges twofold from the regular hierarchy drawn after the fashion of central place theory:

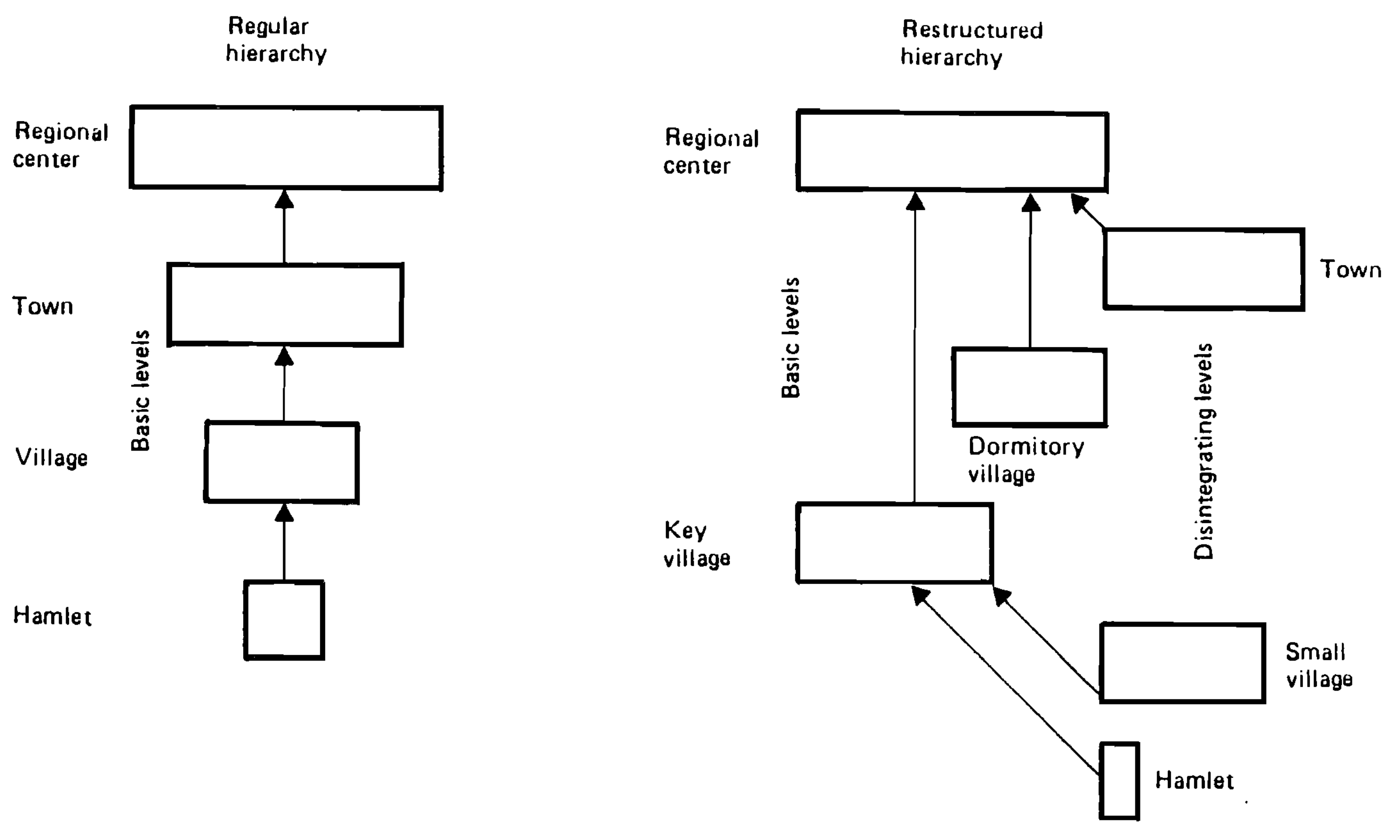

Figure 2. Restructuring of the settlement hierarchy in rural regions.

a) the number of basic levels is smaller, and
b) disintegrating levels appears.

The restructured hierarchy expresses planning concepts supported by some information from countries that have begun to apply the policy of rationalization, but it lacks a sound theoretical basis. It may be possible to justify a transition from one to another hierarchy by indicating the necessary and sufficient conditions. Critical analysis of these conditions would allow one to ascertain whether or not the transition is realistic and whether or not the planning concepts were right.

In Table 1 some of the necessary and sufficient conditions required for the transition from a regular to a restructured hierarchy are identified. Comments relating to Table 1 are given below.*

Table 1. The conditions of transition to a new hierarchy.

Conditions	Consequence
1. Dense network of small towns	Selective growth and decline
2. Increase in the scale of profitable production and services	Increase in threshold of goods, enlargement of the range, decrease in the number of small towns really needed, increase in their spacing
3. Lengthening of the distance of cheap journeys and freight transport	Increase in accessibility of medium-size cities (regional centers), increase in mobility of rural population
4. Quantitative and qualitative increase in the demand of the rural population, multipurpose shopping trips	Small towns are unable to meet the demands of the rural population
5. Occurence of the growth potential of medium-size towns (regional centers)	Taking over of functions performed so far by small towns, increase in the number of medium-size towns, decrease in their spacing

*Readers interested in the subject are refferred to Parr (1978).

In the period after the formation of the basic pattern of rural settlements, a considerable shift in the scale of profitable production and services occured. A constant increase in scale was witnessed, with the following consequences: the threshold of profitable production and services increased, the range of goods enlarged, the number of really necessary small towns decreased and their spacing increased. The inefficiency of small towns and the decline of some of them is probably the most dramatic consequence. In order for all these consequences to occur, it was necessary for the function expressing economies of scale in terms of lower costs to change in a specific way. Its minimum had to shift to the right and fall in relation to its former position (Figure 3).

Transport costs have changed in an analogous way and the distance at which they reach the minimum has lengthened (Figure 3). Towns have become more accessible and the mobility of the rural population has increased. The production potential created by

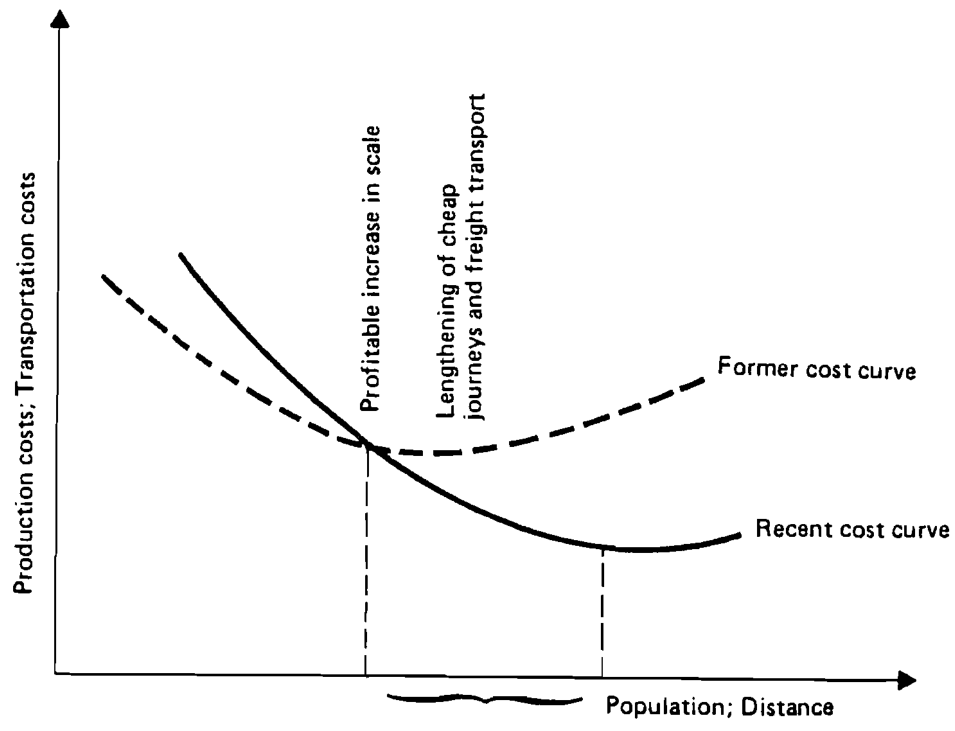

Figure 3. The hypothetical role of scale and transportation in restructuring a settlement hierarchy.

the shift in profitable scale has been realized by more effective and cheaper transport.

The consumption demand of the rural population has increased considerably and today it does not differ as much from that of the urban population as it did several decades ago. Small towns, for the most part, are no longer able to meet this demand. The production demand has also increased. Farms need more machinery, fertilizers, chemicals, electrical goods, and so on. In addition, the purchasing modes of the rural population have changed. Trips to shopping centers have become multipurpose. Farmers prefer larger centers even if they are more distant and do not stop in small towns on the way.

The functions performed so far by small towns will be taken over by medium-size towns (regional centers) and--also partly, by key villages. Therefore, regional centers should have the potential of further growth. As a consequence, the number of medium-size towns will increase (through the growth of some smaller towns) and their spacing will decrease. Thus, the development trends of medium-size towns will be reversed to that of small towns.

A cursory glance at the conditions for achieving a transition from a regular to a restructured hierarchy seems to indicate that the transition is possible and realistic. However, the problem requires further study.

MODELING THE DEVELOPMENT OF THE RURAL SETTLEMENT PATTERN

Extensive literature exists on dynamic simulation embracing methodological work as well as applications in specific fields. Applications to urban and regional economic problems, i.e. in fields related to the subject of this paper are particularly worthy of attention. Significant achievements have also been accumulated in simulating spatial diffusion processes, particularly the diffusion of innovation.

While numerous simulation studies devoted to individual cities have been undertaken, attempts to simulate the system of cities are rare. Recently, however, research has been carried out to create central place dynamic theory in the form of simulation models. Significant results have been achieved by R.W. White (1977, 1978) and P.M. Allen and M. Sanglier (1979). Earlier, R.J. Bennett (1975) elaborated a sophisticated methodology for modeling regional development including both time and space dimensions. However, Bennett does not consider the system of cities. Nevertheless, his methodology has broad applicability and is also inspiring for those studying the system of cities.

The author of this paper was unable to find any publication on simulation of rural settlement patterns. Fortunately, there are some sources of inspiration available, among which the three above-mentioned works are especially stimulating.

In this section the rural settlement pattern is modeled on the basis of the theoretical framework outlined above and the methodology developed by R.J. Bennett (1975). Some of the characteristics of the settlement system in rural regions are described as they change over time and space and an econometric type of model is applied using difference equations.

The following variables are included in the model:

- A = gross agricultural production;
- A^s = agricultural production sold by farms;
- B = regularity of spacing of villages (standard deviation of distances between villages);
- C = net receipt of commuters;
- D = distance to towns interacting with village x;
- E = employment (recounted in full-time employees);
- E^c = employment in towns interacting with village x;
- F = soil quality (weighted mean of the percentages of quality classes);
- G = differences between towns and village x in per capita consumption (personal and collective) per hour of work;
- H = historical factor influencing the size of village x (0; 1 variable);
- I = gross industrial production;
- J = number of persons entering the regional labor market after completing a technical or academic

education;

K = investments;

L = land passing from the agricultural to nonagricultural sector;

M = net migration;

N = employment in nonagricultural sector;

P = population;

P^c = population of towns interacting with village x;

P^u = inhabitants of village x having urban occupations;

Q = measure of the dispersion of village (measure of H. Steinhaus);

R = per capita income of rural population;

S = value of services consumed;

T = measure of terrain relief;

U = number of towns in a region; and

V = variation in the size of villages (standard deviation of the number of inhabitants).

The variables represent the values of individual attributes observed at time t and location x.

The model takes the form:

$$S_{tx} = a_1 + b_1P_{tx} + c_1R_{tx} + d_1Q_{tx} \quad , \qquad (1)$$

$$B_{tx} = a_2 + b_2V_{tx} + c_2U_{tx} + d_2T_{tx} \quad , \qquad (2)$$

$$V_{tx} = a_3 + b_3D_{tx} + c_3F_{tx} + d_3H_{tx} + M_{tx} \quad , \qquad (3)$$

$$N_{tx} = a_4 + b_4P^c_{tx} + c_4D_{tx} + d_4S_{tx} + g_1I_{tx} \quad , \qquad (4)$$

$$L_{tx} = a_5 + b_5P^u_{t-1x} + c_5N_{t-1x} + d_5S_{t-1x} + g_2I_{t-1x} \quad , \qquad (5)$$

$$C_{tx} = a_6 + b_6E_{tx} + c_6P_{tx} + d_6C_{t-1x} + g_3E_{tx} \quad , \qquad (6)$$

$$M_{tx} = a_7 + b_7E_{tx} + c_7E_{t-1x} + d_7E_{t-1x-1}$$

$$+ g_4M_{t-1x} + h_1G_{tx} \quad , \qquad (7)$$

$$E_{tx} = a_8 + b_8E_{t-1x} + c_8E_{t-1x-1} + d_8A_{tx} + g_5I_{tx} + h_2S_{tx} \quad , \qquad (8)$$

$$P_{tx} = a_9 + b_9P_{t-1x} + M_{tx} \quad , \qquad (9)$$

$$R_{tx} = a_{10} + b_{10}A^S_{tx} + c_{10}N_{tx} \quad . \qquad (10)$$

The model represents the spatio-temporal evolution of the settlement system in the rural region. Among its exogenous variables there are terms expressing lags, conditions in contiguous areas, and policy instruments.

Estimation of the model's coefficient values requires time-series data for small spatial units, which are not easy to obtain. This, as well as the methodological complexity makes the estimation extremely difficult. However, one of the ways to reduce the difficulties is to adopt single-equation estimates.

The model can be used to produce a set of forecasts of settlement system development in rural regions. When producing the forecasts, one aims to minimize forecasting errors; namely, to minimize the difference between forecasted and actual evolution of the settlement system.

During the evolution of the actual settlement system, changes in the strength, direction, and form of relationships between elements and their characteristics occur. Hence, it is important that the model accounts for such changes. The model can do so if the parameters that make up the transformation function can be changed.

Parameter variation is needed to express both natural behavioral trends as well as changes induced by policy. By linking the observed shifts in the parameter values to policy changes, one can obtain information about the effectiveness of the policy applied.

The above model describes various elements of the settlement system in rural regions. Two of these elements--employment and population--will be further developed in the next section. Special attention will be given to their interrelations.

THE MODEL OF RESTRUCTURING SETTLEMENT SYSTEMS IN RURAL REGIONS

In this section a model of restructuring settlement systems in rural regions is presented. Restructuring is used in the sense of changes to the locational and hierarchical pattern of the settlement system that occur because of the growth of some elements of the system, the shrinking of others, and the shifting of elements between the hierarchical levels. This also implies that there will be changes in the pattern of mutual interaction between elements.

In general, the process of restructuring results in the emergence of key villages; the decline of small villages, hamlets, and small towns; and the growth of regional urban centers. Since key villages are the settlement units that, rural planners hope, will help in rationalizing the whole rural settlement pattern, most attention is given to the emergence of this type of village. Actual developments may deviate from this generalized picture.

The process of the emergence of key villages may be natural or planned. In the former case, economic laws work without the intervention of a planner; in the latter case such intervention occurs. The planning mechanism is used to obtain a better selection of key villages from the multitude of rural settlements, a better shaping of their functions and spatial structure, and an acceleration of growth.

Planning, however, cannot be arbitrary. It should first reveal natural processes and then evaluate them but should not hinder these processes if their direction is consistent with the objectives, and should correct them if the direction deviates from the objectives. Correction, however, can only be successful if the planner understands the mechanism of natural processes. In this section an attempt is made to reproduce this mechanism.

Structural changes, because of their complexity, are extremly difficult to model. The difficulties may be overcome if one applies the relevant theory and methodology. Among the theories that may be applied, Prigogine's theory of self-organization in nonequilibrium systems (Nicolis and Prigogine 1977) seems to be particularly promising. It has been already successfully applied in economic geography by P.M. Allen and M. Sanglier (1979), who have elaborated a dynamic model of growth in urban systems. In this section the conceptual framework of Allen and Sanglier is adopted and extended to the rural settlement pattern.

The model of restructuring the settlement system in rural regions can be characterized as follows. It is based on the assumption that the evolution of the settlement system results from the mutual interaction of the spatial distribution of economic activities and of the population. The distribution of economic activities can be reflected in the distribution of employment. Thus, in the model employment may be substituted for economic activities and it may be related to population. The increase in employment is followed by an increase in the population. This, in turn, creates new resources of labor, new markets, and new employment opportunities. The impact of employment on population opens the consecutive cycle of mutual interaction. In order to reflect interaction in the model, a mechanism of positive feedback operating between the spatial distribution of employment and population should be incorporated.

Mutual interaction creates conditions in which self-organization of the system can occur. It may start with small changes in density occurring during successive instabilities. These changes are thereafter amplified by the interaction between the elements of the system. Through the cumulative causation and multiplier mechanism, interaction eventually leads to a qualitative change in the macroscopic structure of the system, (Figure 4).

The rural economy is disaggregated into three sectors: agriculture, industry, and services. Agriculture is a basic function of a rural region. It is an activity that is included in each settlement. In some settlements the food-processing industry is also included. Key villages are distinguished from other villages and hamlets because they include service activities. Services can have a dual function. They can be required for agricultural production as well as for the rural population. Their impact on population growth is manifold. It is exerted through the employment of personnel needed to run service facilities; through the intensification of agricultural production, which may require new workers and specialists; and through the attraction of people from small villages and hamlets, who do not have access to service facilities.

In the initial state of the settlement system, the number of the population is assumed to correspond to the economic activities. This state is being changed due to two factors: the introduction of a new activity to a settlement unit, which causes an increase in employment; and the interaction between the settlement units within the system, which induces cumulative causation and multiplier effects.

The establishment of new industrial activities in rural areas is usually determined by external factors. To an increasing extent this is true also in the case of agriculture (governmental contracts). Demand for agricultural and industrial

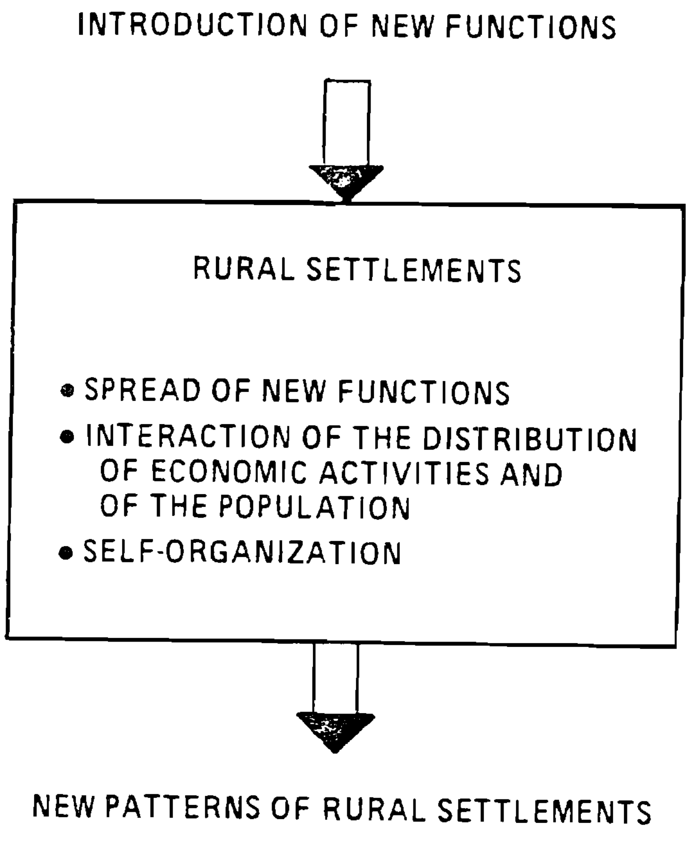

Figure 4. Changes in the pattern of rural settlements.

products is, therefore, assumed to be given.* The introduction of service activities is determined mainly by local factors. Demand for services should be determined in the model and it can be done (Allen and Sanglier 1979 modified) as follows (see the notation on pages 22-23):

$$D_x^{(u)} = \sum_y \frac{P_y q^{(u)}}{F^{(u)} d_{xy}^m} \frac{A_{xy}^{(u)}}{\sum_{x+s} A_{xy}^{(u)}} \quad , \qquad s = 1,\ldots,i \ , \quad u = 1,\ldots,j \ , \quad y = x,1,\ldots,h \ . \tag{11}$$

$$A_{xy}^{(u)} = \left(\frac{(1+cn_x)}{F^{(u)} d_{xy}^m}\right)^b \tag{12}$$

The factor $(1+cn_x)$ expresses economies of scale and the additional attractiveness of the village (town) having several functions. The effect of attraction decreases with distance d_{xy}. The term $A_{xy}^{(u)} / \sum_{x+s} A_{xy}^{(u)}$ represents the fraction of population P_y whose demand for good u attracts them to location x.

Let the demand for agricultural and industrial products be:

$$D_x^{(v)} = R_x^{(v)} \ , \tag{13}$$

Having determined the demand for goods and services, the employment in all three sectors of the rural economy can be computed as follows:

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* At IIASA, models of agriculture and industry are being developed by other authors. See: Albegov (1).

$$E_{tx}^{(w)} = p^{(w)} D_{tx}^{(w)} \quad , \qquad w = u \text{ or } v \quad , \tag{14}$$

$$\Delta E_{tx}^{'(w)} = a(E_{tx}^{(w)} - E_{t-1x}^{'(w)}) \quad . \tag{15}$$

The effect on the population of the changed employment situation is expressed by the equation:

$$P_{tx} = (1+r)P_{t-1x} + M_{tx} + k \sum_{w} \Delta E_{tx}^{'(w)} \quad . \tag{16}$$

In this way the sequence of dependencies leading from demand and employment to population has been reproduced. Now, the reversed interaction, i.e., the effect on demand and employment of the changed population, can be simulated.

The model includes nonlinearities, one of which is the positive feedback mechanism between employment and the population. The other nonlinearity is present in the factor of attractivity $A_{xy}^{(u)}$.

$A_{xy}^{(u)}$ = the attractiveness of location x felt by the consumer of service u resident at location y;

$D_{x}^{(u)}$ = demand attracted to location x for service u;

$D_{x}^{(v)}$ = demand attracted to location x for good v;

$D_{tx}^{(w)}$ = demand attracted to location x at time t for good w;

$E_{tx}^{(w)}$ = potential employment in activity w at time t and location x;

$E_{t-1x}^{'(w)}$ = actual employment in activity w, at time t-1 and location x;

$\Delta E_{tx}^{'(w)}$ = increase in actual employment in activity w at time t and location x;

$F^{(u)}$ = cost per unit distance of transportation;

M_{tx} = net noneconomic migration at time t and location x;

P_{tx} = population at time t and location x;

P_y = population at location y;

$R_x^{(v)}$ = demand for good v at location x;

a = parameter expressing the degree to which the gap between potential and actual employment is filled;

b = a constant that measures the degree of unanimity in the response of population P_y to the relative attractiveness of the location x;

c = a constant;

d_{xy}^m = distance between x and y;

k = average size of family of new employees;

n_x = number of different activities located at x;

$p^{(w)}$ = number of jobs required for the production of a unit of good w;

$q^{(u)}$ = quantity of service of type u bought by an individual at unit price;

r = rate of natural increase;

s = centers located outside the given region attracting population from the region;

u = economic activities - services;

v = economic activities - agriculture (1) and industry (2).

The introduction of a new activity into the settlement system can be simulated in the following way. Every settlement point is tried as a possible center for individual activity. For this purpose demand and employment is computed for every point. Next, the computed values are compared with the threshold value, which is defined as the minimum size at which the facility can operate economically. The size can be expressed by the number of employees needed for operating the facility. If the computed value for the given point is lower than the threshold value, the point is removed from the set of admissible location. If it is higher, the point becomes a center for the activity under consideration.

The simulation procedure is repeated for successive time periods until the new activity becomes fully integrated into the settlement system and a stationary state is approached.

The appearance of a new activity at the second and consecutive settlement point causes a change of market area by cutting off parts of the market areas of neighboring centers (Figure 5). Thus, it may happen that a center having a market area larger than the threshold value loses to a new center such a part of its market area that it drops below the threshold value. In this case, the activity attracted earlier is removed from the center. The shrinking of market areas of existing centers may be expressed by the exponent m attached to distance term d_{xy} in formula 11. Its value would increase as the new centers develop. The demand attracted to existing centers should be recalculated taking into account changing value of the exponent.

The shrinking of market areas of existing centers may be represented in an alternative way by the following formula:

$$\bar{D}_x^{(u)} = D_x^{(u)} \left(1 - \frac{1}{H + zH}\right) \qquad (17)$$

where:

$\bar{D}_x^{(u)}$ = reduced demand;

H = number of successively emerging centers;

z = coefficient reducing the decrease in demand of existing centers (new centers create new demand which in part supports their existence).

As the new activity is introduced and serves the given point as well as its surrounding area, employment opportunities begin to increase, which gives rise to an increase in the population. This causes the demand for all activities to grow and, as a consequence, employment opportunities increase further.

After the integration of one activity into the settlement system, the introduction and spread of the next activity can be simulated and consecutive activities can continue to be added.

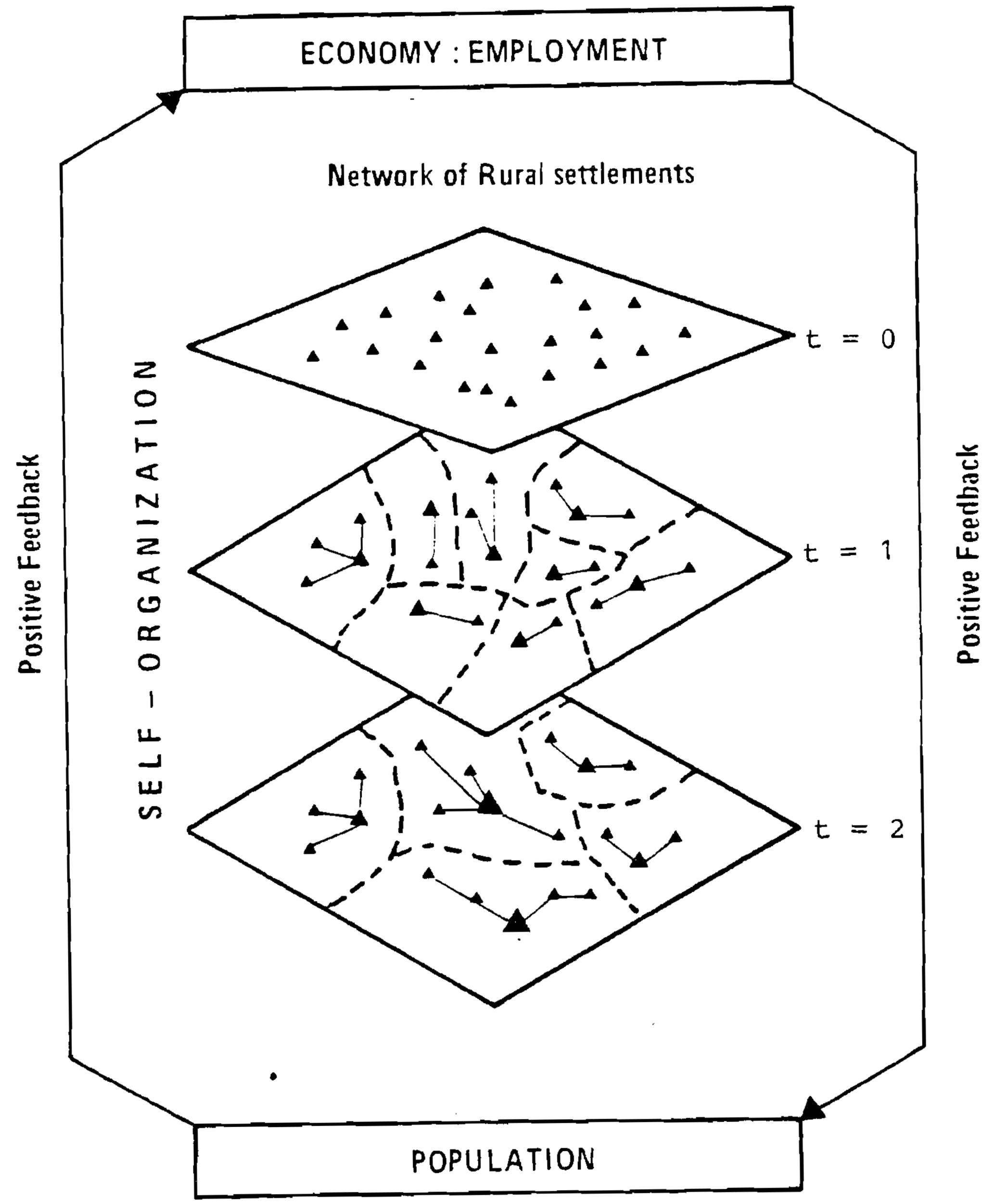

Figure 5. The model of emerging of key villages.

As many activities, as there are in the desired model of the key village (e.g. post office, general store, hardware store, electrical goods shop, barber, health service, secondary school, etc.) will be introduced.

A village that has managed to attract one activity is likely to attract another. If it does, its attractiveness increases and it becomes a center for multipurpose trips and offers economies of scale. Through the attraction of service facilities the selected villages attain the attributes of key villages.

The development of a larger town (regional and subregional centers) in a rural region exerts an influence on the network of key villages. It reduces the hinterland of the key villages that are located within proximity of the town. It may happen that activities served by such key villages drop below the threshold value.

In order to keep the impact of larger towns within reasonable limits, in simulation the number of their activities should be reduced to those serving the rural hinterland. Activities serving town dwellers and remote areas should be excluded from computation.

The self-organization of a settlement system in a rural region, whose course is reproduced above, is revealed in: the differentiated growth of individual settlement units, a new locational pattern of settlements, and new hierarchical relations between the settlement units. The sequence of changes of the system also reveals its development path. All these aspects of development can be analyzed further using relevant methods, e.g., the rank-size rule.

The form of the model indicates some lines of sensitivity analysis. Assuming small spatial differentiation of the price of goods and transportation cost per distance unit, one would expect the results of the model to be particularly sensitive to distance (d_{xy}), number of activities (cn_x), and the response of population to the attractiveness of individual settlement unit (b).

The above model was discussed with Andrzej P. Wierzbicki, Chairman of the System and Decision Sciences Area at IIASA. He made several suggestions modifying the form of the model. Wierzbicki's version of the model is the following.

Consider settlements x,y which, at a given time t, have the actual volume of services u measured by the employment in these services, $E^u_{x,t}$, $E^u_{y,t}$. The distances between those settlements are d_{xy} . For convenience of modeling, we introduce a nonzero istance $d_{xx} = d_o$ for all x, interpreted as an average distance inside settlement x; we assume $d_o \ll d_{xy}$, for all x,y (for example, $d_{xy} \geq 4$ km, $d_o = 0{,}4$ km).

We assume a gravitational model of attraction to services. The index of attractiveness of service u in settlement x to people in settlement y, A^u_{xy} , is thus defined by

$$A^u_{xy} = \frac{E^u_x + \sum_{\bar{u} \neq u} \lambda_{\bar{u}u} E^{\bar{u}}_x}{d^2_{xy}} ,$$

where the subscript t is omitted for simplicity's sake. Here, $\bar{u}$ denotes other services offered in x and $\lambda_{\bar{u}u} \in (0;1)$ are coefficients of attraction by a joint service offer (for example, we might assume $\lambda_{\bar{u}u} = 0.2$ for all $\bar{u}u$). Thus, the numerator corresponds to the perceived volume of services offered, while the denominator is just the square distance. It is useful also to compute the coefficient of attractiveness:

$$\eta^u_{xy} = \frac{A^u_{xy}}{\sum_{\bar{x} \neq x} A^u_{\bar{x}y} + A^u_{xy}} ,$$

that indicates which part of the population of y will go to x for the service u. Clearly, $\eta^u_{xy} \in [0;\ 1]$ and $\sum_x \eta^u_{xy} = 1$.

Now, we can compute the demand for service u in settlement x:

$$D_x^u = \sum_{y \in X} P_y q^u \eta_{xy}^u \quad ,$$

where

X is the set of all settlements, including x,

P_y is the population of y;

q^u is the coefficient of required service per capita (for example, 10^{-3} doctors per capita).

Thus, the demand D_x^u expresses the reguired employment in service u at settlement x.

Observe, however, that the demand $D_{x,t}^u = 0$ if $E_{x,t}^u = 0$ for all u, which can be interpreted as meaning people in x usually go to other places y for services. Thus in the model we must incorporate decisions to develop service centers. To do this, we assume that there is a minimal economical volume E^{uo} of a service center (independent of x,y) and that the authority of x can form expectations on whether it is reasonable to develop the service center. These expectations can be quite simple-minded and myopic. For example, the authority of x can verify the reasonability of offering a service at volume E^{uo} while assuming that all other volumes of services in other settlements and the population of these settlements remains unchanged. Thus, if $E_x^u = 0$, we copmute hypothetical indexes and coefficients of attractiveness which would result after introducing $E_x^u = E^{uo}$:

$$\tilde{A}_{xy}^u = \frac{E^{uo} + \sum_{\bar{u} \neq u} \lambda_{u\bar{\mu}} E_x^{\bar{u}}}{d_{xy}^2} \quad ,$$

$$\tilde{\eta}_{xy}^u = \frac{\tilde{A}_{xy}^u}{\sum_{\bar{x} \neq x} A_{\bar{x}y}^u + \tilde{A}_{xy}^u} \quad ,$$

and the corresponding demand

$$\tilde{D}_x^u = \sum_{y \in X} P_y q^u \tilde{\eta}_{xy}^u \quad .$$

If $\tilde{D}^u_x \geq E^{uo}$, then the service center could be developed for the next time period t+1; the volume of service developed is computed as described below. If there are several services to be developed, we ignore the possible effect of a new joint service attraction in forming expectations $\tilde{A}^u_{xy}$ and we use old $E^{\bar{u}}_x$ (not expectations $\tilde{D}^u_x$) while computing $\tilde{A}^u_{xy}$. The interpretation of this is that the service attraction is habitual, based on past experience.

Now, the dynamics of change of service volume $E^u_{x,t}$ offered might be described as follows.
First, we compute the demand-supply difference $\Delta^u_{x,t}$:

$$\Delta^u_{x,t} = \begin{cases} \tilde{D}^u_{x,t} \text{ if } E^u_{x,t} = 0 \\ D^u_{x,t} - E^u_{x,t}, \text{ if } E^u_{x,t} > 0 \end{cases}$$

(we can use here $E^u_{x,t} \geq b \cdot E^{uo}$; see below).
Based on this difference, a conervative estimate $\hat{E}^u_{x,t+1}$ of future supply is formed:

$$\hat{E}^u_{x,t+1} = E^u_{x,t} + a\Delta^u_{x,t} ,$$

where the coefficient a characterizes the dynamics of service change. If a = 1, the service change responds directly to demand. If a < 1 (say, a = 0.7 or a = 0.5), the service change is lagged beyond demand, and responds conservatively. If a > 1 (say, a = 1.2), the service change tries to exceed demand, in expectation of future demand growth (due to future population growth, etc.) This coefficient also influences the actual development of new services: they will in fact be developed, if $a \cdot \tilde{D}^u_{x,t} \geq E^{uo}$, which characterizes well the conservative or progressive interpretation of a < 1 or a > 1. All this is expressed by the equation that determines the actual new service volume:

$$E^u_{x,t+1} = \begin{cases} \hat{E}^u_{x,t+1} & \begin{cases} \text{if } E^u_{x,t} \neq 0 \text{ and } \hat{E}^u_{x,t+1} \geq b\, E^{uo}, \text{ or} \\ \text{if } E^u_{x,t} = 0 \text{ and } \hat{E}^u_{x,t+1} \geq E^{uo} \end{cases} \\ 0 & \begin{cases} \text{if } E^u_{x,t} \neq 0 \text{ and } \hat{E}^u_{x,t+1} < b\, E^{uo}, \text{ or} \\ \text{if } E^u_{x,t} = 0 \text{ and } \hat{E}^u_{x,t+1} < E^{uo}. \end{cases} \end{cases}$$

Here b is a coefficient, $b \in [0;1)$, characterizing a definitely noneconomical level of maintaining a service center, denoted by bE^{uo}. If, say, $b = 0.2$, this means that a service will be developed if the expected demand $\tilde{D}^u_x$ corrected by the coefficient of conservativeness a, is greater than E^{uo}, and a service will be discontinued only when the actual demand D^u_x, corrected by the coefficient of progressiveness a, is smaller than $0.2\, E^{uo}$.

Naturally, when simulating the dynamics of service development numerically, we can fix the coefficient b to only one value--say, 0.3 or 0.5-- and, by repeating the simulations, analyze the influence of the more important coefficient of progressiveness of expectations, a, setting several numerical values--say, 0.5, 0.75, 1.0, 1.25.

The mechanism of forming expectations, described above, can be further discussed and modified. The development of services can be coordinated between settlements by assuming that the proposed developments of services are jointly evaluated (when computing $\tilde{\eta}^u_{xy}$, the denominator includes not only actual services, but all the proposed developments of services at the level E^{uo}). The expectations can be formed based on future projections: first, we compute how the volumes of services would change in the period t+1 if no developments were made, then estimate the developments of services in the period t+1.

The employment in agriculture and industry is determined separately:

$$E^v_{x,t+1} = p^v R^v_x \quad .$$

By adding the employment in agriculture and industry to that of services, the total employment can be obtained:

$$E^{w}_{x,t+1} = E^{u}_{x,t+1} + E^{v}_{x,t+1} \quad , \qquad w = u \text{ or } v.$$

Hence the increase in employment amounts to:

$$\Delta^{w}_{x,t+1} = E^{w}_{x,t+1} - E^{w}_{x,t}$$

As to the dynamics of population change, two approaches are possible. The first approach assumes that the growth of services in the given settlement attracts new employment and population connected also with other sectors of the rural economy (agriculture, industry). In such a case, the stream of migration should be related to the attractiveness of services in the settlement. This would complicate the equation presenting the dynamics of changes in population.

The other approach does not consider a relationship of this type and assumes that migration is given exogenously. In this case the equation of the dynamics of changes in population may take the form:

$$P_{x,t+1} = (1+r)\ P_{x,t} + M_{x,t+1} + k \sum_{w} \Delta^{w}_{x,t+1} \quad .$$

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