WORKING PAPER

MIGRATION AND COMMUTING:
A THEORETICAL FRAMEWORK

Marc Termote

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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.

The objective of the Urban Change Task in IIASA's Human Settlements and Services Area is to bring together and synthesize available empirical and theoretical information on the principal determinants and consequences of such urban growth and decline.

In this report, Professor Marc Termote, former Research Scholar in the Urban Change Task and currently with the Institut National de la Recherche Scientifique, Universite du Quebec, analyzes spatial and temporal interrelations between migration and commuting. A methodology is proposed for future work starting from an accounting model which allows for the simultaneous consideration of these two types of movements.

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

Andrei Rogers
Chairman
Human Settlements
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ABSTRACT

This paper considers the interrelations between the two basic ways to adjust to spatial separation: migration and commuting. After a brief discussion of the role migration and commuting play in selected urban and regional models, we present a micro-economic theoretical framework for analyzing the interrelations between these two forms of movement. The main part of the paper is devoted to the integration of commuting into demographic analysis. After discussing the demographic meaning of commuting and the problems of statistical information, we present a simple accounting model which allows for the simultaneous consideration of migration and commuting and conclude with some methodological implications.

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INTRODUCTION

In a closed-region situation there are five basic ways for the labor force to adjust to disequilibria in the labor market. The inhabitants may respond by: 1) changing their labor force participation rate, 2) changing their profession, 3) changing their sector of activity while maintaining their profession, 4) changing their occupation within their profession and within their activity sector, 5) accepting partial or total unemployment. In the case of an open region, however, we must consider two more ways of adjustment, 6) migration and 7) commuting.

Many interconnections between these various types of adjustment are possible. For instance, sectoral mobility may be accompanied by professional mobility and migration, or may be a substitute for them. It is clear that the role of each of these seven types of mobility, and the interrelations between them, is a function of the degree of spatial, sectoral, professional, and occupational disaggregation. For example, if the sectors of economic activity are broadly defined while spatial disaggregation is very detailed, then the spatial mobility level (migration and commuting) may appear to be high and the sectoral mobility low; the spatial mobility being in this case more likely to be considered as a substitute for the sectoral mobility. Moreover, the nature of these adjustments depends on the length of time periods used in the analysis. Professional and sectoral mobility levels may appear low over short periods of time and high over a longer time span (for example, a quarter of a century), even if the professional categories and the sectors of economic activity are broadly defined.

In this paper, we will consider only interrelations between migration and commuting, however, all other interconnections with the first five types of adjustment should be kept in mind. After a brief discussion of the role migration and commuting play in selected urban and regional models, we will present a theoretical framework for analyzing the interrelations between those two forms of movement, and conclude with methodological implications in the field of demo-economic analysis.

1. MIGRATION AND COMMUTING IN URBAN AND REGIONAL MODELS

In location theory the problem of locating the place of residence has been disconnected from the problem of locating the place of work. Similarly, urban and regional models treat migration and commuting separately. Let us consider that at time t there are m places of residence and n places of work distributed over space. There are three ways to combine place of residence and place of work that are useful when considering the migration and commuting problem in spatial analysis. These are: 1) the place of residence of each worker is given, but his place of work is not; 2) the place of work of each worker is given, but his place of residence is not; 3) neither place of residence nor place of work is given.[1]

In the first case, when the place of residence is fixed and the place of work is not, we have only a commuting problem, and by definition there is no migration. We have a typical location-transportation problem.[2] Given n fixed destinations, each with its own requirements for some product or service (here, the number of workers), we have to locate m sources from which the product or service is to be delivered, given some unit cost of transportation. The commuting problem is then to find the pattern of commuting flows that minimizes total transportation cost, with respect to some constraint on transportation capacities and on source capacities (which in our case is the number of workers residing at each of the m places of residence). One could also consider it as a maximization problem, that is the problem of selecting the commuting pattern that maximizes total production or marginal productivity of labor.[3] An alternative would be to consider it as an intervening opportunity problem[4] or as an entropy maximization problem, in order to calculate the most probable pattern of commuting consequent to a given spatial distribution of residences and of labor demand.[5]

The difficulties derived from fixing the place of residence independently from the place of work, and thus treating separately migration and commuting, is easily illustrated in this case. What happens if the observed or most probable (entropy maximizing) pattern of commuting varies substantially from the optimal one? In order to influence the commuting behavior of the population, one may change the commuting costs, intervene in the housing sector (in order to affect the spatial distribution of labor supply), or intervene through investments in capital (in order to affect the spatial distribution of labor demand). Except for a change in commuting costs, all these types of intervention also change the optimal pattern, so that "for planning purposes, a delicate problem of coordination...arises."[6]

Besides the fact that migration and commuting are completely dissociated, one may question the relevance of the basic assumption of such an approach. By assuming that workers first select their place of residence, and from there look for a place of work, these models turn around the usual direction of causation in urban economic theory, which often assumes that workers have a fixed location of their job and from there select the location of their residence. The hypothesis of a given place of residence may however appear to be justified for working women. One has indeed explained the shorter commuting trips usually observed for married women by the home responsibilities they are confronted with and by the fact that being secondary wage earners, they have a more "casual" attitude towards job-seeking.[7] It has, however, been shown that this kind of exogenous "psychological" explanation is not needed: two-worker households can choose for purely rational, economic reasons to locate so that women workers commute shorter distances than men. Women's place of work is therefore not necessarily determined by the place of residence of the household, but rather the place of residence of the household is chosen by taking simultaneously into account the place of work of both members of the household.[8]

One may conclude that this type of commuting model, where the commuting trip is derived from a given place of residence, is more useful for consumption-oriented trips (shopping, recreation, etc.) than for production-oriented trips (journey-to-work). Consumer commuting models are, however, rare.[9]

In the second case when the place of work is given, and the place of residence is not, the situation becomes one which has been traditionally analyzed in urban residential location theory. Most of these theories and models assume that all employment is concentrated in one place: namely, the center of the city (CBD). Models based on the Wingo-Alonso framework[10] are in this category, see for example Muth.[11] Some models however, provide for more than one employment center, but the place where each worker is employed is still given.[12] Instead of using a consumer equilibrium approach, as in Alonso's and Muth's models, one may adopt an intervening opportunities model for allocating places of residence to workers whose place of work have been predetermined.[13] Other models have made explicit the sequential search process for a home in the face of uncertainty; the only thing which is certain, however, is the location of the place of work...[14]

Place of employment is given also in the case of the Lowry model as well as in Garin's extension of this model. Indeed, the location of the individual's residence remains determined by the location of his job. But at least Garin introduces explicitly travel "from work to home" in order to link both locations. Actually, this way of introducing commuting requires a model of employment growth, from which we may analyze the implications of this growth on the population of each area.[15]

The problem with all these models is that the individual "falls from heaven". These workers, whose place of work is given, are all assumed to have no prior residence.

In the third case when neither the place of work nor the place of residence is given, most models do not integrate migration and commuting within a single framework. The simultaneous determination of place of work and place of residence does not imply the simultaneous determination of migation and commuting. Indeed, there are two ways of eliminating the mobility problem in order to ensure the choice of both place of work and place of residence at the same time. This can be done either by assuming zero costs of commuting, or by assuming zero costs of migration. Most models of so-called "simultaneous determination" solve the problem in this manner.[16]

One way to eliminate the commuting problem is to assume that employment opportunities are uniformly distributed throughout the area so that the workers in the household can always find a job near their home.[17] This kind of reasoning is similar to the one adopted in traditional location theory. Weber assumes that labor supply is infinite at any point in space where the plant may decide to locate. Similarly, Lösch assumes implicitly that commuting costs are zero, in order to reconcile his hypothesis of uniform distribution of population over space with the spatial hierarchical concentration of production he obtains through his model.

The above assumption of zero commuting costs is also implicit in most migration models. These migration models actually are models defining the location of labor (the place where workers consume) in the same way as location models define the location of capital (the place where workers produce). By assuming that the place where the worker will reside is determined by the availability and not the accessibility of a job, most migration models in fact exclude the costs of commuting as a factor of migration; thus, they implicitly assume these costs equal zero, in the same way as plant location models do.

Some models where place of residence and place of work are determined simultaneously do, however, take into account at least implicitly, the cost of commuting. For instance, W. Fisher and M. Fisher propose a simultaneous equation model which explains the spatial distribution of employment and of residences. They introduce in their employment and residence functions potential variables where the marginal cost of commuting is used as a weight for calculating the potential; however, these potential variables are assumed predetermined. In this kind of model, the spatial distribution of employment and of residence may therefore be determined simultaneously, but they are not connected by a commuting flow, nor is the chosen place of residence connected with a previous place of residence (since there is no migration function).[18] Gat's simultaneous model has two commuting functions, one for work trips (to a place of work which is not necessarily the CBD) and a second one for non-work trips (assumed to have the entire CBD as the destination), but there is no migration function either. Households in the total area are merely allocated to each geographic cell according to a given density function.[19] Richardson's "generalization" of residential location theory also has an explicit commuting cost function (contrary to Gat however, work trips and non-work trips are combined into an "aggregate travel cost function"), but again there is no explicit migration and commuting function.[20]

Of course, one may always justify the elimination of either commuting or migration by arguing that these models are designed for different areal delimitations. One could argue that when the problem of location-of-residence-location-of-work is considered at the intraregional (urban or metropolitan) level, migration costs within the area are low relative to commuting costs. When the problem is viewed at the inter-regional level, however, migration costs are determinant so that commuting costs may be disregarded.

This way of deriving the nature of the mobility problem from the type of territorial delimitation adopted is highly disputable, for empirical as well as for theoretical reasons. There are many cases where commuting across regional borders is an important phenomenon even when regions are very large. Much depends in this respect upon the spatial distribution of population and employment within the respective regions. Moreover, the vast majority of migrants are intraregional, and their average migration distance is probably not much larger than the average commuting distance. In countries benefiting from an extensive (railway) transportation network, the number of inter-regional commuters may be much larger than the number of inter-regional migrants.

Deriving the nature of the mobility process from the existence of a border is unfortunately a traditional way of reasoning in economic theory. "Classical" trade theory assumes that when interrelations between countries are concerned, international equilibrium may be reached only through moving products across the border, while factors of production, assumed to be immobile between countries, are considered as completely mobile within countries.

The problem however is not so much one of territorial delimitation, but rather one of temporal dimension. Commuting, as such, is a static phenomenon. Commuter flows are the link between the spatial distribution of residences at a given moment in time, and the spatial distribution of employment at the same moment in time. But as soon as one considers migration, and therefore the possibility of combining migration and commuting, then one necessarily obtains a dynamic model. This makes it much more difficult. As J. Huff puts it, one has "suggested frameworks for incorporating both the distribution of job opportunities and (housing) opoortunities within a single dynamic model, but the resulting complexity of the models precludes their use as a practical forecasting devise."[21] No attempt will be made here in this direction. We will limit ourselves, in the next section, to a micro-economic theoretical framework for the simultaneous determination of place of work and place of residence.

2. A MICRO-ECONOMIC THEORETICAL FRAMEWORK

One may consider two approaches for analyzing the problem of the place-of-residence and place-of-work and thus the migration-commuting problem: either by considering it as a location problem, or by considering it as a consumption problem. The first approach leads us to an examination of economic location theory and the possibility of this theory providing us with a useful framework, while the second approach implies a spatialization of the traditionally "punctiform" theory of consumer behavior.

Location theory has almost completely neglected the spatial mobility of population and has analyzed only the location of capital, assuming either perfect spatial mobility of labor or complete immobility. An exception, however, among space economists is August Lösch, who in his *Economics of Location* came close to a relevant framework. Lösch considers that "our theme is the combination of people, work and place", and from this triad develops what he calls the "six cardinal problems of the spatial division of labor": the occupation of a person, the personnel of an industry, the location of a person, the occupants of a location, the production at a location, and the location of production. By treating these three elements only in a pairwise fashion, Lösch fails to take full advantage of his approach. He analyzes separately the problem of choosing a job (the occupation of a person), the problem of determining the location of the job or place of work (the location of production), and the problem of determining the location of residence (the location of a person).[22]

The second theoretical approach, which consists in a spatialization of the theory of consumer behavior, has proved to be more fruitful thanks mainly to the works of William Alonso and Richard Muth. In this approach, the urban residence pattern is reviewed as the result of location decisions made by consumers who maximize their utility under (monetary and time) budget constraints. The Alonso-Muth models continue however to consider pairwise the three elements of the spatial structure of residences and employment, and thus fail to determine simultaneously the place of residence, the place of work, and the structure of consumption. In order to reach this goal, the following approach may be useful.

We start by assuming that the economic activity of an individual is polarized around two points in space: a point where he produces and a point where he consumes. We assume that the individual consumes where he has his residence. This seems a fairly reasonable assumption, particularly when we take into consideration the consumption of land and of leisure time, two kinds of increasingly important goods.

This individual residing in region j has an action space, which is the set of points of residence and of places of work perceived by him. At each of these places of work in region i, some wage w_i is paid, but in order to obtain this wage, the individual must support some costs, resulting either from a migration (defined as a change of residence) between j and i, from a commute between j and i, or from some combination between these two fundamental means of spatial adjustment. The combination of migration and commuting could be a spatial one: residing in j, the individual migrates to h, a place normally closer to i than j, and commutes between h and i. The combination in time is also possible, i.e., commuting between j and i during the $t_0 - t_k$ period, followed by a migration from j to i at time t_k. Finally, a space-time conjunction of migration and commuting is also conceivable: the individual could migrate to h at time t_0, and during a $t_0 - t_k$ period commute from h to i, migrating a second time from h to i or to another place at time t_k. With m perceived locations of residence and n perceived places of work, and with k periods considered in the life span of the individual, the number of combinations between migration and commuting open to the individual is very large indeed.

Each of these various spatial adjustments is characterized by a particular cost structure. One may consider three broad categories of "inputs" which are to be used by the individual when he moves in space. First, there is the *space* input: in some way, the individual uses space when he moves from j to k, and this is normally reflected by the transport cost in its monetary expression. Second, there is a *time* input, reflected by the opportunity costs resulting from the duration of the move. Third, by moving from j to i, the individual uses a set of non-economic goods (affection, solidarity, prestige, health, nervous equilibrium, etc.) reflected in what is often called *psychological* or *non-monetary* costs.

The relative importance of these various components differs according to the form taken by the spatial adjustment. Actually, a basic difference between migration and commuting is to be found in the structure and in the distribution over time of these costs. In the case of migration, the migrant has to support an important monetary cost over a short period (cost of moving people and belongings, cost of settlement, etc.) and a psychological cost which could be high during some time, but usually decreases fast once the period of adaptation is over. On the other hand, in the case of commuting, which by definition is a recurrent phenomenon, the direct monetary cost is relatively low, but is repeated at each time period. Moreover, a large part of commuting costs results from the duration of the journey-to-work, while these opportunity costs are negligible in the case of migration.

In order to reach some place of work i, the individual residing in j will choose, among all those various combinations of migration and commuting, one that minimizes his costs (discounted over his life span) at the same time choosing a particular cost structure. The consideration of a spatial sequence of work places implies the substitution of one combination of migration and commuting into another, and therefore, the substitution of one structure of mobility inputs to another. In other words, the mobility costs function is not linear and homogeneous: doubling the distance over which spatial mobility is considered does not imply doubling the quantity of each input used.

It seems reasonable, even necessary, to take into consideration spatial changes in the price of those mobility inputs. For instance, it is obvious that the value of a time unit spent in commuting increases when the distance increases. More particularly, once a certain distance of commuting is reached, the value of a unit of time spent in commuting increases exponentially, and, if one wishes to reach a further point, one has to substitute non-economic goods (psychological inputs) for time, by migrating instead of commuting. Similarly, if it is difficult to substitute a psychological good for a time input, which is often the case with older workers, the individual will usually favor the psychological goods. He will therefore prefer commuting to migration.

Besides substitution effects on mobility inputs, we must consider substitution and income effects of spatial mobility on consumption. Indeed, the price structure is not spatially constant, and, moreover, migration and commuting imply that income is spatially different. This will lead to a modification in the consumption structure of the individual who moves. Often, it is precisely because the individual wants to change the structure of his consumption, that he will change the location of his residence. For example, an income elasticity of demand for land (price of land being held constant) which is greater than unity, and a lower price for land as one leaves the center of the city, will lead to a migration to the suburbs. In the suburbs the individual will consume more space (land) and substitute cultural goods delivered at home (television) for cultural goods which have to be consumed at the place of production (theater).

According to the approach adopted above, a change in the employment-residence pattern implies a change in the marginal utility of places. This change is related to a change in the elasticity of substitution between mobility inputs, of substitution between goods consumed, of demand with respect to income, and to a change in the marginal utility of each good, and the spatial evolution of prices and income.[23]

3. INTEGRATING COMMUTING INTO DEMOGRAPHIC ANALYSIS

3.1 The Demographic Meaning of Commuting

Commuting is not, strictly speaking, a demographic phenomenon, since it does not directly affect the level and structure of the population. Commuting involves the daytime population whereas the nighttime population is the one commonly recorded as the *de jure* population and the one to which demographic analysis refers. As long as there is no migration, the level and the structure of the nighttime population does not change.

However, even if commuting is not a demographic phenomenon, it is an area of interest to demographers because of its strong direct links with migration, which in turn is an increasingly important component of demographic change. These links are obviously more important for relatively small regions, and are, at least in part, dependent on the location of the region within a regional system. This may be illustrated by some empirical data, in this case for selected administrative units in Belgium (Table 1).[24]

The Aalst and Dendermonde regions of Belgium are characterized by heavy out-commuting but low outmigration, while Arlon shows one of the lowest commuting rates and one of the highest outmigration rates. It seems clear that this reflects a substitution process between commuting and migration. The absence of nearby employment centers means that for some regions (for example, Arlon), the spatial adjustment of the working population is accomplished mainly via migration, while in regions close to those economic centers (Aalst and Dendermonde are located within the Brussels-Antwerp-Ghent triangle) the population is able to adjust to local economic conditions by commuting. The demographic and socio-economic consequences, and correspondingly the impact on urbanization, are obviously different in the two cases.

Table 1. Commuting and migration for three Belgian "arrondissements".

	Arrondissement			
	Arlon	Aalst	Dendermonde	Country
Commuting rate in percent (outflows) (1961 census)	3.7	35.4	29.4	12.7
Outmigration rate in percent (annual average for 1954-1962)	3.3	1.5	1.7	2.0

The importance of commuting in the urbanization process is also illustrated by the fact that all but 5 percent of the population of the United States resides within the daily commuting field of a metropolitan area, and that those fields spread over the entire land area except where population densities are less than two persons per square mile and where there are national parks, forests, and Indian reservations. Data for the United States show that "labor markets are more extensive than the 1960 standard metropolitan statistical areas, and represent the real functional economic areas surrounding the central cities".[25]

In order to stress the relationships between commuting, migration, and urbanization, the following typology may be used:

I. Commuting as a pure substitute for migration: commuting from place B to place A which reduces migration from B to A, correspondingly

II. Commuting as a complement of migration:
   (a) commuting from B to A by previous residents of A
   (b) commuting from B to A by previous residents of C who would otherwise have remained stationary
   (c) commuting from B to A by previous residents of C who would otherwise have migrated to A

III. Commuting with neutral effect on migration: commuting from B to A by residents of B who would not have migrated in any case

Type II(a) differs considerably from all other types in that it implies a voluntary decision to assume the costs of both migration and commuting although work does not make it necessary. This type of flow may be considered a luxury good, and it is correspondingly highly selective. This flow neither implies greater equality of employment opportunity [as in the case of Types II(b) and III], nor is it an alternative to migration to place of employment [Type I and II(c)]. By definition, the destinations of such migrationflows become places of high social rank. This type of commuting probably is predominant in the United States, and it is quite likely a factor in determining that country's particular kind of urbanization. According to the U.S. Census, however, a reversal seems to have occurred recently in intra-metropolitan migration flows in the United States. The growth of jobs in the suburbs has changed commuting patterns, with not only a large increase in the number of commuters who live in the city and commute to work in the suburbs (345,000 in 1960 and 615,000 in 1970), but also a large rise in the number of workers who work and live in the suburbs (an increase of 40 percent to 8.7 million). On the other hand, European-type commuting generally represents an alternative to migration, permitting a concentration of production points along with a certain dispersion of the population, which produces a different urban spatial structure. Despite the role of commuting in the migration and urbanization processes, commuting studies are rare, largely because of the lack of data.

3.2 Sources of Data

Most data on commuting are collected in censuses and sample surveys. Unfortunately, most nations do not include a question on commuting in their census, and when they do the results are often not tabulated.

The usual way of collecting commuting data is to ask for the regular place of work, which, coupled with the regular place of residence, gives the commuting flow for the individual (and thus commuting distance). For instance, the 1960 U.S. Census (which was the first in American history to include questions on commuting) asked all persons 14 years of age and over who reported working at some time during the reference week, to specify city or town, county, and state where they worked. Replies on place of work were tabulated in various ways according to the worker's place of residence, such as working in the same county or different county from worker's place of residence, or working in the same state, or in the state continguous, or non-contiguous, to place of residence. For some professions (traveling salesmen, sailors, etc.), there is, by definition, no regular place of work; they should not be considered as commuters. A way to handle this problem is to introduce a question on the periodicity of the move. In 1970, respondents were also asked to specify the exact street address where they worked. This allows for tabulations by small geographic areas, such as tracts or enumeration districts.

Census data on commuting usually refer to flows at a given moment in time--the day the census was taken or the last working day--while data on migration flows, obtained either by a census or by a population register, usually refer to a period of time. This reflects a basic difference between commuting and migration. The latter represents a dynamic process, while the former is a static phenomenon. It also implies that a comparison between commuting flows and migration flows makes sense only if we compare the variation ot commuting flows between points in time (usually, two censuses) with the migration flows over the same period. The problem is to decide whether the mere spatial difference between place of residence and place of work may necessarily be considered as a commuting flow. This becomes a problem of defining space and time scales.

The scale of *spatial units* will, to a large extent, determine the level of commuting. Flows between large-sized regions will generally be less than flows between small municipalities. The choice of a spatial unit will clearly depend on the problem being considered; if commuting is viewed as a dimension of urbanization, the spatial unit should be quite small. When commuting is analyzed in relation to migration, or viewed as a process of economic adjustment to space, the spatial unit should be large enough to eliminate as much of the urbanization dimension as possible but not so large that it extends beyond the distances over which commuting is feasible.

Collecting commuting data for very small spatial units is, of course, a huge task. This has, however, been done in Belgium, where census data (for 1961) on commuting flows between each of the 2,663 municipalities are available. These data reveal that 2,424 municipalities (91 percent of all Belgian municipalities) send commuters to the Brussels agglomeration (which combines the municipality of Brussels and 18 surrounding municipalities). As a result of a particularly dense public transportation system, the commuting shed of Brussels covers almost the entire nation. The total number of commuters between all Belgian municipalities according to the 1961 census was 1,663,000 (after rounding), which represents about 48 percent of the Belgian employed labor force; 445,000 of these commuted between the 41 arrondissements.

The *time scale* involves two problems. First, what do we mean by a periodic move between place of residence and place of work? For instance, does a weekly, monthly, or seasonal move represent a commuting flow? Second, should a move which takes five or ten minutes be considered a commuting flow?

It seems reasonable to consider as commuters only members of the labor force who move daily to a regular place of work. Some authors, however, consider only those daily moves which involve more than a certain amount of time, for example a 30-minute round trip. This, in fact, largely excludes flows which are most likely to be related to the urbanization process. These distinctions obviously require the addition of two new questions into the census: "Do you travel daily to your place of work?" and "How much time does your journey take?" According to the 1961 Belgian census 94 percent of the commuters are daily commuters; among these daily commuters, 41 percent had a total (round trip) commuting time below one hour, and 25 percent traveled more than two hours.

Commuting time also depends on the transport mode used. Some census questionnaires contain a question such as "What transport mode do you use in order to reach your place of work?" In the 1960 U.S. Census, the categories were: private auto or car pool; railroad, subway, or elevated (the latter two categories were combined in tabulations); bus or streetcar; taxicab, other means (taxicab was included in other means of tabulations); walked only; worked at home. The 1970 U.S. Census added a distinction between driver and passenger of private auto. The tabulation of these data indicate an important difference between the American and the European experience. In the United States in urban areas (with a population of 2,500 or more) 64 percent of the commuters went to work by car[26], while in Belgium only 14 percent used this transport mode.[27] A survey conducted during the fall of 1963 in the standard metropolitan statistical areas (exclusive of New York) found that of all journeys to work, 84 percent were made by car, with 90 percent of the cars containing only one person; 77 percent were parked in lots, and 18 percent on the street.[28]

The Belgian policy of cheap season-tickets plus direct subsidies to railways greatly encourages commuting by other means than the automobile. In 1961, 35 percent of the active population of the arrondissement of Aalst worked outside the arrondissement (compared to 26 percent in 1947), and half of these commuters went to Brussels. It has been estimated that the difference between the receipts from these season-tickets (to which employers contribute) and the operating costs to the railways for the Aalst-Brussels line during peak hours represents an annual deficit of U.S. $16,000,000 or U.S. $600 for each commuter from Aalst to Brussels. This deficit is covered by state subsidies. In other words, society is subsidizing this commuting flow and indirectly the economic activities located in Brussels. One could, however, argue that this kind of subsidy to cities constitutes a form of compensation. Indeed, commuting implies that incomes earned in one locality are "imported" to another locality where they can be locally taxed while the expenditure for infrastructure making the income possible has to be borne by the locality from which the incomes are "exported". Again, these differences in commuting help to explain differences in the spatial structure of American and European cities.

The survey (either exhaustive, like the Census, or based on a sample of the population) enables measurement of commuting flows. Two limitations are that such data are valid only for a given point in time and that annual data are exceedingly difficult to collect. As far as we know, no country keeps a permanent record of commuting flows. This is a major drawback since commuting, much more than migration, is a short-term spatial adjustment process to socio-economic conditions. In some cases, however, it is possible to estimate partial commuting flows on an annual basis. This is feasible in countries where a fairly large number of the commuters are using public transportation, particularly railways, on a season-ticket basis. The annual counting of season tickets for the main railway lines may provide a good estimate of the evolution of commuting flows. In many less developed countries, however, "office vehicles" carry a large number of workers, especially in the industrial sectors. In these countries reliance on public transport statistics alone will result in a sizable understatement.

In some countries, an important source of commuting data is the sampling of employer's work records. These give figures not only on net commuting, but also on commuting flows.

Another means of obtaining annual estimates exists in countries where employment data are collected by various institutions according to place of residence of the job holders or place of work. These data allow calculation, by difference, of (annual) net commuting for each region. A problem arising from this approach lies in the fact that these annual employment data are often collected from different sources. Generally, they do not cover the entire labor force (professionals are often excluded), or they cover different parts of the labor force. We may, however, assume that these weaknesses are generally insignificant if we wish to analyze the evolution of net commuting over time.

3.3 Combining Migration and Commuting into a Demographic Growth Model

We want to formulate population growth in a way that integrates migration and commuting so as to allow us to make explicit the interrelations between them. Even if commuting is not a demographic phenomenon, the evolution of population over a time interval depends upon the various combinations between migration and commuting which have taken place during the period.

At some moment t (a census, for instance), the working population[29] of each region may be decomposed according to their place of work:*

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*Some symbols denoting variables in this section may not necessarily follow the previous notation which referred to alternative models.

$$P_{i(t)} = \sum_{j=1}^{n} P_{i(t)} c_{ij(t)}$$

where $P_{i(t)}$ = the (working) population residing in region i at time t;

$c_{ij(t)}$ = the proportion of the (working) population residing in region i but working in region j (i.e., commuting between i and j) at time t.

At the end of the time interval, say at (t+1), the population residing in region i has to be disaggregated not only according to their place of work but also according to their previous (i.e., at time t) place of residence and place of work. If there are n regions in the spatial system, there are n^2 categories within the group of those residing in region i at time (t+1) and working in region j at time (t+1). For instance, for i = j = 1, we have:

$$\begin{aligned} P_{1(t+1)} c_{11(t+1)} = & \left[\left(\sum_{j=1}^{n} P_{1(t)} c_{1j(t)}\right) m_{11}\right] c_{11(t+1)} \\ & + \left[\left(\sum_{j=1}^{n} P_{2(t)} c_{2j(t)}\right) m_{21}\right] c_{11(t+1)} \\ & + \quad . \; . \; . \\ & + \left[\left(\sum_{j=1}^{n} P_{n(t)} c_{nj(t)}\right) m_{n1}\right] c_{11(t+1)} \end{aligned}$$

where m_{ij} = the probability of migrating, i.e., the probability of residing in j at time (t+1) if one is a resident of region i at time (t).

Similarly, for i = 1 and j = 2 (residents of region 1 who work in region 2 at time t+1), we have:

$$P_{1(t+1)}c_{12(t+1)} = \left[\left(\sum_{j=1}^{n} P_{1(t)}c_{1j(t)}\right) m_{11}\right] c_{12(t+1)}$$

$$+ \left[\left(\sum_{j=1}^{n} P_{2(t)}c_{2j(t)}\right) m_{21}\right] c_{12}(t+1)$$

$$+ \quad . \; . \; .$$

$$+ \left[\left(\sum_{j=1}^{n} P_{n(t)}c_{nj(t)}\right) m_{n1}\right] c_{12(t+1)} \quad .$$

In order to make explicit the interrelations between commuting and migration, let us now disaggregate the population residing in region i, according to its mobility (migration and commuting) status in (t+1). Those residing in region 1 at time (t) may be classified in eleven groups:

1. Those who have the same place of residence and same place of work in (t) and in (t+1):

$$(P_{1(t)}c_{11(t)})m_{11} \cdot c_{11(t+1)} + (P_{1(t)}c_{12(t)})m_{11} \cdot c_{12(t+1)} + \ldots + (P_{1(t)}c_{1n(t)})m_{11} \cdot c_{1n(t+1)} \; .$$

2. Those who have changed their place of work in order to avoid previous commuting:

$$(P_{1(t)}c_{12(t)})m_{11}c_{11(t+1)} + (P_{1(t)}c_{13(t)})m_{11}c_{11(t+1)} + \cdots + (P_{1(t)}c_{1n(t)})m_{11}c_{11(t+1)} \quad .$$

3. Those who have adopted commuting as a substitute for migration:

$$(P_{1(t)}c_{11(t)})m_{11}c_{12(t+1)} + (P_{1(t)}c_{11(t)})m_{11}c_{13(t+1)} + \cdots + (P_{1(t)}c_{11(t)})m_{11}c_{1n(t+1)} \quad .$$

4. Those who have changed their commuting destination:

$$(P_{1(t)}c_{12(t)})m_{11}c_{13(t+1)} + (P_{1(t)}c_{13(t)})m_{11}c_{12(t+1)} + \dots + (P_{1(t)}c_{1n(t)})m_{11}c_{1(n-1)(t+1)} \quad .$$

5. Those who have used migration as a substitute for previous commuting by migrating to their previous place of work:

$$(P_{1(t)}c_{12(t)})m_{12}c_{22(t+1)} + (P_{1(t)}c_{13(t)})m_{13}c_{33(t+1)} + \dots + (P_{1(t)}c_{1n(t)})m_{1n}c_{nn(t+1)} \quad .$$

6. Those who have used migration as a substitute to previous commuting, by migrating to a new place of work:

$$(P_{1(t)}c_{13(t)})m_{12}c_{22(t+1)} + (P_{1(t)}c_{12(t)})m_{13}c_{33(t+1)} + \dots + (P_{1(t)}c_{1(n-1)(t)}m_{1n}c_{nn(t+1)} \quad .$$

7. Those who have used migration as a substitute for becoming commuters:

$$(P_{1(t)}c_{11(t)})m_{12}c_{22(t+1)} + (P_{1(t)}c_{11(t)})m_{13}c_{33(t+1)} + \dots + (P_{1(t)}c_{11(t)})m_{1n}c_{nn(t+1)} \quad .$$

8. Those who have become in-commuters in region 1 as a consequence of out-migrating from region 1, i.e., by keeping their job in 1:

$$(P_{1(t)}c_{11(t)})m_{12}c_{21(t+1)} + (P_{1(t)}c_{11(t)})m_{13}c_{31(t+1)} + \dots + (P_{1(t)}c_{11(t)})m_{1n}c_{n1(t+1)} \quad .$$

9. Those who have become in-commuters in region 1 after out-migrating from 1, by taking a job in 1:

$$(P_{1(t)}c_{12(t)})m_{12}c_{21(t+1)} + (P_{1(t)}c_{12(t)})m_{13}c_{31(t+1)} + \dots + (P_{1(t)}c_{12(t)})m_{1n}c_{n1(t+1)}$$

$$+ (P_{1(t)}c_{13(t)})m_{12}c_{21(t+1)} + (P_{1(t)}c_{13(t)})m_{13}c_{31(t+1)} + \dots + (P_{1(t)}c_{13(t)})m_{1n}c_{n1(t+1)}$$

$+ \ldots$

$$+ (P_{1(t)}c_{1n(t)})m_{12}c_{21(t+1)} + (P_{1(t)}c_{1n(t)})m_{13}c_{31(t+1)} + \cdots + (P_{1(t)}c_{1n(t)})m_{1n}c_{n1(t+1)} \ .$$

10. Those who have adopted a combination of migration and commuting as a substitute for previous (usually longer) commute:

$$(P_{1(t)}c_{13(t)})m_{12}c_{23(t+1)} + (P_{1(t)}c_{12(t)})m_{13}c_{32(t+1)} + \cdots + (P_{1(t)}c_{1(n-1)(t)})m_{1n}c_{n(n-1)(t+1)} \ .$$

11. Those who have adopted a combination of migration and commuting as a substitute for a new commuting destination:

$$(P_{1(t)}c_{12(t)})m_{12}c_{23(t+1)} + (P_{1(t)}c_{13(t)})m_{13}c_{32(t+1)} + \cdots + (P_{1(t)}c_{1n(t)})m_{1n}c_{n(n-1)(t+1)} \ .$$

Type (1) and (4) obviously do not affect either the migration balance (inmigration minus outmigration) or the commuting balance (incommuting minus outcommuting), while type (2) and (3) affect only the commuting balance (the former leading to an increase, the latter to a decrease) and type (7) affects only the migration balance. All other types of spatial adjustment imply that both the migration balance and the commuting balance are affected: they lead to a decrease in the migration balance and an increase in the commuting balance; in the case of type (5),(6),(10) and (11) this increase in the commuting balance is due to a decrease in the out-flow, while in the case of type (8) and (9), the increase in the commuting balance is due to an increase in the in-flow.

Having made explicit the various combinations between migration and commuting, we now want to have a population growth model that takes these interrelations into account. As a first step, we present a simple accounting model where migration and commuting are simultaneously considered.* Because, by definition, we consider only the population of working age (i.e., 15 years of age and over), and for the sake of simplicity, we will disregard fertility. This would be valid in the case of medium-range projections, for instance.

At time t, the regional distribution of the population by place of residence and place of work is given by

$$\underset{\sim}{P}_t \underset{\sim}{C}_t \tag{1}$$

where $\underset{\sim}{P}_t$ is a diagonal matrix with the elements on the diagonal representing the population residing in each region

$$= \begin{bmatrix} P_1 & 0 & 0 & \cdots & 0 \\ 0 & P_2 & & & \vdots \\ & & \ddots & & \\ 0 & \cdots & & 0 & P_n^0 \end{bmatrix} \tag{2}$$

and $\underset{\sim}{C}_t$ is the commuting matrix, each element $c_{ij(t)}$ representing the proportion of those residing in i at time t who work in (and thus commute to) region j.

$$= \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & & \vdots \\ \vdots & & \ddots & \vdots \\ c_{n1} & c_{n2} & \cdots & c_{nn} \end{bmatrix} \tag{3}$$

In order to obtain the distribution of the population by place of residence and place of work at time (t+1), we first take into account migration.

*In a forthcoming paper, this migration-commuting model will be coupled to socioeconomic variables in order to obtain a model of population redistribution allowing for the treatment of both types of mobility simultaneously.

Let $\underset{\sim}{M}_{(t,t+1)}$ be the migration matrix, where each element m_{ij} represents the probability that an individual residing in region i at time t will reside (and thus survive) in region j at time t+1.

Then $\underset{\sim}{M}'\underset{\sim}{P}_t\underset{\sim}{C}_t$ gives the distribution of the population at time (t+1) by place of residence and previous place of work

and

$$\underset{\sim}{M}'\underset{\sim}{P}_t\underset{\sim}{C}_t\xi = \{P_{t+1}\} \tag{4}$$

where ξ is a column vector with all elements equal to 1

$\{P_{t+1}\}$ is a column vector representing the regional distribution of the population at time (t+1) by place of residence only.

The distribution of the population by place of residence and place of work at time (t+1) is thus given by

$$\left[\underset{\sim}{M}'\underset{\sim}{P}_t\underset{\sim}{C}_t\xi\right]_{dg} \underset{\sim}{C}_{t+1} = \underset{\sim}{P}_{t+1}\underset{\sim}{C}_{t+1} \tag{5}$$

where $\underset{\sim}{P}_{t+1} = \left[\underset{\sim}{M}'\underset{\sim}{P}_t\underset{\sim}{C}_t\xi\right]_{dg}$, a diagonal matrix with the elements on the diagonal representing the population residing at time (t+1), as obtained from (4)

This formulation has the advantage of allowing for the simultaneous integration of both migration and commuting, and of taking into account all interrelations between both phenomena.[30] As explained above, the size of the population residing in each region at time (t+1) will indeed depend upon the type of combination between M, C_t and C_{t+1}, and upon the relative weight of each of these combinations.

Matrix derivation could be used for evaluating the impact of a change in one of the determinants of migration or commuting on the regional distribution of the population at time t+1, once all interrelations between migration and commuting have been taken into account.

Suppose indeed we have the following gravity type commuting function

$$c_{t+1} = f(E_{i(t+1)}, E_{j(t+1)}, d_{ij(t+1)}) \qquad (6)$$

where E_i and E_j represent the number of jobs in i and j respectively
d_{ij} is the distance (in terms of time and monetary costs) between i and j.

An interesting problem could be: What would be the effect on the distribution of the population by place of residence and place of work (for <u>each</u> region i = 1,...,n) of a highway (or a rapid railway connection) being built between two particular regions i and j, considering all the possibilities of combining (between all regions) migration and commuting? Deriving (5) with respect to $d_{ij(t+1)}$, one obtains:

$$\frac{\delta [\underset{\sim}{M}' \underset{\sim}{P}_t \underset{\sim}{C}_t]_{dg}\ \underset{\sim}{C}_{t+1}}{\delta\ d_{ij(t+1)}} = [\underset{\sim}{M}\ \underset{\sim}{P}_t \underset{\sim}{C}_t \xi]_{dg}\ \frac{\delta\ \underset{\sim}{C}_{t+1}}{\delta\ c_{ij(t+1)}} \cdot \frac{\delta\ c_{ij(t+1)}}{\delta\ d_{ij(t+1)}}$$

where $\frac{\delta\ \underset{\sim}{C}_{t+1}}{\delta\ c_{ij(t+1)}}$ is a (n × n) matrix with zero elements everywhere, except for one unit element, in the i-th row and the j-th column;

and $\frac{\delta\ c_{ij(t+1)}}{\delta\ d_{ij(t+1)}}$ is obtained from (6).

The same type of sensitivity analysis could of course have been done for migration.[31]

3.4 Methodological Implications

Some important methodological remarks may be inferred from this discussion on the interrelations between migration and commuting.

The first and most important remark concerns the way migration and commuting are compared and combined. Since migration data refer to a time interval, while commuting data usually refer to an event observed at some moment of time, it is in most cases not valid to compare commuting data as obtained for one particular census or survey with migration data. In order to be meaningful, the comparison and combination should be done between migration flows for one time interval and the change in commuting flows over the interval.

This represents a highly constraining statistical limitation. Survey data on commuting are indeed in most cases not comparable over time, and it is very rare that the moments at which these surveys have taken place correspond to the time interval for which migration data are available. For this reason, census data on commuting are more useful. Countries for which this type of commuting data are available at two successive censuses are, however, rare. This also implies that only a cross-sectional analysis is possible.

A second methodological implication is that it is not necessary to have, for each individual, his place of work and his place of residence at two moments of time. For the purpose of the demographic growth model outlined above, it is "sufficient" to have data on the regional distribution by place of work for the population residing in each region, at two moments of time, and data on the number of interregional migrants over the interval defined by these two moments.

A third remark concerns the importance of using age-sex-specific migration and commuting data. The possibilities of combining (either by substitution or by complementarity) migration and commuting are indeed highly dependent upon the age-sex status. For instance, workers who are close to the end of their working years, will prefer commuting to migration, all other things being equal.

Finally, a thorough critical analysis of the way commuting flows have been defined should be made in order to make them comparable to the migration flows. Commuting as well as migration implies a fixed residence. The problem is thus to see what is meant by a "fixed" residence, and whether the same definition of a fixed residence has been used for commuting and for migration. Moreover, in the case of commuting, we have also to define a "fixed" place of work (for instance, how do we deal with workers who have multiple places of work?) and a "meaningful" commuting time (for instance, should workers who commute weekly or monthly, or whose commuting time is very short, be considered as commuters?). Even if "correct" definitions have been chosen, it is not definite that they will correspond to the spatial and temporal perceptions of those who will answer the questionnaire. For instance, some Canadian data on commuting obtained from the 1971 census are not useful because people misinterpeted what was meant by the "usual" place of work being "different" from the place of residence. The development of empirical studies on the interrelations between migration and commuting would require a considerable investment to be made in the area of these methodological problems.

NOTES

1. The fourth combination (both place of residence and place of work are given) is irrelevant for our purpose, since in this case the mobility problem is assumed to have been solved.

2. For instance, see L. Cooper, An efficient heuristic algorithm for the transportation-location problem, Journal of Regional Science, 16(3):309-315.

3. See A. Anderson and A. La Bella, A System of Models for Integrated Regional Development. An Application to the Silistra Case Study. Proceedings of Task Force Meeting I on Regional Development Planning for the Silistra Region (Bulgaria), edited by A. Anderson and D. Philipov. CP-79-7, Institute for Applied Systems Analysis, Laxenburg. (Pages 127-130.)

4. M. Schneider, Gravity Models and Trip Distribution Theory, Papers and Proceedings of the Regional Science Association, (1959) 5:51-58, and Chicago Area Transportation Study, Final Report, (1960) 2.

5. A.G. Wilson, Entropy in Urban and Regional Modelling, (1970) London: Pion; J.M. Choukroun, A General Framework for the Development of Gravity-Type Trip Distribution Models. Regional Science and Urban Economics, 5(2):77-202 (1975).

6. A. Anderson and A. La Bella, op. cit. Page 130.

7. For an example of this type of explanation, see J.F. Kain, The Journey-to-Work as a Determinant of Residential Location. Papers of the Regional Science Association, 9:137-160 (1962).

8. M.J. White, A Model of Residential Location Choice and Commuting by Men and Women Workers, Journal of Regional Science, 17(1):41-52 (1977).

9. See however: P. Burnett, Markovian Models of Movement Within Urban Spatial Structures, Geographical Analysis, 10(2):142-153 (1978); H. Eliot and M. Eliot, The Structure of Movement and Household Travel Behavior, Urban Studies, 6:70-82 (1969); R. Vickerman, The Demand for Non-Work Travel, Journal of Transport Economics and Policy, 6:176-210 (1972); P.L. Watson, Homogeneity of Models of Transport Model Choice: The Dimensions of Trip Length and Journey Purpose, Journal of Regional Science, 14(2):247-257 (1974).

10. L. Wingo, Transportation and Urban Land Use, Washington, D.C.: Resources for the Future, 1961; W. Alonso, Location and Land Use, Cambridge Massachusetts: Harvard University (1964).

11. R. Muth, Cities and Housing. Chicago, Illinois: University of Chicago University Press, (1969); and The Allocation of Households to Dwellings, Journal of Regional Science, 18(2): 159-178 (1978); J.P. Stucker, Transportation Improvements, Commuting Costs, and Residential Location, Journal of Urban Economics, 2(2):123-143 (1975).

12. See for example, R. Muth, Cities and Housing, op. cit., Pages 86-90; M.C. Romanos, Household Location in a Linear Multi-Center Metropolitan Area, Regional Science and Urban Economics, 7(3):233-250 (1977).

13. A. Okabe, Formulation of the Intervening Opportunities Model for Housing Location Choice Behavior. Journal of Regional Science, 17(1,:31-40 (1977).

14. T.R. Smith, W.A.V. Clark, J.O. Huff, and P. Shapiro, A Decision Making and Search Model for Intra-Urban Migration, Geographical Analysis, 11(1):1-22 (1979).

15. See A. Rogers, Matrix Methods in Urban and Regional Analysis, San Francisco, California: Holden-Day, (1971, Pages 49-54.)

16. One could of course also introduce both migration and commuting in the model, but for different population sub-groups. This, however, is not a simultaneous choice of place of residence and place of work. For an example of this kind of model, see D.E. Boyce and F. Southworth, Quasi-Dynamic Urban-Location Models with Endogeneously Determined Travel Costs, Environment and Planning, 11(5):575-584 (1979).

17. J.S. Desalvo, Theory of Locally Employed Urban Households, Journal of Regional Science, 17(3):345-355 (1977).

18. W. Fisher and M. Fisher, The Spatial Allocation of Employment and Residence within a Metropolitan Area, Journal of Regional Science, 15(3):261-276 (1975).

19. D. Gat, The Demand for Housing and Supply of Labor. A Model of Simultaneous Choice, Review of Regional Science and Urban Economics, 4(1):61-64 (1974).

20. H.W. Richardson, A Generalization of Residential Location Theory, Review of Regional Science and Urban Economics, 7(3):251-266 (1977).

21. J.O. Huff, Residential Mobility Patterns and Population Redistribution within the City, Geographical Analysis, 11(2):133-143 (1979).

22. M. Termote, Migration and Commuting in Lösch's Central Place System. The Analysis of Regional Structure, Essays in Honor of A. Loesch, edited by R. Funck and J.B. Parr. (Pages 83-90.) London: Pion, (1978).

23. For a mathematical formulation of this model of simultaneous determination of place-of-residence and of place-of-work, and of migration and commuting, see M. Termote, Migration et équilibre économique spatial. Louvain: Institut des Sciences Economiques. (Pages 152-162, 1969).

24. Belgian data were chosen because 1) Belgium is one of the very few nations for which census data on commuting are available, 2) data are available for flows between municipalities, administrative regions, provinces, and for border commuting, 3) the Belgian commuting flows and urbanization process may be considered as representative of the European case, as opposed to the American urban sprawl type of urbanization.

25. B.J.L. Berry, Spatial Organization and Levels of Welfare: Degree of Metropolitan Labor Market Participation as a Variable in Economic Development, paper prepared for the Economic Development Administration Research Conference, Washington, D.C., 1967, Page 4.

26. See U.S. Bureau of the Census, Place of Work and Means of Transportation to Work, for the United States: 1960, Supplementary Reports, Pages 51-22, Washington, D.C.,: U.S. Government Printing Office, (1962).

27. Institut National de Statistique, Résultats du Recensement du 31 décembre 1961, 9: La Mobilité Géographique de la Main d'oeuvre, Brussels (1965). The percent of Belgian commuters using a car in order to reach their place of work increased markedly, however; between 1961 and 1970, this figure rose from 14 to 43 percent.

28. J.B. Lansing, E. Mueller and N. Barth, Residential Location and Urban Mobility, Ann Arbor, Survey Research Center, Institute for Social Research, University of Michigan (1964).

29. By definition, we consider only the working population employed (at the moment of the census for instance), since only commuting to work is taken into account here.

30. Of course, instead of considering separately the $c_{ij(t)}$, the m_{ij} and the $c_{ij(t+1)}$, one could also use directly the product of these three probabilities. Data limitations, however, do not usually allow for this type of information. In most cases, we will indeed have to estimate separately each of the three sets of probabilities [the $c_{ij(t)}$, the m_{ij}, and the $c_{ij(t+1)}$]. A welcome exception in this respect is to be found in an extensive survey made in the Netherlands. See A.C.P. Verster and M. De Langen, Residential Mobility, Work Mobility, and Home-to-Work Accessibility, Netherlands Economics Institute, Rotterdam (1978).

31. For a very useful review of matrix differentiation techniques and applications, see F. Willekens, Sensitivity Analysis in Multiregional Demographic Models, Environment and Planning, A, 9(6):653-674 (1979).

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