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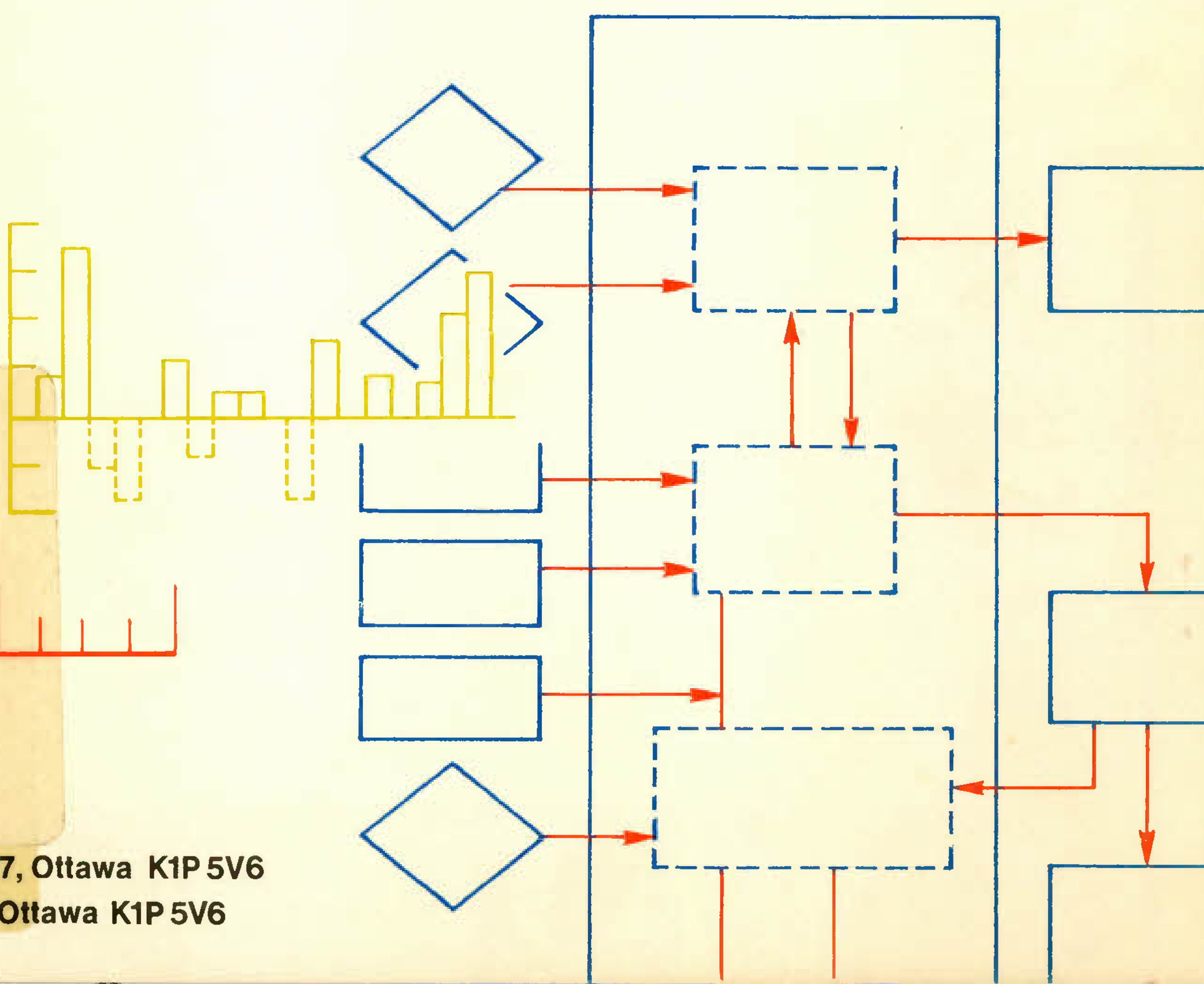

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DISCUSSION PAPER NO. 102

Residential and Job Location and The Journey-To-Work: A Review and Theoretical Perspective

Urban Paper No. 1

by

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and
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December 1977

Catalogue No. EC25-102/1977
ISBN 0-662-01445-6

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Economic Council of Canada
P.O. Box 527
Ottawa, Ontario K1P 5V6

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ABSTRACT

To a great extent, the combined choice of thousands of individuals as to where to live and where to work determine the physical and social character of the urban area and of the various communities therein. This paper delves into the literature in order to provide essential background material on the question of why people live and work where they do within the urban context. Starting with the early work relating the value of agricultural land to its proximity to the marketplace, and the transference of this concept to the urban context where a relationship between land and the proximity of this land to centres of activity was first posited, this document discusses the major landmarks in the economic and sociological literature concerned with residential choice, job location choice, and the relationship to these of the distance/cost of the jouney-to-work.

This paper then goes on to specify two potentially complementary models concerning these choices -- a Residential Location Model, and a Job Location Model. These models, which will be examined empirically in a subsequent paper, can each be considered either on a zonal basis, or from the viewpoint of the individual worker.

RESUME

Dans une grande mesure, le choix combiné de milliers d'individus en ce qui concerne leur lieu de résidence et leur lieu de travail détermine le caractère physique et social de la région urbaine et des diverses collectivités qui l'habitent. Dans le présent document, les auteurs scrutent les ouvrages disponibles afin d'y trouver les données essentielles touchant les facteurs qui motivent le choix du lieu de résidence et du lieu de travail, dans le contexte urbain. A l'aide des premiers travaux établissant la valeur des terres agricoles d'après leur proximité du marché, et de l'application de ce concept au contexte urbain où pour la première fois un rapport a été énoncé entre les terres et leur proximité des centres d'activités, ce document analyse les principaux textes de la littérature économique et sociologique qui traitent du choix du lieu de résidence et du lieu de travail, et du rapport de ceux-ci avec les éléments distance/coût du trajet quotidien au travail.

Les auteurs déterminent ensuite deux modèles potentiellement complémentaires au sujet de ces choix : l'un pour le lieu de résidence et l'autre pour le lieu de travail. Ces modèles, qui seront examinés de façon empirique dans un document ultérieur, peuvent tous deux être considérés tant sur une base zonale que du point de vue du travailleur individuel.

PREFACE

The Social Indicators Group of the Economic Council has undertaken a significant project the purpose of which is to examine residential, employment and corresponding journey-to-work patterns for the twenty-two Census Metropolitan Areas (CMA). Our *Urban Papers* series presents the background research, quantitative analysis, findings and conclusions and our policy and operational suggestions related to this project.

This project is made possible by the availability of small area (Census tract) data collected in the 1971 *Census of Population and Housing*, particularly that generated by the responses to Form B, the comprehensive inquiry made of each third household in Canada. From this data base it is possible to ascertain many of the economic and social characteristics of the employed labour force in each CMA, as of June 1, 1971, without breaching confidentiality.

While the data base first became available in 1975 and is now dated by seven years we feel that this place of residence-place of work information and the analysis based thereon is still relevant to current and future urban issues. Clearly these data represent the most comprehensive sample of information in this area that has ever been compiled; moreover, it is extremely unlikely that the same inquiry will be undertaken by the 1981 Census. Thus, the compilation of urban place of work, place of residence records provides an unique record of the shape of Canadian cities in this respect. More importantly, although it must be recognized that journey-to-work patterns may have changed to some extent since 1971 as cities have grown and evolved and other factors (e.g., the energy crisis) have come into play, the socio-economic motivations and forces which underlie individual choices of where to live and where to work, we suggest, change much more slowly. It is this set of socio-economic factors that our investigations emphasize. We expect that the personal motivations underlying the choice of residential and job location in 1971 are very similar today.

This project is the first major *intra*-urban research undertaking by the Council. It deals with small districts within each major urban area and evaluates the ways in which each district differs from the overall norm for the same urban area. One of the most obvious variations from district to district is the ratio of employed persons resident in the district to the number of persons employed in the same district. Clearly, if this ratio is greater than one, there must be a net out-commuting flow of people; if it is less than one, there must be a net in-commuting flow. This observation leads us to the consideration of journey-to-work flows. It follows that the *gross* flow of job commuters in and out of all districts gives rise to demands on the urban transportation system and this turns out to be a major factor determining the physical infra-structure of cities.

From a social perspective it is interesting and helpful to seek out the socio-economic aspects of the population which lead to residential, job and commuting choices as well as the physical/environmental manifestations which affect and are affected by the combined influence of thousands upon thousands of like decisions. As we stated earlier, the social relationships are likely to be enduring over time and our improved understanding of them should greatly assist in the planning and management of urban reality, now and in at least the medium-term future. Thus our emphasis is on the socio-economic analysis of the place of residence-place of work data base.

Clearly, as others before us have done, we could limit our research on flows to observing the realities indicated by the data available for a single particular urban area, and to describing the relationships between the factors observed and propose theories about urban relationships. While such an approach would have some operational value the hypothesis derived might well be too specific to our sample city to have relevance for Canadian urban areas in general. Our *Urban Papers* series will contain twenty-two "urban journey-to-work profiles", one for each CMA. These, together with the background data (which will be available on request), should be of interest and use to planners and managers in each urban area.

Turning to the objective of deriving information on the socio-economic factors underlying urban patterns of residence, job location, and journey-to-work choice, we believe that an approach quite different from that outlined in the previous paragraph is necessary. In this instance, we review the main literature in several disciplines and derive two general models -- a Residence Location Model and a Job Location Model. These models incorporate a number of variables (and proxies for those which are not directly observable), many of which represent social rather than specifically economic attributes associated with the urban labour force. We can then test these models using a data base which reflects reality.. If the models and their component variables are correctly specified, the results of our tests should confirm (or reject) the importance of the socio-economic factors, *in general*. That is, we need not examine each and every urban area to be confident in the validity of our "proven" hypothesis. Moreover, the compilation of the data required to test the general models over all cities would require a large, expensive and time-consuming effort. Thus, although our models are tested using data related to the Toronto CMA, we are confident that the findings and their inferences will be applicable in a general sense to most urban areas.

Interested researchers and urban managers should be able to make good use of our models and findings by applying parallel data for other urban areas.

In summary, the *Urban Papers* series will include:

- a literature review which traces the evolution of theory and empirical studies together with a general description of the two models we have developed;

- a detailed analysis of the journey-to-work patterns in the Toronto CMA and a sub-series of twenty-one "urban journey-to-work profiles" designed to be of direct planning/management interest and use to local governments (with background data available on request) and dealing with some specific inquiries (such as "job-sheds" which may be helpful in the design of planning zones);

- a paper which will evaluate the influence of socio-economic factors on the length of journey-to-work in the Toronto CMA and will draw general policy conclusions as to important socio-economic factos that might well be considered in the design of infra-structure (e.g., public housing and its location), zoning (e.g., appropriate placement of employment sites) and social services locations.

- a paper which will report on the results of the testing of our two proposed models including the interpretation of the relevance of our findings for urban planning and management and for policy design at the two sovereign levels of government.

The individual papers will be released upon completion and each paper will appear under the authorship of the principal researchers involved; however, most of the work will reflect some input from all members of the Social Indicators Group.

PREFACE

Le Groupe des indicateurs sociaux du Conseil économique a entrepris un important project dont l'objet est d'examiner les caractéristiques relatives aux lieux de résidence et d'emploi ainsi qu'au transport vers le lieu de travail dans les 22 régions métropolitaines de recensement (R.M.R.). Dans une série de *Cahiers urbains*, nous présenterons les recherches fondamentales, l'analyse quantitative, les constatations et les conclusions de cette étude, ainsi que des suggestions qui en découlent tant au plan des politiques que du point de vue pratique.

Ce projet est possible grâce à des données portant sur des régions peu étendues (secteurs de recensement), qui ont été recueillies à l'occasion du recensement de la population et des caractéristiques du logement, en 1971, notamment celles qui proviennent des réponses au questionnaire B dans le cadre d'une vaste enquête effectuée auprès d'un ménage sur trois au Canada. A l'aide de cet ensemble de données, on peut vérifier un bon nombre de caractéristiques économiques et sociales de la main-d'oeuvre employée dans chaque R.M.R., à partir du 1er juin 1971, sans accroc à la confidentialité.

Même si les données recueillies ne sont devenues disponibles qu'en 1975 et qu'elles datent donc maintenant de sept ans, nous croyons que les renseignements qu'elles fournissent sur les déplacements entre le domicile et le lieu de travail, ainsi que l'analyse qui en découle, sont toujours pertinents aux questions urbaines tant actuelles que futures. En fait, ces statistiques constituent l'échantillon le plus complet établi jusqu'à maintenant dans ce domaine. De plus, il est tout à fait improbable que la même enquête soit entreprise à partir du recensement de 1981. Par conséquent, la compilation de données sur le lieu de travail et le domicile des citadins fournit un dossier unique sur la structure des villes canadiennes à ces deux points de vue. Même s'il faut reconnaître que les caractéristiques des déplacements pour aller au travail ont peut-être changé dans une certaine mesure depuis 1971, à cause de la croissance des villes et d'autres facteurs (comme la crise de l'énergie), les motivations et les forces socio-économiques qui déterminent, chez les gens, le choix de l'endroit où ils veulent vivre ou travailler, évoluent, croyons-nous, beaucoup plus lentement, et c'est là un phénomène très important. C'est cet ensemble de facteurs socio-économiques que nos recherches mettent en évidence. Nous croyons que les motifs personnels qui déterminent le choix d'un endroit où demeurer et un lieu de travail sont très semblables aujourd'hui à ce qu'ils étaient en 1971.

Ce projet représente la première étude intra-urbaine d'importance entreprise par le Conseil. Il porte sur de petits secteurs dans chaque grande région urbaine et montre comment chacun d'eux diffère de la norme générale dans une même région.

L'un des phénomènes qui varient apparemment le plus d'un secteur à l'autre est le rapport entre le nombre de personnes employées demeurant dans le secteur et le nombre de celles qui y travaillent. Si ce rapport est supérieur à un, c'est qu'il doit y avoir un mouvement net de travailleurs hors du secteur; s'il est inférieur à un, c'est le contraire, soit un flux net vers le district en cause. Cela nous amène à la question des déplacements pour aller au travail. Il s'ensuit que le flux brut des travailleurs en provenance et à destination de tous les secteurs accroît le recours au système de transport urbain, ce qui représente l'un des principaux facteurs déterminant de l'infrastructure matérielle des villes.

Du point de vue social, il est intéressant et utile de chercher à connaître les aspects socio-économiques de la population qui sous-tendent les choix des gens quant à leur domicile, à leur lieu d'emploi et aux modalités de transport au travail, ainsi que les phénomènes physiques et écologiques qui subissent les effets de milliers et de milliers de décisions semblables qui les influencent à leur tour. Comme nous l'avons déjà dit, les relations sociales deviendront probablement plus durables à la longue, et, si nous les comprenons mieux, nous serons mieux en mesure de planifier et de gérer la réalité urbaine, maintenant et au moins dans l'avenir à moyen terme. Voilà pourquoi nous insistons sur l'analyse socio-économique des données relatives au lieu de résidence et au lieu de travail.

Vraiment, comme d'autres l'ont fait avant nous, nous pourrions, dans nos recherches sur les flux, nous borner à observer les faits que révèlent les données disponibles pour une seule région urbaine en particulier, à décrire les relations entre les facteurs observés, puis proposer des théories au sujet des relations urbaines. Bien qu'une telle approche aurait une certaine valeur pratique, l'hypothèse qui en découlerait pourrait bien être trop particulière à la ville retenue comme échantillon pour s'appliquer à l'ensemble des régions urbaines du Canada. Dans nos *Cahiers urbains*, nous présenterons 22 "schémas de transport au travail", un pour chaque R.M.R. Ces schémas ainsi que les données de base (qui seront disponibles sur demande) devraient intéresser les planificateurs et les gestionnaires de chaque région urbaine, et leur être utiles.

Dans la recherche de renseignements au sujet des facteurs socio-économiques qui sous-tendent les schèmes de choix relatifs aux lieux de résidence et d'emploi, ainsi qu'aux moyens de se rendre au travail, nous pensons qu'il y a lieu d'adopter une approche tout à fait différente de celle que nous avons décrite au paragraphe précédent. Pour ce faire, nous étudions les principaux ouvrages, dans plusieurs disciplines, en vue d'en tirer deux modèles généraux, l'un sur le lieu de résidence des gens, et l'autre, sur leur lieu d'emploi. Ces modèles comprennent un certain nombre de variables (et des variables instrumentales pour remplacer celles qui ne sont pas directement observables). Plusieurs d'entre elles représentent des caractéristiques sociales, plutôt que nettement économiques, de la population active urbaine. Nous pouvons ensuite vérifier ces modèles au moyen de données reflétant la réalité. Si la spécification des modèles et de leurs variables est correcte, alors les résultats de nos tests devraient confirmer (ou contester) l'importance des facteurs socio-économiques *en général*. Autrement dit, nous n'avons pas besoin d'examiner chacune des régions urbaines pour croire à la validité de l'hypothèse que nous avons prouvée". De plus, la compilation des données nécessaires pour tester les modèles généraux en les appliquant à toutes les villes demanderait une dépense considérable d'efforts, de temps et d'argent. Par conséquent, bien que nos modèles soient vérifiés au moyen de données relatives à la région métropolitaine de recensement de Toronto, nous avons bon espoir que leurs résultats et leur conclusions s'appliqueront en général à la plupart des régions urbaines.

Les chercheurs et les gestionnaires urbains intéressés devraient pouvoir tirer parti de nos modèles et de nos constatations en appliquant des données parallèles pour d'autres régions urbaines.

En résumé, la série des cahiers urbains comprendra:

- un survol de la littérature retraçant l'évolution des études théoriques et empiriques ainsi qu'une description générale des deux modèles que nous avons mis au point;

- une analyse détaillée des caractéristiques du trajet quotidien vers le lieu de travail dans la région métropolitaine de recencement de Toronto et une sous-série de vingt et un "schémas de transport au travail" que les administrations municipales pourront utiliser dans leurs travaux de planification et de gestion (avec données de base disponibles sur demande) traitant de certaines questions particulières (comme par exemple les réservoirs d'emplois qui peuvent se révéler utiles dans l'élaboration des zone de planification);

- un document évaluant l'influence des facteurs socio-économiques sur la durée du trajet vers le lieu de travail dans la région métropolitaine de recensement de Toronto et tirant des conclusions générales en matière de politique en ce qui concerne les importants facteurs socio-économiques dont il faudrait peut-être tenir compte dans la conception de l'infrastructure (exemple : l'emplacement du logement public), le zonage (exemple : le choix approprié des lieux d'emploi) et l'emplacement des services sociaux.

- un document qui fera connaître les résultats des tests effectués sur les deux modèles proposés et qui fournira une interprétation de la pertinence de nos conclusions pour la planification et la gestion urbaine, ainsi que pour l'élaboration des politiques aux deux niveaux souverains de gouvernements.

Chaque document sera publié dès qu'il sera terminé, sous la signature des principaux chercheurs concernés; toutefois, la majeure partie des travaux sera le fruit de l'effort collectif de tous les membres du groupe des indicateurs sociaux.

ACKNOWLEDGEMENTS

For their useful comments at various stages of research and on earlier versions of this paper, we thank all members of the Council's Social Indicators Group and P.S. Rao of the CANDIDE Group. We thank in particular David Henderson and Dennis Paproski for their invaluable advice, comments, and suggestions during the course of writing this paper and for reviewing and editing the final draft. The expert typing by Jocelyne Parisien is much appreciated. Remaining shortcomings are the responsibility of the authors alone.

INTRODUCTION

The choice of "where to live" is one of the most crucial decisions made by urban households -- crucial not only to them, but to the urban area as a whole -- for the sum and synthesis of this residential decision by households, through the urban land market, through the creation of social neighbourhoods with distinct characteristics, and through their demand for different amounts and types of housing, is one of the prime determinants of the structure and character of our urban areas.

The explanation of why households live where they do, however, is a complex and difficult task. Besides a host of other social and economic factors, one of the important determinants of this decision is the location of the workplace(s) of the household's working member(s) and the cost of travel to the workplace. Indeed, there exists a complex interdependence between job location, length of work-trip, and residential location, so that if we are to really understand the household's residence choice, we are immediately led into a consideration of such other factors as job location alternatives (if any), the amount of housing the household wishes to consume, the alternative means of transportation available to the working members of the household, the household's income, and so on.

This paper undertakes a critical review of the literature pertaining to the series of decisions concerning location that face all urban households. This examination of the major ideas and problems in the literature will serve as the foundation for our own theoretical models.

In this paper we present two models. The first deals with residential location assuming that the job location is given. The second examines job location assuming a given residential location. Most of the background literature pertains to the former model but the more limited literature on the latter suggests that this second model is necessary. Thus the second model represents a considerable original input in addition to concepts discovered in the literature. Both models are tested in a following paper. It is hoped that a better understanding of the behaviour of households (both individually and in the aggregate) in this regard will contribute to our understanding of the structure of urban areas.

Since the concerns involved are so numerous and diverse (ranging from the social characteristics of neighbourhoods to the price of land and its determinants), this review encompasses areas of sociology, geography, and economics. We consider, in turn, the early economic theory of land-rents, the relatively non-economic work of the Chicago school on urban residential patterns, the basic modern economic theory of residential location, and the various empirical models of journey-to-work patterns that have been developed in 1960s and 1970s by both geographers and economists. We then summarize the main problems raised in the literature and indicate how they are circumvented in our own models.

Section 1: LAND-RENTS AND RESIDENCE PATTERNS -- EARLY ECONOMIC THEORY

The basic notion of a trade-off between the price paid for the use of a particular location and the transportation costs arising from its distance from other locations of interest has existed in economics for a long time. As we shall see, this notion has been gradually applied over time to the choice of residence sites.

The earliest literature that dealt with the relationship between transportation costs and the location of activities in general dealt with agricultural land. This is understandable given the predominantly agricultural character of the economies of the time. While Ricardo attributed differences in land-rents[1] primarily to fertility differentials (Alonso, 1964) [2],[2] Von Thünen (1826) [68] was the first to show that the rents of land around a marketplace would also be determined by their proximity to that marketplace. The process of competitive bidding between potential users of various parcels of land would thus simultaneously determine both the level and rate of decrease of rents for land progressively farther from the central marketplace. As well, the location would determine various types of land use. Land use patterns in the Von Thünen model, would appear as concentric rings around the market. Alonso [2] summarizes Von Thünen thus:

> The various agricultural land uses around a marketplace bid for the use of land, and land is assigned to the highest bidder in each case. The rent each crop can bid at each location will be the savings in transportation of its product that the site affords in contrast with a more distant site. (p. 3) [2]

Von Thünen's view of the relation between land, rents, transport costs and the allocation of land uses was not applied

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1. In this context rent is simply the payment for the use of land.

2. Numbers in square brackets indicate the sequence number in the alphabetically ordered list of references.

to urban land[1] until 1903, in Hurd's *Principles of City Land Values* (1903) [31]. Hurd recognized the applicability of the previous theory on agricultural land to land use in cities:

> As first laid down, the theory of agricultural ground rents emphasized fertility as a source of rent. Later ... accessibility or proximity to cities was recognized as an important factor in creating agricultural ground-rent. In cities, economic rent is based on superiority of location only ... (p. 1) [31]

The basic idea that the distribution of land uses in a city is determined by a bidding process in which transport costs to the centre are dominant considerations was already present in Hurd's analyses. However, this idea was not thought applicable to the question of *residential* land (and thus the transport costs associated with it, i.e., the work trip) until quite some time later. Rather, Hurd's explanation of the location of residences hinges mostly on "social" factors:

> ... the basis of residence values is social and not economic -- even though the land goes to the highest bidder -- the rich selecting the locations which please them, those of moderate means living as nearby as possible, and so on down the scale of wealth .... (pp. 77-78) [31]

Thus, for Hurd, the main factor determining residential location is the social class of the household and the neighbourhood. The length of the journey-to-work is seen as a secondary factor to social considerations -- a view we shall see expounded by several more recent theorists as well.

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1. Aside from a few comments by A. Marshall -- see Alonso [2], (p. 4).

In 1926, however, Haig (1926) [25] did apply Von Thünen's basic "economic" hypothesis to urban residential land. To him, there was no difference in principle between factors affecting residential location and those affecting industrial location in cities. The trade-off between accessibility and housing-rents is at the centre of this analysis, so that Haig at least implicitly considered the length of the work-trip as a primary determinant of residential location:

> An economic activity in seeking a location finds that, as it approaches the centre, site-rents increase and transportation costs decline. As it retreats from the centre, site-rents decline and transportation costs increase.... The theoretically perfect site is that which furnishes the desired degree of accessibility at the lowest costs of friction.
>
> If the economic activity seeking a site happens to be housing is not the problem worked out in this fashion...? (pp. 422-23) [25]

Although Haig outlines the basic economic factors affecting the household's choice of residential location, this early economic analysis contained a number of shortcomings. For one, Haig did not adequately explain why different groups of people choose different residential sites. Because the comparative static implications of his hypothesis were never clarified (for example, if the income of a group increases relatively, how does this change the location of the optimum residential site for this group?), the analysis remained centred on the individual household; it did not consider the distribution of residences of various groups throughout the city. A second problem which Haig does not deal with is related to the first and concerns the influence of social factors such as the establishment of socially homogeneous neighbourhoods throughout the city and the effect of these on the choice of residential location. A third is the lack of explicit recognition of role of the work-trip in the decision concerning residential location; presumably this is included in the general notion of "accessibility".

We now turn from the domain of economics and enter those of urban sociology and geography where the work of the Chicago school is particularly important. In contrast to Haig, the main focus of the Chicago school (especially in the earlier works of Burgess (1925) [13] , Hoyt (1939) [30], and Harris and Ullman (1945) [26]) was on the determinants of overall urban structure, with primary focus on residential neighbourhoods and their social characteristics. Much of this earlier work lacked the theoretical underpinnings illustrated in Haig's economic approach, but, being quite frankly descriptive and inductive, it provided a useful set of descriptions, generalizations and concepts for further analysis. Later, as we shall see, two distinct theoretical explanations of residential location did emerge from this earlier work. One of these focused directly on the trip to work and soon led to a refinement of Haig's hypothesis and a return to the field of economics as a theoretical basis. The other remains an alternative to the economic approach.

Section 2: THE CHICAGO SCHOOL

2.1 Early Work: Urban Residential Patterns

The first theory describing the location of activities within metropolitan areas was put forward by Burgess [13] in 1925 and was generally known as "the concentric zone theory". Burgess' five concentric zones were: a central business district (CBD) where there is the greatest concentration of employment; a zone in transition, being invaded by business and light manufacturing activity; an area of working men's residences; a zone of middle class residences; and finally, a zone of commuters' homes.

The reasons for the emergence of this particular spatial pattern were not made explicit by Burgess. However, it was implicitly assumed that as the population of a city grew and the housing stock increased, the higher income groups gravitated towards the newer and larger accomodation in the recently established outer rings, while lower income groups lived in housing that had been abandoned by the higher income groups and had thus "filtered down" to them (Evans, 1973) [19]. Thus Burgess' zonal hypothesis argues that urban areas are differentiated in their patterns of residential location by socio-economic groups, the lower status groups increasingly inhabiting the central area to live within easy access of their work and the upper status groups moving to the outskirts as cities age and become larger. Though Burgess' basic ideas explaining residential patterns were analytically sound, his model remains completely inductive in nature and is based on only one observation -- the Chicago of the 1920s. It is thus severely limited in its generality (Senior, 1973) [59].

Other mostly inductive models of residential patterns in the city were constructed by Hoyt [30] who abstracted from observations of residential patterns in 142 American cities, and by Harris and Ullman [26]. Hoyt [30] found evidence for a sectoral pattern of residential location in contrast to a pattern of concentric circles, as in Burgess. He also argued that the patterns of residential location are not fully explained by the filtering-down process. Based on the economic criterion reflected in the rental value of the dwellings, the sector theory explained that the higher-income groups will tend to occupy new housing situated on the best residential land in the high-rent sector and the lower income groups will locate in the adjacent sectors to the extent that they can also afford new housing. Hoyt placed considerable emphasis on the shifting location of the high-class residential district which, like other land uses and residential districts, tended to move outward along a transportation axis running through the same sector in which it started.

Harris and Ullman [26], in contrast to both the Burgess and the Hoyt models, which assumed the growth of the cities around a single centre (the CBD), presented another ideal-typical view of the distribution of urban land uses in their "multiple nuclei" model. They asserted that land use patterns may be oriented to more than one centre of activity. Thus they pictured the growth of cities around several discrete nuclei, while not denying the dominance of the CBD over all these. While Harris and Ullman do not suggest any consistent spatial form for urban land use, they rather vaguely explain the existence of separate centres by four factors:

(i) Certain activities require specialized facilities (access to water or cheap land, etc.).

(ii) Certain like activities group together because they profit from cohesion.

(iii) Cetain unlike actvities are detrimental to each other.

(iv) Certain activities are unable to afford the high rents of the most desirable sites. (pp. 283-84) [26]

Thus, according to Harris and Ullman, different land uses in a city will locate according to their own particular needs, and this creates various centres of activity. Some broad generalizations about residential areas are made:

> In general, high class districts are likely to be on well-drained, high land and away from nuisances such as noise, odours, smoke and railroad lines. Low class districts are likely to arise near factories and railroad districts, wherever located in the city. (p. 285) [26]

However, since the pattern they present "represents one possible pattern among innumerable variations" (p. 281) [26], their model is too general to explain or predict any specific city-wide distribution of residence.

Indeed, while all three constructs (zone, sector and multiple nuclei) and combinations of them (see Evans [19], who reconciles Hoyt and Burgess) are useful descriptive formats their explanation of existing patterns is basically *post facto*. They have, however, provided useful, thought-provoking ideas, which could later be systematized into more or less testable hypotheses of residential location.

2.2 Developments

During the 1940s and 1950s, a great deal of empirical work emerged from the Chicago school, in particular in relation to the development of factorial ecology and social area analysis using census tract data. Shevky and Bell (1955) [62] constructed three basic indices concerning social rank, family status and ethnicity respectively. These three are thought by many to represent the most important dimensions by which the patterns of residential differentiation of metropolitan areas can be studied. This type of analysis demonstrated the utility of the factor analytic technique as a sensitive and efficient methodology. In general the basic procedure that was followed in such analyses was to measure the socially significant characteristics of supposedly homogeneous census tracts and to correlate these with other factors, especially distance from the CBD. Blumenfeld (1949) [10] extended support to the "Burgess zonal hypothesis" by finding a significant relationship between socio-economic status and distance from the centre in the Philadelphia metropolitan area.

Up to this point, the work of the Chicago school focused on residential patterns, while the journey-to-work -- one of its main determinants -- received little attention. At best, it was occasionally invoked in an *ad hoc* fashion, as for example, in Burgess' contention that working men desire to live close to their workplaces. However, after 1944, one very important branch of the literature focused increasingly on the work-trip and its relation to residential location.

In 1944, Liepman (1944) [41], in England came to see the journey-to-work as a major factor in social choice. She focused on the social and economic factors related to the ever-longer journey-to-work -- the most important of which was the increasing "catchment area" of the labour market and thus the number of opportunities available for both employers and workers -- postulating that perhaps the social costs of the longer work-trip could be reduced by a change in urban form without losing any advantages provided by increased opportunities. Her main contribution, from our point of view, was to focus attention on the work trip itself as a significant private and social cost, and as a crucial influence on the spatial pattern of residence and work-places in cities.

A considerable amount of empirical work had been done on the length of the journey-to-work by the 1950s. Loewenstein's (1965) [42] summarizes some of the factors that were found important:

> ... the predisposition to travel between place of residence and place of employment varies according to attributes of the employee. It has been documented, for instance, that men will journey farther than women, renters farther than homeowners, non whites farther than whites, members of upper socio-economic status groups farther than members of lower groups, higher incomes farther than middle or lower incomes, and that recent employees travel greater distances to work than those with more seniority. (p. 131; references omitted) [42]

In 1952, Carroll (1952) [14] proposed a theory of the "spatial relationships of homes to workplaces" based upon Zipf's principle of least effort (1947) [77]. He stated that "forces are in operation tending to minimize distances between home and place of work" (p. 271) [14]. This suggests that the relationship between the spatial distribution of residences and the spatial distribution of workplaces tends to reflect an effort on the part of workers to minimize the journey-to-work distance. Three major generalizations were made to describe spatial patterns of home and workplace:

(i) Total urban area population is residentially distributed about the central business district of the principal city.

(ii) Residential distribution of persons employed in central districts tends to approximate that of the entire urban area population.

(iii) Residences of persons employed in off-center workplaces are concentrated most heavily in the immediate vicinity of the place of work. (p. 271-82) [14]

Although Carroll's initial study focused on the importance of the concept of journey-to-work and its implications for city planning, it never made explicit any of the other major forces at play in the locatin of residence which work against the minimization of the length of the journey-to-work.

This was first done by Schnore (1954) [58]. He modified Carroll's hypothesis that the fundamental determinant of a worker's residential location is his desire to minimize the journey-to-work, proposing that it is not simply transportation costs to work (approximated by distance) that are minimized, but rather the sum of transportation and housing costs. He recognized, as did Haig back in 1926, that housing costs fall as the household moves away from the city centre(s) (also job site for most), while transport costs rise. The optimum location for the household is then "at that point beyond which further savings in rent are insufficient to cover the added costs in transportation to these centres" (p. 342) [58].

The similarity of Schnore's proposition to the early suggestions of economists (Haig, etc.) should be apparent. Schnore, however, provided the first systematic formulation of what we shall call the economic trade-off hypothesis of urban residential location, specifically pointing out the relation of the trade-offs between commuting and housing costs to the overall spatial pattern of cities.

On the basis of Schnore's cost-minimization hypothesis, Duncan (1956) [18] proposed that the following results should be observable:

> (i) the degree of work-residence separation varies directly with the socio-economic level of the worker,
>
> (ii) the degree of separation is directly related to the centralization of the workplace, and
>
> (iii) the degree of separation is greatest for workers of high socio-economic level with centralized workplaces. (pp. 48-56) [18]

In Chicago, Duncan found empirical evidence to support hypotheses (i) and (iii); in the case of the second hypothesis the results were not clear and consistent. Schnore's and Duncan's ideas mark the logical conclusion of the work done by members of the Chicago school that led to an emphasis on the economic aspects of the impact of the journey-to-work on residential location. This approach was subsequently taken up by economists, forming the basis of the economics of urban residential location.

Within the Chicago school, however, there developed in parallel to this approach another type of explanation of residential location, using a sociological approach stressing non-economic factors ((Park, 1925) [54]; (Firey, 1947) [20]). This approach emphasized factors such as neighbourhood quality, social climate, compatible friends and neighbours, shared values and sentiments in the choice of residential location, and the concept of the neighbourhood as a relatively homogeneous and "natural" social unit (Greer, 1968)[22]. Residential choice was thus based on the match between the household's social characteristics and those of the (potential) residential neighbourhood, or in other words, on the "social distance" between them (Moriarty, 1970) [46]. Furthermore, many studies such as Boyce (1969) [11], Rossi (1955) [57], Stegman (1968) [64], and Webber (1963) [69] emphasized the importance of amenities and argued that accessibility is not the primary determinant of residential location.

In summing up the work of the Chicago school, or the "urban ecologists" as they are sometimes called, Senior [59] has rightly assessed the contributions of the school as a whole to the study of residential location patterns:

> ... this approach has been predominantly descriptive in its model-building activity... These findings have sufficiently clarified our picture of urban residential structure as to be suggestive of hypotheses of residential location behaviour which may be fruitfully incorporated into more analytically-oriented model designs...
>
> The concepts from which these models have originated are inadequate for explaining the spatial patterns identified ...
>
> The major implication of this work is that it should be used as a foundation on which to build models that attempt to incorporate 'how' and 'why' residential location patterns come about. (p. 177) [59]

To sum up, we have seen that it is possible to construct, following Moriarty [46], two competing explanations or hypotheses regarding the emergence of residential patterns: the "economic competition" and "social choice" hypotheses. Both these hypotheses focus on the factors affecting the household choice of where to live, but they stress different types of influences on this decision. The "social choice" hypothesis (following the work of Firey [20]; Rossi [57]; Webber [69]; Greer [22]; Stegman [64]; and Boyce [11]) assumes that the residential location of the individual household in an urban area is due to differences in the values, needs and desires of the social groups. The "economic competition" hypothesis proposes that the residential location of an individual household can be described in terms of a trade-off between transport costs and housing costs. Given the trade-off, varying space needs and income resources of different groups then determine their residential location ((Alonso, 1960) [1]; Alonso [2]; (Wingo, 1961) [73] and [74]; (Kain, 1962) [34]; (Mills, 1967) [45]; (Muth, 1961) [49]; (Muth, 1969) [50]; (Blackburn, 1971) [9]; (Papageorgiou and Casetti, 1971) [53]).

Although the social choice hypothesis points out important factors in the residential location decision, it has not inspired a great deal of research or enlightening findings. One reason is that it focuses on social amenities which are difficult to measure and have no market prices, *per se*. The main problem, however, is that while this hypothesis may be able to explain an individual household's choice of residence, given a pre-existing urban structure and the existence of such separate residential areas for different income and status groups, it cannot by itself explain (without recourse to historical or economic factors) why any particular residential area is where it is, say in relation to the CBD.

Yet, this is precisely what the "economic competition" approach seeks to do. Thus, while not denying the importance of social factors in the household locational decision, we now turn to the more quantifiable and therefore testable, economic approach and its development. This approach, as has been suggested, stresses the interdependence of the journey-to-work and residential location and offers an explanation of existing urban residential patterns.

Section 3: THE ECONOMIC THEORY OF RESIDENTIAL LOCATION

3.1 The Basic Economic Theory

Following Schnore's [58] hypothesis, that housing costs fall while transport costs increase with increasing distance from a centre of activity, Hoover and Vernon (1959) [29] were the first economists to explain the pattern of residential location in a city in terms of the trade-off between travel costs and housing costs. In a study of the relationship between home and workplace for the New York Metropolitan Region, they argued that in making a choice of residential location, Manhattan workers traded-off travel time for spacious living.

This theory was formally stated by Alonso [1, 2], and Wingo [73, 74] and forms the basis of what is now called the "economics of residential location". By considering the supply of and demand for residential, industrial and agricultural land, Alonso formulated a general theory of the determination of urban *land* uses and *land* rents, based on the principle of accessibility. Clearly other factors, such as housing structures and the supply of housing may be as important as accessibility in determining *housing* costs and, therefore, residential choice; Alonso did not incorportate these factors in his general theory (Senior, 1974) [60]. Wingo, on the other hand, attempted to explore the effect of changes in the transportation system on urban land use. Both these studies present theoretical analyses of the household's residential location decision which incorporate workplace location and trip-to-work as major factors.

In these analyses, it is assumed that workers first establish their place of employment, generally assumed to be the CBD, and then select a suitable place of residence. In order to minimize the time and cost of travel, the workers desire to live near the employment site as long as suitable residences are found. If the neighbouring areas around the CBD tend to be congested or environmentally undesirable, the workers will move farther out from the centre of the city, increasing the distance of the journey-to-work in order to obtain residential lots that have certain desirable features. Both Alonso and Wingo argue that higher status workers, in particular desire low density housing or land. In general, then, workers maximize their utility, given available income, by trading off the attractiveness of the residential lot against their proximity to employment.

The work done by Alonso and Wingo, refined and made more comprehensive by Muth [50], provides a basic, common theoretical framework for all recent economic models of residential location and trip-to-work. Because of its importance, a generalized presentation of this basic framework, in its simplest form, is given here.

Within this framework construct, it is assumed that the household chooses a residential location in an urban area situated on a homogeneous plain (i.e., a plain with undifferentiated physical features in all directions). All the jobs are assumed to be located in the urban centre, so that the household chooses its location site in r lation to the exogenously given job site in the CBD. Transport costs are a monotonically increasing function of distance from the centre of the city regardless of the direction of travel. The housing market is assumed to be competitive and to have reached a state of long-run equilibrium, although no changes in the supply of housing are considered.[1] In the competitive housing market, the bidding process by various households has established a negatively sloped location rent gradient as one moves away from the city centre, implying that housing prices or rents decrease with incresing distance from the CBD job site. Housing of varying quality is available in all parts of the urban area. All the households working in the CBD are assumed to be of the same size, and to have identical tastes and preferences.

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1. See pp. 30-31 for a fuller explanation of this point.

Each household is assumed to derive utility from housing (which includes housing characteristics or attributes such as type of structure, size of the lot, number of rooms, etc.), and from a composite commodity representing all other goods and services, while disutility arises from commuting activity (Alonso [2]). In order to maximize utility subject to budgetary outlays, the household may trade off a centralized location against more or better housing and/or other goods and services.

The representative houshold's utility function[1] is expressed as:

$$u = U(z, q, d) \tag{1}$$

where q represents the quantity and quality of housing consumed; z represents the consumption of all other goods and services and d is the distance between the centre of the city and the household's residence. The household faces a budget constraint of the form:

$$Y = P \cdot z + R(d) \cdot q + T(d) \tag{2}$$

where Y represents the income of the household, P represents the price per unit of the composite commodity (z), R is the rent per unit of housing[2] and T is the transportation cost of commuting,

---

1. Alonso [2] and Wingo [73] treat this utility function as being for the "individual" and the "workers" whereas Muth [50] regards this as being for the "household".

2. To avoid thorny definitional problems and confusion between different expressions, for example, land-rent, location-rent, cost of housing, price of housing etc., it is convenient to use the term 'rent' or 'location-rent'. It is assumed that site rents, land values, price of housing, etc. are included in rent/location-rents. This is appropriate since most of the discussion focuses on housing expenditures rather than housing costs. Moreover, henceforth, we shall term q as representing the quantity of housing demanded (for a given level of quality).

which are both assumed to be a function of distance d from the CBD. It is assumed that these expenditures exhaust imcome; i.e., these are no household savings.

Some variation in this basic framework occurs between Alonso's and Muth's presentation. For example, in Alonso [2], q represents the quantity of land whereas in Muth [50], q represents the quantity of land and housing together. Muth [50] did not include 'd' in the utility function, as his transportation costs T(d) include travel-time costs, varying by income, and Y includes a money valuation of time.

Equation (2) contains within it the alternative ways in which the individual may spend his income. The individual will try to maximize his satisfaction within the restraint of his income. In other words, the problem is to find out which combination of z, q, d, satisfying the budget constraint (Equation (2)), yields the highest value of u in Equation (1). In order to maximize the utility function (Equation (1)) subject to the budget constraint, an individual's Lagrangian function can be expressed as

$$L = U(z,q,d) + \lambda(y - P\cdot z - R(d)\cdot q - T(d)) \qquad (3)$$

where L is a function of z,q,d and λ. L is identically equal to u for those values of z,q and d which satisfy the budget constraint, since then $y - p\cdot z - R(d)\cdot q - T(d) = 0$. λ is the as yet undetermined Lagrangian multiplier. To maximize L, we calculate the partial derivatives of L with respect to z,q,d, and λ and set them equal to zero (in order to derive the first order conditions):

$$U_z - \lambda P = 0$$

$$U_q - \lambda R(d) = 0$$

$$U_d - \lambda(R_d \cdot q + T_d) = 0 \qquad (4)$$

$$Y - P \cdot z - R \cdot q - T = 0$$

where U_z, U_q, U_d are the respective marginal utilities of the composite commodity (z), housing (q) and commuting distance (d). R_d is the marginal expenditure/savings in rent and T_d is the marginal commuting costs. The Lagrangian multiplier λ can be interpreted as marginal utility of income. Utility is maximized when,

$$\lambda = U_z/P = U_q/R(d) = U_d/(R_d \cdot q + T_d) \qquad (5)$$

The above first order conditions (Equation (5)) indicate that utility is maximized when the household allocates its income in such a way as to equalize the ratios of the marginal utilities of the goods to their respective prices. For achievement of locational equilibrium, a process of substitution takes place between marginal increases in commuting costs T_d, and marginal savings in the housing expenditures $R_d.q$, as the household considers sites at increasing distances from the CBD. For the household's utility to be at a maximum,[1] it must locate at a distance from the centre of the city where the marginal rent-cost is equal to the marginal journey-to-work cost (Muth [50]).

In consideration of distance alone, disutility arises from commuting activity i.e., $U_d < 0$. This being the case, equation (5) can hold only when $(R_d.q + T_d) < 0$.

---

1. Assuming that the second-order conditions are fulfilled.

Since as assumed earlier, transportation costs increase monotanically with distance, this would imply that the marginal increase in commuting costs would always be positive. Thus T_d must be positive, and if this is so then $R_d.q$ must be negative.[1] Further, the marginal savings in housing expenditure must be greater than the marginal increase in commuting costs inside the optimum location distance of the household from the CBD; that is $- R_d.q > T_d$ must hold ((Stucker, 1975) [66]). Intuitively we can see that this must be so since with an increase in distance from the CBD, the commuting costs increase and if the housing rents (for a given quality of housing) do not decrease by a greater amount, the household would have no reason to move farther away from the CBD. In other words, if a household behaves rationally, it will locate at a distance from the CBD where the marginal savings in housing expenditure from a small increase in the distance from the CBD (given by $- R_d.q$) is equal to the marginal increase in commuting costs (T_d).

Different researchers in this field have focused on explaining different considerations in the equilibrium model, discussed above, but here we have outlined a *general* version of the trade-off theory of residential location. Evans [19] suggested an alternative formulation by introduing commuting time and working time into the utility function and then maximizing the utility function subject to a budget constraint and a time constraint. The approach was also adopted by Kirwan and Ball (1973) [36] and Nelson (1977) [51].

---

1. Given that the employment site is the CBD, $R_d.q$ will generally be negative ((Brigham, 1965) [12]; Papageorgiou and Casetti [53]).

The utility function in this formulation is written as:

$$u = U(z, q, Tc, Tw) \tag{6}$$

Utility is maximized subject to a budget constraint:

$$Tw.\bar{w} = P \cdot z + R(Tc) \cdot q + g \cdot Tc \tag{7}$$

and a time contraint:

$$\bar{T} = Tc + Tw + Tq \tag{8}$$

where Tc is the time expended in commuting activity, Tw denotes the hours of work, R(Tc) the unit price of housing services expressed as a function of commuting time, g is the operating costs (per hour) of commuting, $\bar{T}$ is total time in the period, Tq is the time devoted to consumption of housing services (including leisure time) and $\bar{w}$ is the after tax wage rate. In Nelson's [51] model, the travel costs are treated as the sum of the three components:

> (i) operating costs such as expenditures on gasoline, oil, tires and maintenance;
>
> (ii) time expended in travel; and
>
> (iii) phychic costs due to strain, discomfort and weariness. (p. 1322) [51]

By making various substitutions and maximizing utility subject to constraints, the first-order conditions imply that the consumer will equate marginal reductions in housing expenditures for a given quantity of housing services to the marginal additions to the operating and time costs of a longer commute. This model is very interesting as it incorporates the concept of the value of time ((Becker, 1965) [6]) and it stimulates interest in the empirical evidence on the cost of travel and the value of time in urban commuting.

This alternative approach (by Evans etc.) was taken up by a number of researchers since a transportation cost function allowing for the value of time spent in transit cannot be directly incorporated into an Alonso-like model without the value of leisure time being added to the household's income. This alternative approach explicitly takes into account the time spent in work, commuting and leisure so as to determine the imputed value of travel time and, thus the optimal location (Casetti and Papageorgiou, 1971) [15a]).

Other versions of this model have also been developed, among them Casetti (1967) [15], Papageorgiou (1971) [52], and Pleeter (1974) [55], who aside from incorporating a time constraint, also introduce neighbourhood quality variables into the analysis. One of the most important results of this work is the demonstration by Papageorgiou and Casetti [53] that the maximization of $U(z, q, T_L)$ -- where T_L is leisure time -- subject to income and time constraints, can be converted into maximization of $U(z, q, d)$, subject only to an income constraint (as described in equations (1) and (2)). In other words, the two approaches we have just outlined are to some extent interchangeable.

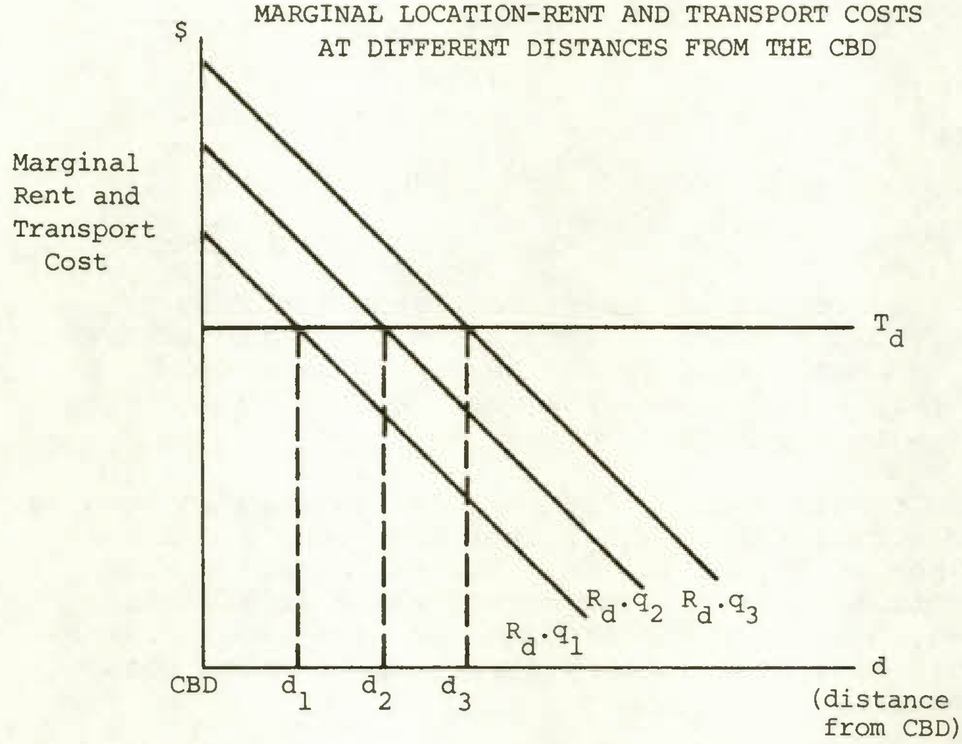
3.2 Comparative Static Implications

The purpose behind a comparative static analysis is to find out how a change in any parameter will affect the equilibrium position of the model; such an equilibrium in the present context implies that the variables z, q, and d, where these notations are the same as defined in Equation (1), are at their optimal values. In comparative statistics, we are concerned with the comparison of different optimal values of z, q, and d that are associated with different sets of values of other parameters and exogenous variables. For the purpose of illustration, let us assume that an increase in income (y) would increase the demand for housing (q). Then, the question posed in the comparative static analysis is: how would the new optimal value of q compare with the old value of q (before an income change has taken place)? Essentially, then, this analysis, which assumes the household is free to choose levels of z, q, and d, given budget constraint, will yield a set of demand functions for z, q, and d that include income and the relevant prices as their arguments.

For purposes of illustration, we present a simple diagrammatic version of the basic theory, which reduces the problem to two dimensions by holding constant the consumption of all other goods and services (except q and d) and assuming that the decision on amount of q demanded is made previously and independently of the demand for d.

Figure 1

MARGINAL LOCATION-RENT AND TRANSPORT COSTS AT DIFFERENT DISTANCES FROM THE CBD



In Figure 1, the horizontal axis measures the distance between the residential location and the CBD; the vertical axis represents the marginal rent and marginal transport costs in monetary units. Since the transportation costs per unit distance are assumed to be constant, the marginal transport cost curve, T_d, is flat. The (total) location-rents are assumed to decline at a diminishing rate from the city centre,[1] so that the corresponding marginal curves -- 'marginal savings in housing expenditure' curves ($R_d q_1, R_d q_2$, etc.)[2] -- are negatively sloped. These curves each represent the incremental savings in housing expenditures with respect to d, for a given quantity of housing q.

---

1. The assumption of this shape for the location-rent surface can be justified in several ways. Kain [34] provides an intuitive explanation, and Knos (1968) [38] provides empirical support. As well, the second-order conditions, given by Equation (9) below, require that location-rents decline at a diminishing rate from the CBD. The second order conditions are derived by finding out the second order total differential of Equation (4) (assuming P as constant). These conditions would give us the 'rate of change' of location-rents from the CBD.

$$\begin{bmatrix} U_{zz} & 0 & 0 & -P \\ 0 & U_{qq} & -\lambda R_d & -R(d) \\ 0 & -\lambda R_d & [U_{dd} - \lambda\{R_{dd}\cdot q + T_{dd}\}] & -[R_d\cdot q + T_d] \\ -P & -R(d) & -[R_{dd}\cdot q + T_d] & 0 \end{bmatrix} \begin{bmatrix} dz \\ dq \\ dd \\ d\lambda \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ dy \end{bmatrix} \quad (9)$$

The double subscripted variables represent the rate of change of U_z, U_q, R_d, and T_d (where these notations have been explained earlier). It can be easily seen from Equation (9) that location-rents must decline at a diminishing rate with distance from the CBD.

2. For the sake of simplicity, the marginal savings in housing expenditure curves ($R_d q_1$, $R_d q_2$, etc) have been shown as straight lines in Figure 1. We, however, do not assume that the (total) location rent curve, which is somewhat like the rectangular hyperbola (as shown in Figure 5 later in the text), will have unitary elasticity at each point on the curve.

Given the quantity of housing desired -- q_2 , for example -- the equilibrium location would then be determined by the point of intersection of $R_d.q_2$ and T_d. Thus at d_2 the utility of the household will be at a maximum as the marginal savings in housing expenditure are equal to additional marginal transport costs. If d were any less, the increase in housing expenditures would outweigh the savings in transportation costs; it if were greater, the increase in transportation costs would outweigh the savings in housing expenditures.

Further implications may readily be derived from the figure by considering the effects of changes in q, the demand for the quantity of housing. As is apparent from Figure 1, the higher the level of q the greater will the equilibrium level of d, the distance from the city centre.

There are a number of observable factors which may increase the demand for housing and have precisely this effect:

3.2.1 Income

If we assume that an increase in income will increase the household's demand for housing (i.e., housing is not an inferior good), then a higher income will tend to move the household out on to a higher marginal savings in housing expenditure curve ($R_d \cdot q$). Let us assume, for example, that a household consumes a quantity of housing q_2 at an equilibrium distance d_2. An increase in income would increase the quantity of housing demanded to, say, q_3; the household would then face a higher $R_d.q$ curve ($R_d.q_3$ in Figure 1). Thus, a movement from $R_d.q_2$ to $R_d.q_3$ would increase the optimum distance for the household from d_2 to d_3 in Figure 1. Given that the household's expenditure on the composite good, z is assumed to be fixed and that at distance d_2 from the CBD, the transport costs are fixed, then, if the household's income increases, it has more money to spend on housing so as to increase the level of utility derived from housing and to result in an overall greater utility level. Even if the household's expenditure on the composite good z increases, so long as this increase is less than the increase in income, there will be more money to spend for housing. The trade-off betwen housing, and transport costs would occur involving a marginal substitution between the two so that the household remains in equilibrium. We would expect then, *ceteris paribus*, that higher income households will locate further from the city centre if they conform to the behavioural assumption of this model.[1]

3.2.2 Family Size

This is a factor which will tend, even when income is held constant, to increase the family's demand for q. The same mechanism as above, resulting in movement from d_2 to d_3, will operate here.[2] We would expect then, that if similar budget

1. The change in location with respect to change in income can be seen by deriving an expression for $\frac{dd}{dy}$ from the system of equations given by Equation (9).

$$\frac{dd}{dy} = R_d\, U_{zz}\, [U_q + q \cdot U_{qq}] + T_d\, U_{zz}\, U_{qq}$$
$$= R_d\, U_q\, U_{zz}\, [1 + \zeta_{qu}] + T_d\, U_{zz}\, U_{qq}$$

where ζ_{qu} is the elasticity of the marginal utility of the quantity of housing. Assuming that $R_d < 0$, $U_q > 0$, $U_{zz} < 0$, $T_d > 0$, $U_{qq} < 0$, the sign of $\frac{dd}{dy}$ depends on ζ_{qu}. Thus, with an increase in income, how far the household will move away from the CBD would depend upon the elasticity of its marginal utility function with respect to housing.

2. For a more precise formulation, see Hecht (1974) [27].

constraints exist for two households which have different space requirements due to different family sizes,the household with the greater space requirements would live farther from the place of work than the household with the smaller space requirements.

3.2.3 Other Social Factors

There are other social background variables which may influence the demand for residential space. Most obvious among these would be marital status, which is actually, in a sense, a special case of family size. Other factors like age and sex of the worker may be important, but it is likely that differences in residential location between age and sex groups are attributable more to the income and family size differences between these groups than to the age and sex factors themselves.

The standard implications for residential location behaviour of the household, obtained from the above model, may be summarized as follows:

(i) A household locates at a distance from the CBD such that a small change in distance brings a change in marginal housing expenditures which is equal but opposite in sign to the change in marginal transport costs at the optimum location.

(ii) Any increase in the household's consumption of housing (due to increase in income and/or increase in family size or other social factors) would require it to locate further from the CBD in order to remain at the optimal location. However, the effect of an increase in the household's income upon equilibrium distance is ambiguous because of the two consequent forces working in opposite directions. The increases in the consumption of housing induces an outward move and the marginal value of time induces an inward move. The net effect would also depend upon the elasticity of the household's marginal utility function with respect to housing.[1]

1. As explained earlier in footnote 1 on page 28 of the text.

Other implications of the basic theory can be derived by relaxing some of its assumptions regarding monocentricity and transport costs. Since these are associated with later developments in the theory and modeling, we deal with them in another section. At this point, it is more important to clarify the basic nature of the theoretical framework being discussed here. Two more points on this subject seem to be necessary.

The first point concerns the origin(s) of the location-rent function. Up to now, the discussion has dealt with the origin as a given input into the household's decision-making process; namely, the location-rent function is assumed to be centred in relation to a given Central Business District (CBD). As Alonso [1] shows, however, this function is itself the result of (among other things) a large number of residential decisions made by housholds, not all of which are made with single reference to residential access to the CBD. In reality, the location-rent surface reflects the result of the bidding process, in the market for urban space, between *all* potential users of that space (i.e., including housholds and other potential users of land). A negatively sloped location-rent gradient, as generated in this market process, tends to be produced around the centre of activity in the city. But there is a "feed back" effect from past decisions of a large number of households and others users of land that affects the location-rent function. This is a critically important consideration when dealing as we shall later, with the question of multiple job centres.

The second and final point about the nature of the model discussed here is its long-run equilibrium nature. This is particularly relevant in versions of this model where "housing" is treated simply as if it was synonymous with "residential space". Clearly, the composite good "housing" includes several attributes *besides* space, such as structure type, age, neighbourhood qualities such as good schools and public services, and so on. The questions which arise here are: "To what extent is the choice of residence constrained by the availability in different areas of the desired type of housing and neighbourhood attributes (including those stressed in the 'social choice' approach)?" and "under what conditions, if any, does the distance to work become only a minor factor in the location decision?" Some authors confront the problem underlying these questions by incorporating considerations of housing supply and neighbourhood quality into the theoretical model. In his theory of the demand and supply of housing Muth [50] emphasizes both land and structure and incorporates a comprehensive coverage of consumer and producer behaviour and market equilibrium. As mentioned, Cassetti [15] and others also introduce neighbourhood quality variables.

Another treatment of this problem, which does not amend the basic model but rather justifies it, is that of Kain [34]. He suggests:

> A large number of researchers have emphasized the role of good schools and public services, and the supply of new and high quality dwelling units in determining residential location ... It is my belief that housing quality is less of a determinant of residential choices than are collective residential choices a determinant of the quality of housing services and of the quality of government services. (p. 157) [34]

According to Kain, the basic model implicitly assumes that the demand for housing quality and neighbourhood attributes is a *derived-demand* from the demand by different groups for a certain location with respect to the employment centre. Neighbourhoods with the attributes *desired* by various income and other groups tend to emerge in areas which, in distance-to-work and demand-for-space terms, are ideal for that group.

In a sense, then, it is assumed that the supply of *housing* of different types at various locations has been sufficiently elastic to permit some kind of equilibrium in the demand and supply of housing attributes in various locations. If this is true, the basic theory can ignore the supply-side of the housing market when explaining *existing* residential patterns. While this assumption, of course, has its limitations, and conceeding that a dynamic treatment of housing supply will ultimately be necessary, it is still a very useful simplifying device in the testing of the economic theory of residential location.

Section 4: RECENT EMPIRICAL MODELS OF RESIDENTIAL LOCATION

The plethora of mathematical models which appeared largely in the 1960s and 1970s and which attempt to test hypotheses about and make predictions concerning urban residential patterns have been presented. These models can be divided into two main categories: spatial interaction models (mostly the work of urban geographers) and economic models. The class of economic models can, for our purposes, be further subdivided into the set of models that emphasize mainly factors *other* than the work-trip and the residential decision by households (focusing, for example, on the aggregate bidding process or the supply of housing), and a set of models with which we are concerned, in which the emphasis is upon the relation of work-trips to residential decisions by households. We consider each class of empirical models in turn.

4.1 Spatial Interaction Models

These models are often called "gravity" models because of their basic postulate that the aggregate number of (work) trips between any two zones is negatively related to the distance between them, and positively related to their "attractiveness" (the analogue of "mass" in Newtonian physics, here referring to the availability of job or residence opportunities in the zone in question). Models of this type can now be mathematically derived using the concept of entropy (Senior [59]). Elementary static versions of such models applied to residential location ((Lowry, 1963) [43], (Lowry, 1964) [44]; (Wilson, 1969) [70]; (Cripps and Foot, 1969) [17]; (Batty, 1969) [3], (Batty, 1970) [4]) can be used, given a set of constraints, such as the existing spatial distribution of jobs, and other information (measures of "attractiveness of zones", for example), to determine the most probable residential distribution, given the set of workplaces, or the most probable distribution of trips between specific areas, and so on. Dissaggregated residential location models were then developed which explicitly included the demand and supply of a varied stock of housing (for example, see (Wilson, 1970) [71]; (Senior and Wilson, 1973) [61]; (Cripps and Cater, 1972) [16]).

Later on, other models were developed ((Wilson, 1973) [72]; (Batty, 1972) [5]), relaxing the static equilibrium assumptions of earlier spatial interaction models.[1]

Spatial interaction models have been widely used for transportation planning purposes because of their ease of operationalization, their predictive nature, and a relatively good track record in prediction (Senior [59]). Their deficiency, as Senior points out, lies elsewhere -- in the area of theoretical rationale. The use of entropy-maximizing techniques itself makes a theory of the microstate (in essence, the residential decision of households), both unnecessary and unusable. Despite their predictive power, they cannot easily link the factors affecting residential decisions (and the outcomes of these decisions) to their market-level results. This is rather what the economic models (which indidentally are generally less reliable and less useful for planning purposes) attempt to do. According to Senior [59], spatial interaction models, particularly in planning contexts, will continue to be useful, and hold considerable scope for further improvement.

4.2 Economic Models: 1

Here we note briefly a number of models of urban residential location, whose main focus is on phenomena other than the work-trip itself. Among these is a linear programming model of residential location by Herbert and Stevens (1960) [28] which attempts to simulate the market clearing process of bidding for

1. For a lucid description of spatial interaction models of residential location, see Senior [59].

residential land in a perfectly competitive market -- the process which, in Alonso's [1, 2] model, determines location-rents and the distribution of land uses -- no explicit consideration of the journey-to-work is apparent, however. Another type of model ((Wolfe, 1967) [75]) concentrates on the supply-side of the housing market, dealing with the types and ages of housing units available. Again this kind of model pays little, if any, attention to accessibility. Finally, there are very comprehensive formulations such as the more recent NBER model (Ingram *et al.* 1972) [32]. This model attempts a "comprehensive simulation of the housing market, dealing with residential mobility and demand, supply and market clearing ... incorporating an explicit journey-to-work relationship" (Senior [60] (p. 386)), at a very high level of disaggregation. The high level of disaggregation, though allowing for fine distinction among housing types, classifies households only according to their income characteristics, whereas more details would be of interest to us here. Moreover, the NBER model's main focus is not on the relationship between the journey-to-work and residential location.

4.3 Economic Models: 2

There are a number of economic models that focus specifically on the relationship between the journey-to-work and the household decision with respect to choice of residential site and housing, drawing directly on Alonso's model of household behaviour outlined earlier. Because the main purpose of these models is to add to our understanding of the household's behaviour with respect to the residence-job-location-commuting "decision complex" and the effect of these decisions on urban structure, we continue with a detailed discussion of these models. These models can be seen both as tests of the original theory, and as refinements of it as changes were made so as to produce more comprehensive models. As we shall see, most of the problems involved in refining this basic model have revolved around the need to include non-CBD job centres in the urban residential location model. Much of the remainder of this review is a discussion of these problems.

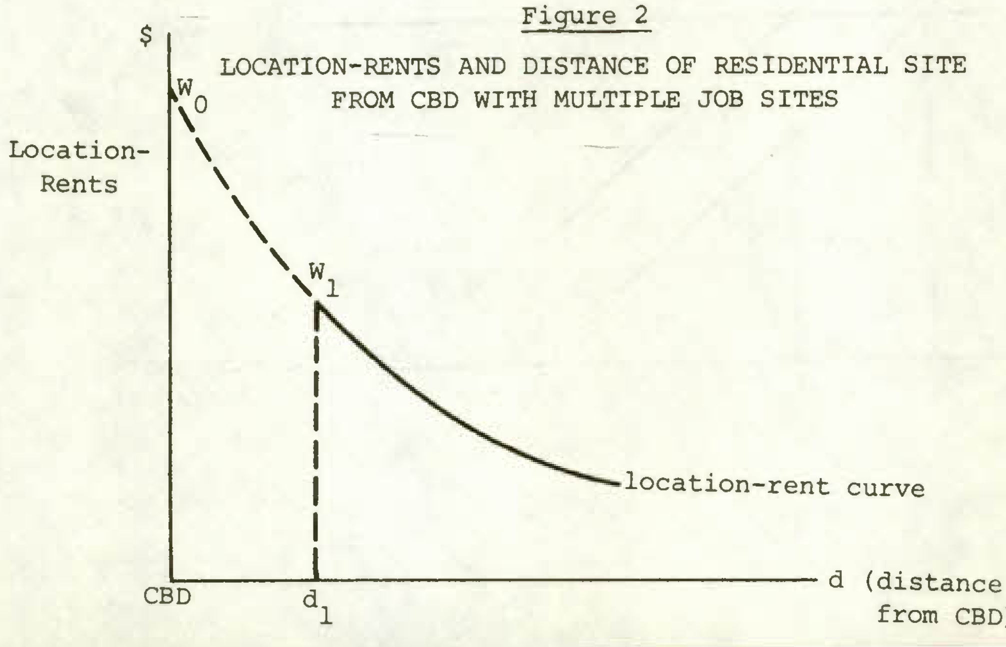
An early confirmation of the original economic theory can be found in an article by Kain [34] where he examined the effects of multiple job locations on the housing consumption-journey-to-work trade-off. Looking at the basic theory, he picked out the main variables affecting the length of the work-trip such as transport costs per mile, the location-rent gradient, household income and the demand for housing, and examined these relationships in the city of Detroit, using data from a 1953 area traffic study. This was done simply by dividing the metropolitan area into six concentric distance rings and examining, in tabular form, the journeys between rings and the characteristics of those making them. Data or proxies were available for all the variables mentioned except for location-rents. Kain assumed a particular form of location-rent surface for Detroit. As is the case in the simple monocentric theory, Kain assumed that location-rents decreased, but at a diminishing rate, in all directions from the CBD.

Kain found, as expected, that higher incomes (measured by an occupation proxy) encouraged longer journeys-to-work, and that larger families (having higher space preferences) tended of course to consume more housing, and as the theory predicts, live farther away from the job site and the CBD in order to do so. But because Kain was dealing with multiple job sites, he had to consider the effects of changes in a parameter that is fixed in the monocentric model of residential location, namely the location-rent function. Since a consideration of this factor will lead to a clarification of one of the main problems of a multicentre approach, a detailed look at the rationale implicit in Kain's treatment of location-rents and its related problems is now undertaken.

In the monocentric theory, all households face the same location-rent curve. But in Kain's framework, since it is the location-rent gradient *around the workplace* that is crucial to the residential location decision, different households may face different portions of the location-rent surface which was assumed for the city as a whole (and based on the existence of multiple job sites) depending on their respective workplace location.

Figure 2

LOCATION-RENTS AND DISTANCE OF RESIDENTIAL SITE FROM CBD WITH MULTIPLE JOB SITES

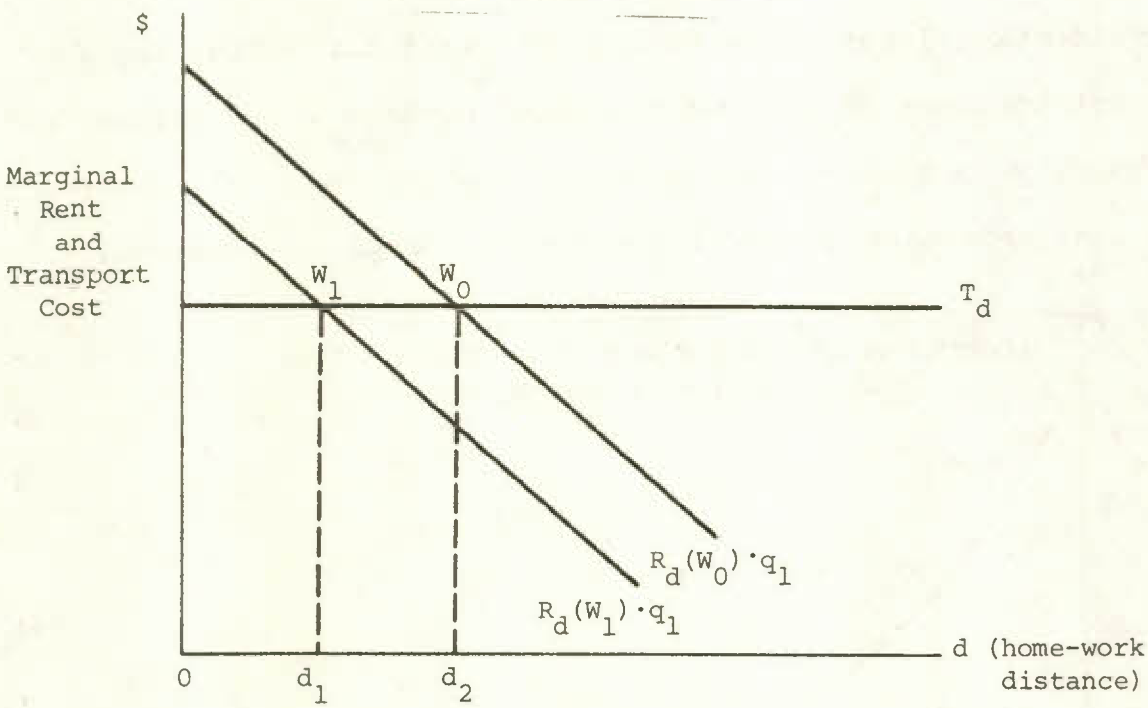


In Figure 2, which is one representation of Kain's approach, the horizontal axis measures the distance of the residential site from the CBD; the vertical axis represents location-rent in monetary units. In the above radial cross-section of the city, we represent a workplace at the CBD, W_0, and one away from the CBD, W_1. Clearly, households working at W_0 will get higher *marginal* savings in rents from moving away from the workplace than those working at W_1 under the assumption that location-rents decrease at a diminishing rate, in all directions from the CBD.

The implications of this are apparent in the following diagram which is similar to that used earlier to illustrate comparative statics of the basic model, except that the horizontal axis now measures home-work distance.

Figure 3

MARGINAL LOCATION-RENTS AND JOURNEY-TO-WORK DISTANCE



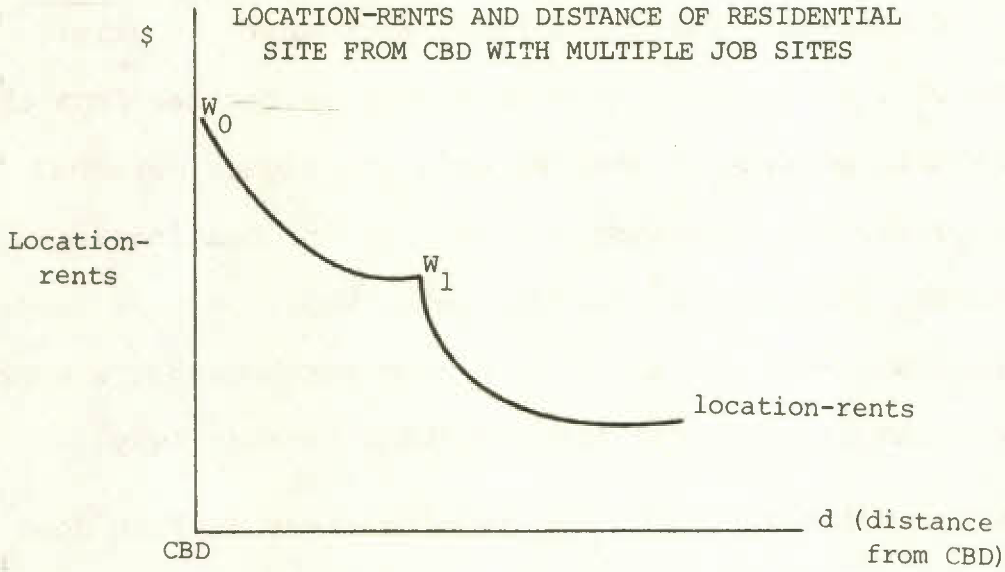
Consider two households demanding the same quantity of housing q_1. One household has a workplace at the CBD, and thus faces a marginal savings in housing expenditure curve R_d (W_0). The other, working at W_1, faces a marginal savings in housing expenditure curve $R_d(w_1)$. Both these marginal savings in housing expenditure curves are derived from the (total) location-rent function shown in Figure 2 in the same manner described in the context of Figure 1. With the assumed shape of the (total) location-rent function, being such that location-rents decrease at a diminishing rate as one moves farther from the CBD, the household working at the CBD will get higher marginal savings in location rents because the decline in location-rents is steeper around the CBD than further out. Thus, *ceteris paribus*, the optimum home-work distance is higher for households working at or near the CBD than for those working further away.

Kain concludes that if the location-rent surface does have the assumed shape, households working in outer rings will tend to cluster much closer to their workplaces than those working in inner rings. He does, in fact, find evidence to support this proposition. Taaffe, Garner, and Yeates (1963) [67], using data derived from the Chicago area transport study also found that the average distance of journey-to-work for peripheral commuters was significantly less than that for CBD commuters. Thus there is a tendency for those working in the periphery to cluster around their workplaces.

One problem with Kain's treatment of location-rents, however, should be apparent; that is, if location-rents are assumed to be produced by the bidding of various possible users of land/housing, and if non-CBD employment centres exist, we might expect location-rents to be bid up around them, violating Kain's original assumption, and producing a location-rent surface more like Figure 4 below.[1]

Figure 4

LOCATION-RENTS AND DISTANCE OF RESIDENTIAL SITE FROM CBD WITH MULTIPLE JOB SITES



The implication of Figure 4 is that models of residential location which treat multiple job sites must treat the crucial rent gradient between the workplace and the potential home site as a function not only of the workplace's distance from the CBD, but of the demand for land at the workplace as well. This kind of treatment would be consistent with Harris and Ullman's concept of multiple nuclei, and with attempts such as those by Evans [19] to incorporate these into more rigourous

1. This figure is drawn on the assumption that there is another employment centre in addition to the CBD.

theories of urban land-rents and uses. The upward displacement of rents in any area should then be seen as a function of the number of jobs in the area (whether it is a major centre or not), its proximity to *other* employment centres (since an overlap of commutersheds will bid rents upward), and other factors affecting its residential attractiveness (nuisance variables like pollution, for example). As we shall see later, Beesley and Dalvi (1974) [8]; Steinnes and Fisher (1974) [65]; and Fisher and Fisher (1975) [21] attempted to take some of these aspects into account.

In a later paper, Kain (1964) [35] considerably refined his earlier approach and developed a consumer choice multiple regression model testing hypotheses on the residential and trip-making behaviour of an individual worker. An important improvement in this model is the inclusion of a mode of transport-choice relationship. This clearly adds another dimension to the worker's trade-off in residential location since workers can increase their "accessibility" to the job site not simply by moving closer and paying higher location-rents but also by their decision either to own a car for use in the journey-to-work, or to use other means of transportation.

Specifically, Kain's nine-equation model estimates residential space consumption, auto ownership, the mode of transport-choice relationship and the length of the journey-to-work, and does so in a definite causal sequence. The underlying assumption for this sequence is that the worker first chooses the residential density in which he wishes to live on the basis of his income, demand for space, and the price per unit of residential space. The demand for space in this consumer choice model is closely approximated by house type as a measure of residential density. This in itself is explained as a function of several "taste" factors relating to workers' characteristics and of a proxy for the price of residential space per unit quantity. Then a decision on auto ownership is made, followed by a decision on transport mode used in the journey-to-work. Finally, the time of the journey-to-work trip is explained, among other things, by the previous decisions on space consumption and transport mode.

In the residential space consumption equations, Kain again finds the expected relationship with family size, while the other "taste" factors also work in the direction he predicts. The income variable is insignificant, he says, due to inadequate space consumption and income measures. The price of residential space is indicated by a proxy based on workplace-CBD distance, which does perform as expected, despite being the weakest point of the model.

In the car ownership equation, Kain finds that car ownership is positively related to income, family size, sex and residential space consumption and negatively related to the availability of transit service. The same variables, of course, also determine the transport mode choice, with the number of family members competing for use of the car also being important.

The final equation which contains a variable describing the elapsed time in the journey-to-work, does not perform well due to the obvious problems of money and time-cost substitution effects.

We feel that Kain's model is one of the most promising economic approaches made to date. However, it illustrates several problems which must be accounted for in further refinement of such models. These are noted below.

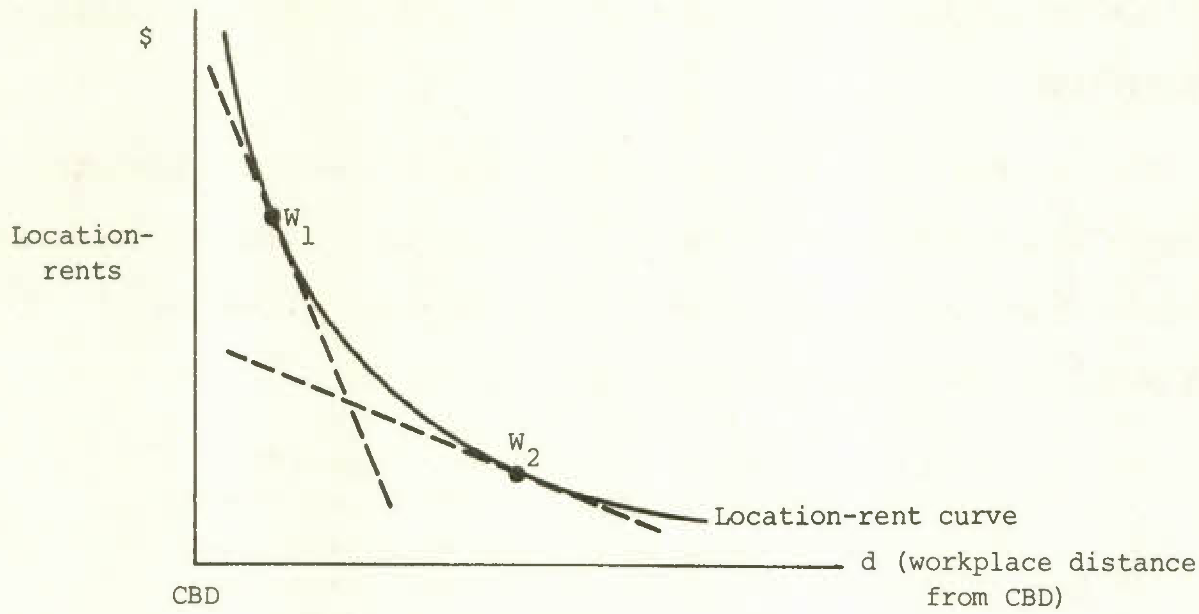
(i) As in his 1962 paper, the effect of non-CBD employment centres on location-rents is ignored.

(ii) Although the assumption is made that location-rents decrease *at a diminishing rate* from the CBD, the proxy used for marginal savings in location-rents at the workplace (which is the relevant factor to the worker) is a linear function of CBD-workplace distance.

In fact, empirical studies like Knos [38] and Yeates (1965) [76] support Kain's original assumption, showing rents declining dramatically near the CBD and much more slowly in outlying areas, giving us a rent-function somewhat like the rectangular hypoerbola in Figure 5 below. If the location-rent function is in fact of the form $R.d_{jc} = k$ (where R is location-rent, d_{jc} is the distance between workplace and CBD and k is a constant such that $k > 0$) then the marginal change in location-rents ($\partial R/\partial d_{jc}$) should be proportional to $1/d_{jc}^2$, and not a linear function at all.

Figure 5

LOCATION-RENTS AND DISTANCE BETWEEN WORKPLACE AND CBD



(iii) The definite causal sequence assumed in the model has been criticized by Kirwan and Martin (1970) [37] on the grounds that residential space corsumption and locational decisions should be simultaneous outputs of the market clearing process. Whether housing quantity decisions and distance decisions should be modeled simultaneously or sequentially is basically an empirical question, but the greater theoretical appeal of modeling them simultaneously should be recognized.

(iv) Kain's last equation, measuring elapsed travel time, performs badly because of the substitutability between time and money costs which transport mode-choice allows. Time taken represents only one component of total trip costs, the other being of course money. Certainly, ample theoretical justification for the assumption that households can, and do, value their travel time exists (Becker [6]; (Johnston, 1966) [33]; (Moses and Williamson, Jr., 1963) [47]; (Quandt, 1970) [56]) and several empirical studies have attempted to infer households' monetary valuation of commuting time ((Beesley, 1965) [7]; (Gronan, 1970) [24]; (Lansing and Hendricks, 1967) [40]; Stucker [66]; Beesley and Dalvi [8]; (Seigal, 1975) [63]). However, in most of these studies, there are substantial problems in interpreting the results obtained, particularly in the context of residential location models. Because of the problem of time-money substitution, we argue that, given the assumptions made, distance is in fact a sophisticated proxy for total transport costs (including time). This contention is developed below.

Assume an individual worker, who for any distance, D, that he would like to travel, will minimize the total cost of that trip, which consists of both time and money components. Total trip cost is thus given by:

$$C = V_t . Tc + m.D \tag{11}$$

$$Tc \equiv D/s \tag{12}$$

where C = total trip cost

V_t = value of time

Tc = time taken in commuting activity

m = money cost per mile

D = distance travelled

s = speed of transport

To account for the fact that transport mode-choice is available to the individual, we also assume that a continuous range of transport modes is available, and that these transport modes can be characterized by two factors, their speed (s) and their money cost per mile (m). The choice between alternate transport modes is such that any increase in speed (choice of the faster transport mode) is accompanied by an increase in price,[1] so that we have:

$$m = m(s) \qquad (13)$$

and

$$m'(s) > 0$$

Substituting (12) and (13) into Equation (11) we have:

$$C = V_t(D/s) + D(m(s)) \qquad (14)$$

Minimizing C gives us an optimum level of s, i.e., the optimum mode of transport. Setting the derivative with respect to s for Equation (14) equal to zero, we obtain:

$$\frac{dc}{ds} = \frac{-V_t \cdot D}{s^2} + D(m'(s)) = 0 \qquad (15)$$

$$s^2 = \frac{V_t}{m'(s)}$$

$$s = \frac{V_t}{m'(s)} \qquad (16)$$

Substituting (16) into (14) gives us the transport cost function under the assumption that the individual always minimizes total transport costs:

$$C = V_t \cdot D\sqrt{\frac{m'(s)}{V_t}} + D(m(s))$$

$$C = D[m'(s)\sqrt{\frac{V_t}{m'(s)}} + m(s)]$$

$$C = D[m'(s) \cdot s + m(s)] \qquad (17)$$

---

1. This could not really be otherwise, since if any mode were both slower and more expensive, it would not be chosen at all (except for "comfort" factors, which we leave out here).

Thus, even when we account for transport mode-choice and time costs, total transport costs are proportionate to distance travelled for the individual worker. Distance, besides giving obvious spatial implications, is in fact a sophisticated proxy for transportation costs.[1] Its use as a proxy thus avoids the problems of trade-off between money and time costs which is important in the context of a model which focuses on transport-mode-choice.

Moreover, it can be shown that if the worker makes his residential location decision, given information on the minimum-total cost transport mode for each distance, the actual transport mode used is determined *within* the structure of the residential location decision. Let us assume, as we did before, that the worker, for any given distance to work, makes a transport mode-choice that minimizes total trip costs, giving us the optimum transport mode-choice function which depends on s and d like that in Figure 6(b). Each mode, say a, b, and c will have a marginal transport cost curve represented, respectively by MTC_1, MTC_2 and MTC_3 in Figure 6(a). These curves, along with the marginal savings in housing expenditure curve ($R_d \cdot q$) determine d as d_1, d_2 and d_3, respectively. That is, a lower marginal transport cost curve implies a faster form of transportation and a residential location farther from the place of work for any given quantity of housing.

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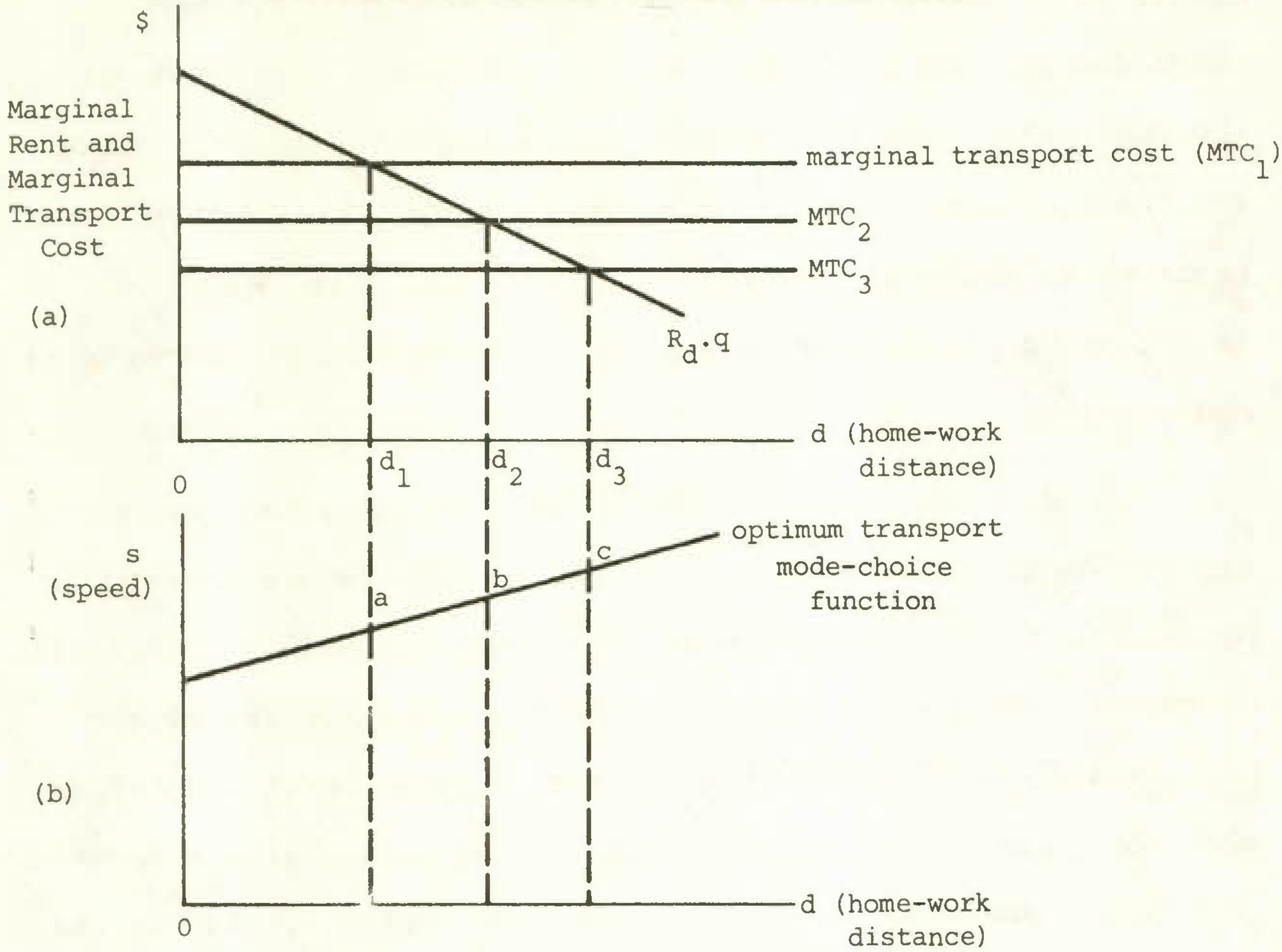
1. Note, however, that there are constraints on D as a proxy for transport cost, namely m(s) and s. We, however, assume that m(s) and s are constant for the individual worker.

Figure 6

TRANSPORT MODE-CHOICE AND WORK-TRIP DISTANCE



In Kain's model, the car ownership decision is made prior to the decision concerning the distance between residence and place-of-work, thus exogenously affecting this latter decision. This is consistent with Beesley and Dalvi's contention that cars are usually acquired "for reasons other than their implications for commuting (perhaps, as many have suggested, for other non-work journeys, family trip-making, or prestige)" [8] (p. 220). In this context, ownership can be seen as creating an exogenous shift in the marginal trip-cost function that tends to encourage longer work-trips, since if a worker already has a car for some exogenous reason, the marginal costs of using the car for the work-trip may be relatively low such that the worker faces a lower marginal trip cost curve relative to other transport mode-choices. However, there are certain situations in which the car ownership decision and the distance decision will be made concurrently (e.g., for some newly-formed families). Thus, in reality, the car ownership decision is sometimes made exogenously and somtimes in relation to work-trip considerations, making it necessary to separate conceptually the effect of commuting distance on car ownership from that of car ownership on distance in order to provide a truer picture of reality and better models within the context of the economic theory of residential location.

Since the two early papers by Kain, some theoretical analyses of the effect of non-central workplaces on urban land uses have appeared (especially Muth [50]). Unfortunately, much of this tends to be at a high level of abstraction, so much so that Muth, in his empirical work, reverts to the use of the distance of the residence from the CBD as his primary measure of accessibility.

Evans [19] attemps to link theory and empirical work on multiple nuclei in his analysis of residence and journey-to-work patterns. He proceeds by outlining theoretical expectations concerning journey-to-work patterns and then testing these using 1951 census data for London. Although Evan's work is fascinating and goes a long way toward a theory of residential location in a multi-centred city, Senior [60] concludes that, "the results are only partially convincing, because (the theories used) are in need of a much more radical reappraisal than Evans gives them". (p. 402) [60].

A more recent paper by Beesley and Dalvi [8] raises an additional major issue. This concerns the direction of causation in a model that allows for multiple job sites. In the simple monocentric model, it is clear that the worker's job site is exogenously given and he then chooses a residence site in relation to it, based on housing preferences and transport costs. In a multi-centred urban area, however, it is no longer clear whether households tend to locate their residences in response to a given job location or whether they tend to view their residence as given and look for a job in relation to it.[1] Depending on how we view the process, different causal factors will seem the most important ones influencing the length of the journey-to-work. For example, if workers look for a job site from a fixed residence site, location-rents should have no effect on the length of the journey-to-work. Several models, which we will consider briefly later, have attempted to solve this problem by modeling the job and residence location decisions as simultaneous (Siegel [63]; Steinnes and Fisher [65]; Fisher and Fisher [21]).

---

1. It is also possible that *employers* tend to orient themselves in relation to pools of labour, but since availability of labour is only one of many factors affecting the firm's location, and since it would greatly complicate the analysis, most models, including Beesley and Dalvi's as well as our proposed approach, view the location of firms as basically fixed.

Despite the appeal of this technique, however, Beesley and Dalvi [8] reject it:

> Actually, it is rather far-fetched to consider the 'average' household as taking such simultaneous decisions ... In reality, one cannot ignore the possibility that many journey-to-work decisions proceed from a fixed residence... and [that] it is not uncommon for people to start looking for jobs from given home locations. This is particularly true for women and young entrants into the labor market, who may not be able or willing to leave their homes to take up better paid job outside their own urban conurbations.... Thus some disaggregation [of the decision process that determines journey-to-work length] seems plausible. (pp. 199-207) [8]

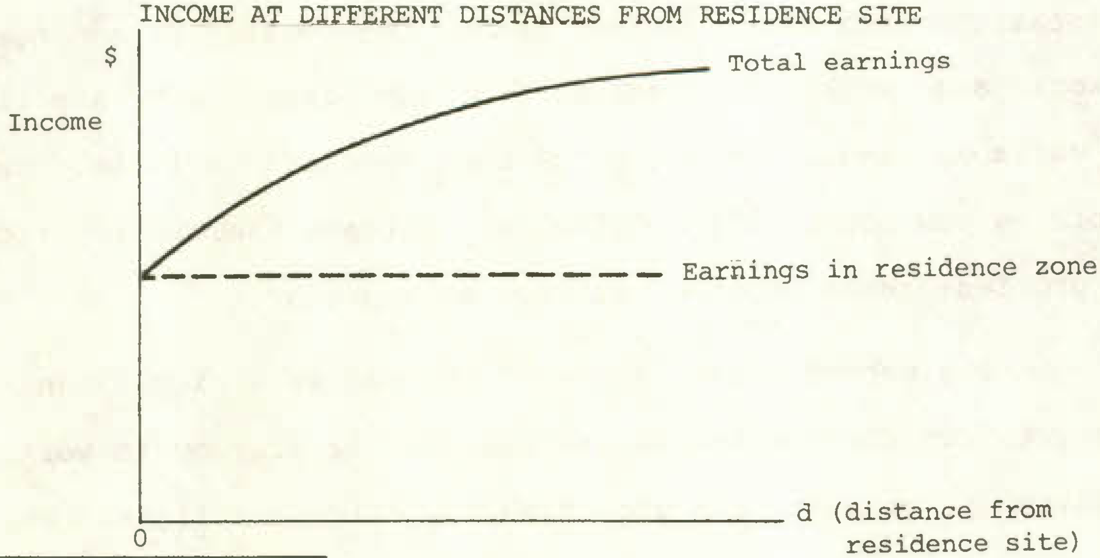
Beesley and Dalvi, therefore, construct two separate, single-equation models explaining the length of the journey-to-work; one assuming a fixed workplace (residence location model), the other assuming a fixed residence (job location model). The first is derived from the standard Alonso-Muth residence location theory, and explains the average work-trip length of workers employed at a given site using five variables: two proxies for location-rents which reflect demand for housing at and near the workplace; workplace distance from the centre; a transport cost variable; and a "living space requirements" variable. There is nothing new about this model except perhaps the two location-rent proxies; these perform well and as expected.

The second model, however, represents a significant departure from the previous approaches to the journey-to-work, and casts the problem in a significantly different light. What happens, theoretically, when Beesley and Dalvi assume workers regard their residences as fixed and choose an appropriate job site in the metropolitan area? Given that there is disutility of commuting to the job site and utility from income earned, the focus in this model is on the increase in transportation costs versus the increase in potential earnings as the worker ranges farther afield from his/her residence site. Assuming a positive relationship between income and distance,[1] Beesley and Dalvi indicate, for the individual's utility to be at a maximum, the worker will locate his job at a distance from his residence site where the marginal increase in his income is equal to the marginal increase in his commuting costs. The model assumes, however, that there exists a 'wage surface' in cities.

The esse~ce of Beesley and Dalvi's theoretical argument can be shown in two simple diagrams. The assumed relationship between income and distance is shown in Figure 7.

Figure 7

INCOME AT DIFFERENT DISTANCES FROM RESIDENCE SITE



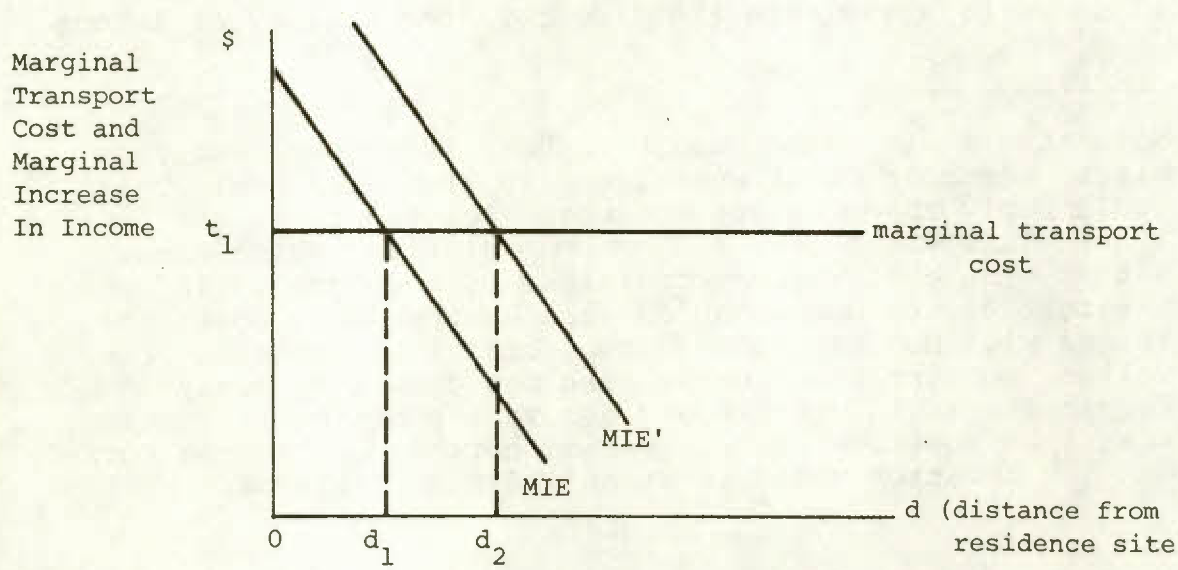
1. However, income is bounded from above, in the sense that there is an upper limit upon the amount of income one may earn by taking up jobs farther away from the residence site.

It is assumed in this diagram that total earnings increase at a diminishing rate with distance, giving us the downward-sloping marginal increase in earnings (MIE) function in Figure 8.

The optimum length of trip-to-work for the individual can be shown in a figure similar to that used in the residential location model. In Figure 8 below, the marginal transport cost curve is derived in the same way as before and MIE curves represent the marginal increases in the individual's earnings available by taking a job farther away from the residence site. Both are plotted against trip-to-work length, measured from the residence site. For the individual for whom the MIE curve is relevant, the optimum trip-length will be at d_1, where marginal transport costs and marginal increase in earnings are equal. Beyond this point the costs of a longer journey outweigh possible earnings increases, while a shorter journey would imply a sacrifice in earnings greater than the reduction in transport costs.

Figure 8

INCOME AND COMMUTING COSTS AT DIFFERENT DISTANCES FROM RESIDENCE SITE



Two points of clarification are needed here. The first concerns the construction and shape of the MIE curve. The downward-sloping MIE curve, as shown above, is derived from the assumption made regarding the relationship between income and distance.[1] A second point of clarification concerns moving costs. Assuming that there is a limit to search for a better job, at some point there may be a disincentive to commute beyond a certain length; if the cost of moving is sufficiently low relative to commuting costs, the point will arrive at which the worker will move in order to have a shorter journey-to-work (in Beesley and Dalvi's words, a "domicile shift effect" occurs(pp. 205-206)). The job location model, then, is only applicable for a certain range of distances, or for those people whose residence is exogenously fixed for social (family structure) reasons.

Based on this rudimentary theory, Beesley and Dalvi construct an operational model that explains the average length of trip-to-work of workers living in a given residential area using three variables: a variable representing the cost of travel to work; a variable standing for "the utility of income

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1. Note that it is quite possible that, from some residence sites, earnings might even *decrease* with distance. This would imply that the optimum work location is in the home zone. This would give a " corner solution" which cannot satisfy the equilibrium conditions of the model. In such a situation, other variables such as transport costs and income will not have their usual effect on distance travelled. On the other hand, earnings cannot be always *increasing* (i.e., the *second* derivative of the Y function *cannot* be positive except over a short range) or the optimum job location would be at an infinite distance.

or the value of time"; and age, which presumably is related somehow to willingness to travel. Both age and travel costs turn out to have the expected negative signs, while the income variable, whose expected sign was ambiguous, also had the negative sign.

The most interesting part of Beesley and Dalvi's paper, however, is the attempt to apply the different models to various population groups. The utility of having two models is most important here, since despite rather severe data constraints, they were able to demonstrate the greater applicability of the Job Location Model and its assumptions to females (the situation of the working housewife comes to mind immediately) and the Residence Location Model to males. More work in this direction would seem to be very important, given Beesely and Dalvi's success in this regard.

A problem with respect to wage surfaces that emerges from Beesley and Dalvi's Job Location Model should be mentioned. In the Job Location Model, Beesley and Dalvi assume an increase in earnings is available to the worker if he works at a greater distance from home. Although this concept is theoretically analogous to the variation in location-rents around the workplace in the Residence Location Model, no attempts are made to account for variations in the "wage surface" as were made for the location-rent surface. Several authors, among them Evans [19] have suggested by deduction that there should exist, in cities, a "wage gradient", or surface, analogous to the rent surface. Specifically, wages should be highest at the CBD and should achieve lower peaks at secondary employment centres in order for equilibrium in the labour market to exist. Unlike the rent gradient, however, the wage gradient has found little empirical support. Indeed, Evans concludes: "The most favourable interpretation of the available evidence is that it is inconclusive" [19] (p. 190). This suggests that, while evidence on the wage surface is a necessary part of a job location model, we cannot, as for location-rents, use a set of well established proxies, like distance to the CBD, to account for its effects. Evidence on average wage levels themselves in various parts of the city will be necessary.

Although Beesley and Dalvi ignore the wage surface, they do take into account the proximity of job opportunities to the residence site in their model. This suggests that a clarification is in order: the effects of the amount of extra earnings available (given by the slope of the wage surface) should take into account job search cots -- which is related to the probability of finding a job in a given area (given by the geographical concentration of job opportunities). This can be easily illustrated in Figure 8 above by letting the MIE curve represent incremental earnings *net of search costs.* Then a *fall* in search costs would have the same effect as an *increase* in marginal income available, both of which would raise MIE to MIE' and increase the optimum distance from d_1 to d_2. Operationally, this would imply the inclusion of variables indicating the proximity of high-wage areas in order to represent the wage surface, and other variables indicating the proximity of job opportunities in order to approximate search costs. This refinement is one we will attempt in our proposed job location model discussed later in this paper.

As mentioned, some authors have confronted the problem of whether job sites determine residential location choices or vice versa, not by constructing alternative models for different population groups as in Beesley and Dalvi, but by making both residence and job locations endogenous in one model. This is done in two quite different ways by Siegel [63] on the one hand, and Steinnes and Fisher [65] and Fisher and Fisher [21] on the other.

In the case of Steinnes and Fisher, and Fisher and Fisher, the model attempts to explain simultaneously the location of employment and residence within a metropolitan area. What is estimated in the model is the number of people residing and working in each of their sample zones of Chicago. Although commuting costs between zones are taken into account, the focus is on the response of households to the demand for and supply of both housing and labour in different areas. However, the role of commuting in the model is a relatively minor one; further, the exact role of location-rents in it is not very clear.

Siegel's [63] model, unlike those discussed in the previous paragraph, is more in the style of the original Alonso-Muth theory, since it extends the framework to allow the household to determine housing consumption as well as residential location and job location simultaneously. Essentially, the automobile driving time between residence and CBD and between workplace and CBD is estimated simultaneously; the commuting time operates through the interaction of two simultaneous location decisions. The model is recursive in the sense that the locational choice variables enter in the determination of the bundle of housing services but the quantity of housing and type of structure do not determine locational choice decisions. This procedure, while interesting, creates two main problems:

(i) The role of commuting in the model is considerably changed. Whereas in the basic framework, commuting costs are a main element of the choice problem, their role is greatly reduced here. In Siegel's own words, "... commute time no longer plays a direct role in the model. Rather it operates through the interaction of two locational choice variables, home and job location" [63] (p. 31). The focus of Siegel's study was, however, on intra-metropolitan migration.

(ii) Since housing location is measured in terms of commuting time from the CBD, only the CBD can be included as "the reference point for the cost of accessibility and therefore the rent of land at a specific location" [63] (p.32). Thus, in essence, the assumption of monocentricity is not fully relaxed. It would seem that while Siegel gains from relaxing the one-way causation assumption, he does not allow for secondary peaks in location-rent that may be caused by non-CBD job centres.

Finally, there is one more major problem which, although inherent in all previously discussed models, becomes most apparent in Siegel's, particularly in relation to his assertion that the number of employed persons in the household should enter into the determination of housing locations, since the number is directly related to transport costs. In a monocentric model, this is easily dealt with since all wage earners travel to the CBD and transport costs are measured by distance to the CBD. In a multi-centre model, however, if we propose that workplace location determines residence location, we must decide, for individuals belonging to families with more than one wage earner, *whose* workplace location is the crucial one.

The problem is essentially that while the location of employment and commuting distance are factors involving the individual worker, the residential location decision is very much a family decision. While in most conventional cases this is not a serious drawback (see (Lancaster, 1975) [39], who shows that given certain relatively common conditions, there is little divergence between individual and household decisions), it causes a degree of ambiguity in a multi-employment centre residence choice framework because of the following two problems:

(i) Dealing with the data on an individual basis ignores the fact that, for some working family members, residential location is not a choice variable at all, but determined by the decision of another family member, presumably the primary wage earner.

(ii) If workplaces are scattered, the direction of the effect of the "number of wage earners" variable becomes ambiguous: the fact that a person's spouse works may either increase or decrease his or her distance to work.

However, partial solutions to these two problems (assuming that certain detailed household data can not be obtained) are available. In the case of problem (i), we can label each individual with his or her family characteristics, thus attempting to incorporate the effect of the number of wage earners in a worker's family in his or her work-trip length (as most authors have done). In regard to problem (ii), there is no apparent solution; however, if the other wage earners in the worker's family tend to commute in the *same direction* (as is shown by Evans [19]), we would expect a higher number of wage earners to decrease the length of the primary worker's work-trip. If this is the case, then the variable is not completely ambiguous as to the direction of its effect.

Section 5: STRUCTURE OF THE PROPOSED MODELS

In the earlier portion of this document, we have reviewed the residential-location literature and noted some of its main problems. Naturally, this review is heavily weighted towards those areas of the literature which deal with the questions of interest to us in the construction of our own models. We conclude this paper with an outline of the basic structure of our proposed models, which will be tested and detailed in a later document. In our models, we have made attemps to cope with some of the problems discussed above. Our emphasis in the models is both on operational constructs and theoretical propositions. The modest aim is to develop more general, and hopefully richer, models.

Like Beesley and Dalvi [8], we "disaggregate" the decision which encompasses residential location, job location, and journey-to-work, presenting as they do, two models both explaining the length of journey-to-work directly. One of these, the "Residential Location Model", assumes a given job site and allows for a choice of residence sites, while the "Job Location Model" assumes a given residence site and choice of job location. The two models are perhaps best viewed as alternative explanations of the same phenomenon, i.e., the length of the trip to work, perhaps differentially applicable to various subpopulations.[1] The disaggregation of the decision process that determines journey-to-work length and reasons for not relaxing the one-way causation assumption are practical in the sense that we do not except individuals generally to simultaneously choose their residential and employment locations.

The purpose of these models is to examine the residential location/job location behaviour of the working population within a multi-centre metropolitan area, when the polycentric nature of workplace locations are taken into account during the locational process. We now outline the assumptions and the structure employed for each of the two models in turn.

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1. The Residential Location Model may be more applicable to primary than to secondary earners, although residence location, to some extent, may be the result of a trade off process within the household. The Job Location Model is particularly pertinent with respect to secondary earners, who will tend more to seek work from a given residential location.

5.1 The Residential Location Model

5.1.1 Assumptions

The basic assumptions employed in the development of the structure of the model are summarized as follows:

(i) This is a consumer choice model, framed in terms of the working population (the actions of the members of this population being affected by their own and their families' characteristics) behaving rationally by maximizing utility subject to a budget constraint.

(ii) In contrast to the monocentric theories, we do not assume that all employment is concentrated at a single geographical point, the CBD. We consider workplace locations as being polycentric in nature in a metropolitan area.

(iii) Residential space is assumed not to be an inferior good (Kain [34]), and housing of each type is assumed to be available to the worker in all areas of the city. It is also assumed that the schedule of prices for each potential residential site is known to the worker and that he or she can compute the total cost of a given type of housing at all residence sites. We further assume that the schedule of prices for any housing type reflects fully capitalized locational advantages.

(iv) As in Beesley and Dalvi [8], the location of firms is treated as fixed, i.e., we assume that firms have already achieved locational equilibrium.

(v) Transportation costs are assumed to be a monotonically increasing function of distance regardless of the direction of travel, and we assume that individuals are capable of implicitly computing the transportation costs of their journey to work, including both the value of time and monetary costs.

(vi) The supply-side of the housing market is ignored, as in Kain [34, 35] and in Kirwan and Ball (1973) [36], who argue justifiably that this can be better incorporated in a dynamic analysis rather than in a cross-sectional analysis such as we will be undertaking.

5.1.2 The Structure of the Model

In a standard residential location model, the residential site choice involves maximizing a utility function of the following type:

$$u = U(z,q,d) \qquad (1')$$

subject to

$$Y = P \cdot z + R(d) \cdot q + T(d) \qquad (2')$$

where the notations are the same as defined for Equations (1) and (2).

In the model posited, we assume that the housing quantity demanded by an individual is a function of the type of dwelling and number of bedrooms. Thus,

$$q = H(TY, BR) \qquad (18)$$

where

TY = type of dwelling (structure type)
and BR = number of bedrooms in the dwelling unit.

Thus, in this model, an individual's utility function is expressed by

$$u = U(z,H(TY,BR),D) \qquad (19)$$

where D is the distance between the place of work and residence site. The observed socio-economic characterisitcs that affect an individual's utility are not generally specified in the utility function; however, if we explicitly incorporate them, Equation (19) can be rewritten as

$$u = U(z,H(TY,BR),D,SE) \qquad (20)$$

Where SE is a vector of observed socio-economic characteristics. Maximizing the utility function of the type given in Equation (20), subject to the budget constraint given below by Equation (21), would give us the demand functions for the quantity of housing, the quantity of the composite commodity and commuting distance.

$$Y = P \cdot z + R \cdot H(TY,BR) + T \qquad (21)$$

Where R is the rent per unit of housing and T is the transportation cost. The quantity of housing, q (or the quantity of z or D) that the individual demands, in the general case, depends upon the prices of all the goods (P, R and T) and his or her income.[1]

Our model is an extension of the Alonso-Muth framework and allows individuals to simultaneously choose their residential location and the quantity of housing (the type of structure of the dwelling unit and the number of bedrooms), so as to maximize their utility subject to the budget constraint. The model tests the proposition that utility-maximizing behavior, dependent on income and other socio-economic attributes, can explain the three endogenous variables which we assume are chosen by the worker: home-work distance, type of housing strucutre, and number of bedrooms (controlling for quality).

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1. See Henderson and Quandt (1971) [27a].

Equations (22) to (24) describe the structural relationships.[1]

$$D = f_4 [R, T, Y, O, EDU, S, AG, FS, CO] \quad (22)^{2}$$

$$TY = f_2 [R, D, Y, N, FS, S, M, EDU] \quad (23)$$

$$BR = f_3 [R, Y, FS, M, S, T_y, HQ, D] \quad (24)$$

where D = distance between the place of residence and the place of work.

TY = type of dwelling - structure type.

BR = number of bedrooms in the dwelling unit

R = rent per unit of housing

T = transportation cost

Y = earnings (wages and salaries) of worker

O = occupation of worker

S = sex of worker

M = marital status of worker

EDU = education of worker

AG = age of worker

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1. If the car ownership decision is made in relation to work-trip considerations (see the earlier discussion on pp. 48-49), we may then add one more structural equation to the model -- a car ownership equation. The model would then determine the car ownership decision simultaneously with the residential location and housing consumption decision. Equation (25) describes the factors affecting the car ownership decision.

$$CO = f_4 [R, D, Y, S, FS, N] \quad (25)$$

Besides D, these factors include certain exogenous factors such as income, family size and sex.

2. An alternative form of this equation might replace the three exogenous variables (Y, O, EDU) by Socio-Economic Status (SES). An index of SES is provided by the Blishen Scale of SES((Blishen, 1958) [5a]; (Blishen, 1967) [5b]; (Blishen and McRoberts, 1976) [5c]; (Pineo, Porter and McRoberts, 1977) [54a]).

N = number of workers belonging to families with more than one wage earner

HQ = housing quality

FS = family size of the family to which the worker belongs.

Equations (22) to (24) summarize the model. These factors that affect the simultaneous decision of the worker's choice of residential location and housing consumption fall under four main categories: the location-rent gradient; the quantity of housing demanded; transportation costs; and various socio-economic and demographic variables. The model presented in Equations (22) to (24) specifies the structural relationships but not the functional form of the equations to be estimated.

In our model, Equation (22) determines the residential location of the worker. Equations (23) and (24) describe the housing decisions. These housing equations are defined using proxies for residential density (structure type), quality (age of the unit) and the quantity of housing or interior size (number of bedrooms). In these equations, D, the distance of journey-to-work, is related to the rent per unit of housing with respect to the worker's decision concerning location. Earnings, and other socio-economic variables which might influence the worker's housing-type decision, are also included. In Equation (24), the number of bedrooms is a proxy for the quantity of the housing and the age of the structure is a proxy for housing quality (HQ). Following Muth [48], who estimated the income elasticity of demand for housing (stock) to be approximately unity, the quantity of housing consumed is expected to increase with income. Muth [50] suggested that interior and exterior space may be substitutes and the household could trade housing quality for space. Thus a household could consume a greater quantity of housing by settling for a lower quality. The model assumes that the quality of housing decreases with the age of the stucture.

Although the complete specification of the model and its testing (using the data from Toronto census metropolitan area) will be reported in a later document, we consider here the anticipated effects of the various factors that affect the model, and the operationalization of these factors in the model. The model could easily be tested in two alternative forms (i) in terms of the 'average' characteristics of the workers on a zonal basis, and (ii) in terms of the 'individual' characteristics of the workers.

5.1.3 Model Notations and Operationalization

5.1.3A 'Average' Characteristics of Workers On A Zonal Basis

We now redefine our variables using more precise notations so as to clarify our approach to estimating the equations when the model is being tested in terms of the 'average' characteristics of the workers on a zonal basis.

In general, subscript i refers to the zone in which the residence is located and j to the zone in which the job is located, where i and j = 1, 2, ... n.

5.1.3A(i) Residence Location Equation

The dependent variable in the residence location Equation (22) will be:

D_j = average distance of journey to work by workers in zone j.

$$D_j = \frac{\sum_{i=1}^{n} a_{ij} d_{ij}}{E_j}$$

where a_{ij} = number of workers commuting from residence in zone i to zone j.

d_{ij} = linear distance between i and j

E_j = total number of workers employed at j.

The independent variables in this equation are categorized as follows:

5.1.3A(ia) Location-Rents

R_j = average rent paid by the workers employed at j

$$R_j = \frac{\sum_{i=1}^{n} a_{ij} r_i}{E_j}$$

where r_i = rent paid by workers residing at i. If the data on rents are available, one could impute the value of rent to owner-occupied dwellings. Alternatively, while it is beyond the scope of this paper to empirically estimate the rent gradients in a metropolitan area, we can nonetheless make assumptions about the shape of this surface, based on previous empirical work related to several urban areas. We develop the hypothesis that there are four area-wide influences on the level of rents of those working at j: workplace distance from the CBD, proximity to alternative employment centres, importance of service industries in the area, and attractiveness attributes, if any.

-- Workplace Distance From the CBD (d_{jc}):

Studies have consistently shown that the level of rents decline dramatically in all directions from the CBD. Some demonstrations of this (Knos [38] and Yeates [76]) who show that not only the level but the *rate of decrease* of rents decreases from the city centre, giving us approximately a rectangular hyperbola as shown in Figure 5 of the text. What this implies is that the rate of decrease of location-rents away from the workplace is a function of workplace distance from the CBD and that marginal savings in location rents will be proportional to $1/d_{jc}^2$, as discussed earlier.[1]

-- Proximity to Alternative Employment Centres:

Ever since Harris and Ullman [26] pointed out the possibility of multiple nuclei, attempts have been made to incorporate these into more rigourous theories of urban land-rents and uses.[2] It is assumed here (as was assumed by Beesley and Dalvi, [8]) that significant employment centres are surrounded by residential areas, which exhibit declining rent gradients away from these employment centres. An important implication of this is that, in general, the commutersheds of the centres will to some extent overlap. This overlap will increase competition for residential sites and lead to an upward displacement of the rent gradient. The closer similar sized employment

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1. See p. 43.

2. See Evans [19], pp. (196-201) and (218-23).

centres are to each other, the greater this displacement will be. A model of residential location must, then, take into account not only the individual's job location, but also the impact of other contiguous employment centres. In general, then, we postulate that other centres of activity besides the CBD also create rent gradients around themselves since people will desire to locate nearby. Figure 4 illustrated the shape of the location rent function where there is a secondary employment area (SEA) in addition to CBD.[1]

Thus the position of the workplace, relative to such secondary employment areas (if they exist), will determine the rent gradient relevant to the individual residence location decision. Given this, one can conclude that the level of rents in a given area will depend upon the proximity to alternative employment centres, and the size of these centres.

Despite these theoretical expectations, neither Knos [38] nor Yeates [76] were able to relate minor rent-surface peaks to secondary employment or shopping centres in their empirical work. The evidence on the matter is however still far from conclusive, so we propose a variable called employment potential (EP) as a proxy for the effects of secondary location-rent peaks on residential location.

Employment potential (EP) at the midpoint of each of the zones can be calculated using the formula:

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1. See p. 40.

$$EP_j = \sum_{i=1}^{n} \frac{E_i}{d_{ij}}$$

where E_i = total number of workers employed at residence zone i.

When calculating the contribution of employment within a zone itself to potential at the zone's midpoint (i.e., when $i = j$), d_{ij} will be set at unity. It must be noted, therefore, that the potential values are measures of relative rather than absolute accessibility to employment.

-- Importance Of Service Industries In The Area (SI):

Other researchers have found that the importance of service industries in a zone should have an influence on the level of rents of those working in that zone. We, therefore, propose a variable, SI, as a proxy for capturing location-rents for those working in zone j. We suggest that the distribution of service jobs has a strong influence on location-rents and thus on residential location decisions.

$$SI_j = \frac{\sum_{i=1}^{n} SI_i}{E_j}$$

where SI_i = number of workers employed in service industries in zone commuting from residence zone i.

-- <u>Attractiveness Attributes</u>:

Yeates [76] found that, for Chicago, proximity to Lake Michigan was always a good predictor of land values, due to the locational advantages it offered. Steinnes and Fisher [65] also used this factor with some success in their model. In the initial testing of our model, using data concerning the Toronto CMA, we will use a dummy variable (ALO) indicating whether the workplace is on/near Lake Ontario or not. In case of the Toronto CMA, we presume that nearness to Lake Ontario would influence the level of rents at the workplace j. For other cities, similar significant attractiveness features could be incorporated as a proxy for capturing the location-rents.

5.1.3A(ib) Transportation Costs

Transportation costs play an important role in our model, both because the transportation costs function is a crucial element in the theory of choice which underlies the model, and because shifts in this variable will have observable effects on the distance. Ideally under this category one should include direct and indirect factors affecting transportation costs, such as the availability of public transit, interpersonal variations in the value of time, proximity to main transportation routes, physical barriers, congestion, and so on. In the absence of the availability of data on transportation costs, we suggest the use of the following proxies:

-- The Proportion Of Workers Belonging to Families With More Than One Wage Earner (N):

This factor attempts to account for shared commuting costs within the context of residential location. The proportion of the workers belonging to families with more than one wage earner (N_j) is given by:

$$N_j = \frac{\sum_{i=1}^{n} N_i}{E_j}$$

where N_i = number of workers belonging to families with more than one wage earner commuting from residence zone i to zone j.

-- <u>Average Earnings (Wages and Salaries) (Y)</u>:

The time component of the transportation costs is assumed to increase with the commuter's earnings. The average earnings at the workplace j (Y_j) is given by.

$$Y_j = \frac{\sum_{i=1}^{n} a_{ij} Y_i}{E_j}$$

where Y_i = the earnings (wages and salaries) of residents living in zone i and working in j.

5.1.3A(ic) <u>Socio-Economic And Demographic Factors</u>

There are number of socio-economic and demographic factors which might influence the residential location decision. They include sex, age, marital status, family size, occupation and education. Some of these factors (e.g., age, sex) may have a direct effect, in particular, on average journey-to-work distance. For example, female workers make shorter journeys-to-work (Taaffe, Garner and Yeates [67]; Kain [35]; Hecht [27]). Other factors, such as occupation and education, might have an indirect influence on the average journey-to-work distance. For example, people with similar social backgrounds tend to want to live near one another (the desirability of a type of residential neighbourhood). The proponents of social choice hypothesis have shown, among other things, that in large metropolitan centres, the social characteristics of neighbourhoods (which tend to become homogeneous in certain respects) vary with distance from the CBD. If social characteristics vary with the distance of the residence site from the CBD (d_{ic}) and d_{ic} is positively associated with the residence-work-distance (d_{ij}),[1] we will observe an indirect relationship between social characteristics and the length of average journey-to-work.

-- Sex (S):

The proportion of the male workers at the workplace j (S_j) is given by:

$$S_j = \frac{\sum_{i=1}^{n} s_i}{E_j}$$

where S_i = the number of male workers commuting from residence zone i to zone j.

-- Age (AG):

The average age of the workers at the workplace j,

$$AG_j = \frac{\sum_{i=1}^{n} a_{ij} AG_i}{E_j}$$

where AG_i = age of the workers commuting from residence zone i to zone j.

-- Marital Status (M):

The proportion of married workers employed at workplace j, is as follows:

$$M_j = \frac{\sum_{i=1}^{n} M_i}{E_j}$$

1. This has been shown, among others, by Greytak (1974) [23]. We shall also test to see if a significant relationship exists between d_{ij} and d_{ic}.

where M_i = the number of married workers commuting from residence zone i to zone j.

-- Family Size (FS):

The average family size of the workers at the workplace j (FS_j) can be represented as follows;

$$FS_j = \frac{\sum_{i=1}^{n} a_{ij} \; FS_i}{E_j}$$

where FS_i = family size of the workers commuting from residence zone i to zone j.

-- Education (EDU):

The average education of the workers at the workplace j (EDU_j) can be represented as follows:

$$EDU_j = \frac{\sum_{i=1}^{n} a_{ij} \; EDU_i}{E_j}$$

where EDU_i = education of the workers commuting from residence zone i to zone j.

-- Occupation (O):

The proportion of blue-collar workers at the workplace j (O_j^B) can be written as follows:

$$O_j^B = \frac{\sum_{i=1}^{n} O_i^B}{E_j}$$

where O_j^B = number of blue-collar workers commuting from residence zone i to zone j.

5.1.3A(id) Other Factors

There may be a number of factors, in addition to those discussed above, which influence the residential location decision.

One of these factors is car ownership. If the car ownership decision is not made simultaneously with the work-trip considerations, it might affect the choice of residence site exogenously. If the car is used as a transport mode for journey-to-work, then, this variable could be treated as a part of the transport cost fucntion. In the absence of information on the transport mode used in the journey-to-work, car ownership could be treated as an independent factor affecting the choice of residence site.

The proportion of those owning cars who work in zone j is given by:

$$CO_j = \frac{\sum_{i=1}^{n} CO_i}{E_j}$$

where CO_i = the number of workers having a car and commuting from residence zone i to zone j.

5.1.3A(ii) Housing Equations

The following variables appear in the housing equations:

5.1.3A(iia) Type of Dwelling (Structure Type) (TY)

The proportion of workers who inhabit single detached dwellings and who work in zone i can be presented as follows:

$$TY_j^s = \frac{\sum_{i=1}^{n} TY_i^s}{E_j}$$

where TY_i^s = the number of workers who inhabit single-detached dwellings commuting from residence zone i to zone j.

This variable which is employed as both a dependent and an independent variable can, however, be represented (if desired) in terms of other structure types.

5.1.3A(iib) Number of Bedrooms (BR)

The proportion of workers who inhabit single-detached dwellings with three or more bedrooms and who are employed at zone j is given by

$$BR_j^s = \frac{\sum_{i=1}^{n} BR_i^s}{E_j}$$

where BR_i^s = the number of workers who inhabit single detached dwellings with three or more bedrooms commuting from residence zone i to zone j.

This dependent variable can be also applied to other structure types.

5.1.3A(iic) Housing Quality (HQ)

The age of the structure is used as a proxy for housing quality assuming that the quality of housing decreases with the age of the structure. The number of workers, who inhabit single-detached houses built during the period 1960 to 1971, employed at workplace j, can be represented as follows:

$$HQ_j^s = \frac{\sum_{i=1}^{n} HQ_i^s}{E_j}$$

where HQ_i^s = the number of workers who inhabit single-detached houses, built during the period 1960-1971, commuting from residence zone i to workplace j.

This independent variable can also be applied to other structure types.

5.1.3A(iid) Other Socio-Economic and Demographic Variables

The other socio-economic variables in the housing Equations (23) and (24) are defined in the same manner as explained in context of the locational equation.

5.1.3B Individual Characteristics of the Worker

To test this model in terms of individual characteristics, rather than the average characteristics of workers on a zonal basis, it is necessary to redefine the variables. This redefinition may be in terms of individuals, or in terms of individuals grouped according to certain characteristics. Since each individual worker will be associated with different categories of age, income, occupation and so on, the independent variables can generally be expressed in dichotomous form.[1] To avoid the problems of using a dependent variable which is dichotomous in form, it may be appropriate to rewrite the residence location equation and the housing equations in reduced form, where the dependent variable would be expressed as follows;

d_{ij} = the average linear commuting distance between residence zone i and zone j for a worker living in zone i and working in zone j.

The independent variables for analysis at the level of the individual worker are expressed, for example, as follows:

S_{ij} = sex of the worker commuting from residence zone i to zone j;

M_{ij} = marital status of the worker commuting from residence zone i to zone j;

1. For a description of the estimation methodology, when the independent variables are presented in dichotomous form, see Jac-André Boulet (1975) [32a].

N_{ij} = whether the worker, commuting from residence zone i to zone j, belongs to a family with one or more than one wage earner;

CO_{ij} = whether the worker, commuting from residence zone i to zone j, owns a car;

R_{ij}^{α} = the rent category α (where $\alpha = 1, 2, ..., n_1$) to which the worker, commuting from zone i to zone j, belongs;

Y_{ij}^{β} = the earnings category β (where $\beta = 1, 2, ..., n_2$) to which the worker commuting from zone i to zone j, belongs;

O_{ij}^{∂} = the occupational category ∂ (where $\partial = 1, 2, ..., n_3$) to which the worker, commuting from zone i to zone j, belongs;

EDU_{ij}^{ϕ} = the educational category ϕ (where $\phi = 1, 2, ..., n_4$) to which the worker, commuting from zone i to zone j, belongs;

AG_{ij}^{ψ} = the age category ψ (where $\psi = 1, 2, ..., n_5$) to which the worker, commuting from zone i to zone j, belongs;

FS_{ij}^{δ} = the family size category δ (where $\delta = 1, 2, ..., n_6$) to which the worker, commuting from zone i to zone j, belongs;

Ty_{ij}^{ε} = the structure type of dwelling category ε (where $\varepsilon = 1, 2, ..., n_7$) of the dwelling which the worker, who commutes from zone i to zone j, inhabits;

BR_{ij}^{Θ} = the number of bedrooms, Θ (where $\Theta = 1, 2, ..., n_8$) in the dwelling which the worker, who commutes from zone i to zone j, inhabits;

and

HQ_{ij}^{σ} = the age of dwelling category σ (where $\sigma = 1, 2, ..., n_9$) of the dwelling which the worker, who commutes from zone i to zone j, inhabits.

The variables concerned with structure type of dwelling, number of bedrooms in a dwelling and age of dwelling can also be written in continuous form, which would permit the housing equations to be derived separately, if this was wished. These variables would be associated with workers at the individual level, and could be defined, for example, as follows:

TY_{ij}^{s} = for the worker living in zone i and working in zone j, the proportion of all workers living in zone i who inhabit single detached dwellings (or, alternatively, the proportion of all workers living in zone i and working in zone j who inhabit single detached dwellings);

BR_{ij}^{s} = for the worker living in zone i and working in zone j, the proportion of all workers living in zone i who inhabit single detached dwellings with three or more bedrooms (or, alternatively, the proportion of all workers living in zone i and working in zone j who inhabit single detached dwellings with three or more bedrooms);

and

HQ_{ij}^{s} = for the worker living in zone i and working in zone j, the proportion of all workers living in zone i who inhabit single detached dwellings built during the period 1960 to 1971 (or, alternatively, the proportion of all workers living in zone i and working in zone j who inhabit single detached dwellings built during the period 1960 to 1971).

The detailed definition of the variables, and the most appropriate means to estimate them will be investigated in a later document covering certain empirical work.

5.2 The Job Location Model

This model presents an alternative explanation of work-trip length, based on the assumption that workers or certain groups of workers treat their residences as fixed in location. Under this assumption a somewhat different set of factors determines trip-length. Certain factors included in the residential location model, most notably location-rents and quantity of housing demanded, clearly lose their theoretical significance. In what follows, we outline the assumptions and theory behind the job-location model and then consider its operationalization. Much of the material is new, in the sense that there is no large and established body of literature (as there is in residential location theory) to draw upon. A lot, however, is owed to a model by Beesley and Dalvi [8] which takes this basic approach.

5.2.1 Assumptions

(i) As in the residential location model, this model is framed in terms of the working population. Each member of this population is assumed to maximize his or her net earnings (a necessary condition for utility maximization), this being defined as his other earnings (net of search costs) less the cost of commuting, by trading off travel costs to work against the potential increase in earnings by taking up employment at more distant location.

(ii) Given the polycentric nature of workplace locations, the worker's residence is assumed to be given in any of the i residence zones and he or she is al-allowed to choose a job in any of the j employment zones. As before, every zone in the metropolitan area is considered both a residence and employment zone.

(iii) We assume that there is one, city-wide market for labour of all types, so that the average wage in a zone (when controlling for the effects of its occupational composition) is an indicant of the attractiveness of that area as a workplace to all workers.

(iv) There must be a known and sufficiently high level of costs involved in changing one's place of residence to make the theory workable.

5.2.2 The Structure of the Model

In outlining the theoretical model of job location, the object is to understand the way individuals make their job location decisions with respect to an exogenously determined residential site in any part of the metropolitan area. Under our assumptions, we consider workers who are choosing a job location, in any one of the j zones in the metropolitan area, so as to maximize their net earnings. Following Beesley and Dalvi [8], let Y_i be the worker's earnings from employment nearest to his residence site i (net of search costs), and Y_j be the earnings from employment at a more distant location j (again, net of search costs). Assuming a positive relationship between earnings and distance,[1] let

$$WL = Y_j - Y_i \geq 0 \qquad (26)$$

where WL is the potential earnings (wage) differential between employment sites i and j. We assume that WL is an increasing function of journey-to-work distance (D) but that it increases at a diminishing rate with D.

Thus, the individual's total earnings (net of search costs) at any location j may be expressed as,

$$Y_j = Y_i + WL(D) \qquad (27)$$

and the individual's net earnings, Y_n (earnings net of search costs less commuting costs) will be given by

$$Y_n = Y_i + WL(D) - T \qquad (28)$$

where T is the transportation costs.

Differentiating Equation (28) with respect to D and setting the derivative equal to zero, we obtain

$$WL'(D) - T' = 0 \quad \text{or} \quad WL'(D) = T' \qquad (29)$$

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1. However, income is bounded from above, in the sense that there is an upper limit upon the amount of income one may earn by taking up jobs farther away from the residence site.

where the primed variables represent partial derivatives. The above condition (29) indicates that for the individual's utility to be at a maximum, the worker will locate his job at a distance from his residence site where the marginal increase in his net earnings is equal to the marginal increase in his commuting costs.

The optimum length of journey-to-work for the individual has been shown in Figure 8 of the text. We now assume, however, that total earnings (net of search costs -- search costs probably increase with distance, but this is not crucial to the model) increase at a diminishing rate with distance, giving us the downward sloping MIE function in Figure 8.

The factors that affect residence-work distance in this model fall under three main categories: the "wage surface", transportation costs, and other socio-economic and demographic variables. We now consider in detail the predicted properties of these categories of factors and their operationalization in this model.

5.2.2(a) The "Wage Surface"

Several authors, among them Evans ([19],(pp. 188-95)), have shown by deduction that a "wage gradient", or surface, analogous to the rent surface, should exist in cities. Specifically wages or earnings should be highest at the CBD and should achieve lower peaks at secondary employment centres in order for equilibrium in the labour market to exist. Unlike the rent gradient, however, the "wage gradient" has found little empirical support.

In order to capture this surface, we use a set of proxies discussed below, in addition using earnings (WG) directly.

-- Earnings potential

This variable (WI) gives us an indication of the closeness of employment zones where the wages are relatively high. It is analogous to the employment potential variable in the residential location model.

-- Search Costs

Besides wages, another factor affecting the distance at which a worker will choose a job is the probability of finding a vacancy in the surrounding zones, or in other words, his search costs. Even though wages may be high, it may be difficult to find a job in a zone because few are available. Here we assume simply that search costs are inversely proportional to the number of jobs in a zone (variations in vacancy rates within the CMA are not available and may not be significant). We propose the use of employment potential (EP), as a meaure of nearness to low search cost (i.e., high employment) zones.

In addition, we argue that car ownership (CO) might affect the search for a job as well. Thus, the car might well be used for seeking a new job and explicitly be treated as an argument for search costs.

The predicted effects of the relative wage level and search costs variables can be easily seen in Figure 7 and 8 of the text. Both an increase in WI and in EP (implying a *fall* in search costs) will *diminish* the *slope* of the total earnings curve in Figure 7, giving us a lower MIE curve in Figure 8 and a shorter optimum distance-to-work.

5.2.2(b) Transportation Costs

The factors affecting transportation costs in the job location model are the same as those in the residential location model, namely N -- the number of workers belonging to the families with more than one wage earner (to account for joint commuting costs) -- and earnings (wage and salaries).

5.2.2(c) Socio-Economic and Demographic Factors

As in the residence location model, we recognize the effect of a number of socio-economic and demographic factors that may affect the distance workers are willing to commute. Certainly, family size will be important, especially for mothers, as will occupation, sex, marital status and age. As well as having direct effects, these variables will have indirect effects on the length of journey-to-work (due to the interaction of social factors and fixed elements of urban structure) similar to those described in the residential location model.

We can synthesize all these factors by modeling the choice of job location. The model tests the proposition that utility maximizing behaviour dependent upon earnings and other socio-economic attributes, can explain the journey-to-work distance. Equation (31) below describe the structural relationship.[1]

$$D = f_1(WG, WI, EP, CO, N, FS, M, S, O, AG) \quad (31)$$

where D = distance between palce of residence and place of work

WG = earnings of the worker.

WI = earnings potential

EP = employment potential

CO = car ownership

N = number of wage earners in family

FS = family size of the worker's family

M = marital status of the worker

S = sex of the worker

O = occupation of the worker

AG = age of the worker

In this equation, the first four factors attempt to capture the effects of the wage surface and search costs; N is directly related to transport costs, while the other variables capture the direct and indirect effects of socio-economic background factors.

Like the residential location model, this model could also be tested in two alternative forms (i) in terms of the 'average' characteristics of the workers on a zonal basis, and (ii)

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1. For reasons similar to those stated in footnote 1 on page 65 of the text, car ownership may be determined simultaneously with work-trip distance, assuming that the presence of a car affects both search and transport costs in the job location decision. The structural Equation (32) below describes the car ownership decision.

$$CO = f_2(R, D, WG, S, FS, N) \quad (32)$$

in terms of the 'individual' characteristics of workers. The model can be looked at in terms of all workers, or, in terms of secondary workers.

5.2.3 Model Notations and Operationalization

5.2.3A 'Average' Characteristics of Workers

When the model is tested in terms of the 'average' characteristics of the workers on a zonal basis, the variables are defined, for computational purposes, as follows:[1]

As assumed in the residential location model, subscript i refers to residence location and j to job location, where i,j = 1, 2, ..., n.

The dependent variable in Equation (31) will be defined as follows:

D_i = average distance of journey-to-work for workers living in the residence zone i.

$$D_i = \frac{\sum_{j=i}^{n} a_{ij} d_{ij}}{L_i}$$

where a_{ij} = number of workers commuting from residence zone i to workplace j.

d_{ij} = linear distance between residence zone i and workplace j.

L_i = total number of workers living in residence zone i.

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1. The model can be tested for all workers, or for secondary workers alone.

The independent variables in Equation (33) are re-defined as following:

-- Earnings (WG)

WG_i = average earnings per worker in the residence zone i.

$$WG_i = \frac{\sum_{j=1}^{n} a_{ij} \, WG_j}{L_i}$$

where WG_j = the earnings of the workers employed in zone j.

-- Earnings potential (WI)

WI_i = earnings potential for those living in the residential zone i

$$WI_i = \sum_{j=1}^{n} \frac{WG_j}{d_{ij}}$$

where WG_j = the earnings of the workers employed in zone j.

-- Employment potential (EP)

EP_i = employment potential at the midpoint of the zone i.

$$EP_i = \sum_{j=1}^{n} \frac{E_j}{d_{ij}}$$

where E_j = total number of workers employed in zone j (when i=j, dij will be set at unity)

-- Car Ownership (CO)

CO_i = proportion of workers in residence zone i who own a car.

$$CO_i = \frac{\sum_{j=1}^{n} CO_j}{L_i}$$

where CO_j = the number of workers having a car and commuting from residence zone i to workplace j.

-- <u>The number of wage earners in the family (N)</u>

N_i = the proportion of workers belonging to families with more than one wage earner living in residence zone i.

$$N_i = \frac{\sum_{j=1}^{n} N_j}{L_i}$$

where N_j = the number of workers belonging to families with more than one wage earner residing at i and working at j.

-- <u>Sex (S)</u>

S_i = the proportion of male workers living in the residence zone i;

$$S_i = \frac{\sum_{j=1}^{n} S_j}{L_i}$$

where S_j = the number of male workers commuting from residence zone i to zone j.

-- <u>Family Size (FS)</u>

FS_i = the average family size of workers living in residence zone i;

$$FS_i = \frac{\sum_{j=1}^{n} a_{ij} FS_j}{L_i}$$

where FS_j = average family size of the workers commuting from residence zone i to zone j.

-- Marital Status (M)

M_i = the proportion of married workers living in zone i;

$$M_i = \frac{\sum_{j=1}^{n} M_j}{L_i}$$

where M_j = the number of married workers commuting from residence zone i to zone j.

-- Age (AG)

AG_i = the average age of workers (or secondary workers) living in residence zone i:

$$AG_i = \frac{\sum_{j=1}^{n} AG_j}{L_i}$$

where AG_j = the average age of the workers commuting from residence zone i to zone j.

-- Occupation (O)

O_i^B = proportion of blue-collar workers residing in zone i.

$$O_i^B = \frac{\sum_{j=1}^{n} O_j^B}{L_i}$$

where O_j^B = number of blue collar workers commuting from residence zone i to zone j.

5.2.3B Individual Characteristics of the worker

To test this model in terms of each characteristics of the individual worker, it is necessary to redefine the variables in different notations (from those above) to clarify the computational procedure. As explained in the context of the residential location model, the independent variables can be expressed in dichotomous form.

The dependent variable in Equation (31) will be defined as,

d_{ij} = the average linear commuting distance between residence zone i and zone j for a worker living in zone i and working in zone j.

The independent variables will be expressed in the following manner (to give several examples):

S_{ij} = sex of the worker living in zone i and working in zone j;

M_{ij} = marital status of the worker living in zone i and working in zone j;

N_{ij} = whether the worker, living in zone i and working in zone j, belongs to a family with one or more than one wage earner;

AG_{ij}^{Ψ} = the age category Ψ (where $\Psi = 1, 2, \ldots, n_1$) to which the worker, commuting from residence zone i to zone j, belongs;

CO_{ij} = whether the worker, living in zone i and working in zone j, owns a car;

WG_{ij}^{β} = the earnings category β (where $\beta = 1, 2, \ldots, n_2$) to which the worker who lives in zone i and works in zone j, belongs;

and

FS_{ij}^{δ} = the family size category δ (where $\delta = 1, 2, \ldots, n_3$) to which the worker, commuting from residence zone i to zone j, belongs.

The remaining independent variables can be defined in dichotomous form, as was the case for the residential location model. We shall discuss the detailed definition of the variables and the estimation of the equations in a later document.

Section 6: CONCLUDING NOTES AND FUTURE WORK

Previously we examined the evolution of the foundations of current residential and job location theory -- from early notions about land rents and residential patterns, through the literature expounding social and economic choice hypotheses, to a review of empirical models, the testing of which provided confirmation (or rejection) of hypotheses. In this process we have extracted those theoretical propositions and proven relationships which provide the structure of the two models presented to the reader in the last section. In following papers in our *Urban Papers* series, these models we propose will be evaluated using data from the 1971 Census, for the Toronto CMA.

The second stage in our work will be to analyze commuting patterns in the twenty-two CMA's. A series of "urban journey-to-work profiles" will be compiled which will provide an overview of the journey-to-work and residential and employment patterns in each CMA. For the Toronto CMA, for which planning zone descriptions that are compatible with census tract aggregations have been provided, we will evaluate the role of the journey-to-work in explaining the residential and job location structure of this urban area. This profile, together with the underlying data base, will complement work already completed in the METROPLAN studies undertaken by and for the Municipality of Metropolitan Toronto. For Halifax-Dartmouth, the profile will be developed on the basis of a census tract spatial disaggregation and an effort will be made, in response to requests from this urban region, to indicate "employment-sheds" that could be used as a basis for the design of relevant planning districts. Likewise, for other CMA's residential and job location patterns and journey-to-work flows will be analyzed *by census tract*, unless otherwise requested by these urban centres. The data banks upon which the profiles are based will be available on request.

The third stage of the project will be reported in a paper which evaluates the influence of socio-economic factors on the length of the journey-to-work, tests certain related hypotheses developed in this current paper and draws appropriate policy and planning implications and recommendations. For instance, the research will shed light on the degree to which socio-economic factors appear to constrain or ease access of certain social groupings to employment opportunities and/or housing stocks. Such considerations should enter public decision-making in respect of the provision of transportation facilities (roads and transit), housing (public and private), zoning (the location of employment-generating activities), and social services (training centres, for instance).

In the fourth stage we will directly test the residential and job location models specified in the previous section of this current paper. The results of these tests should indicate the general way in which developments in employment-generating activities, including their location, may lead, somewhat indirectly to corresponding demands for housing in various sectors of the urban area, as implied through the Residential Location model. The results of the Job Location model may provide general insights into the constraints to successful job search, particularly on the part of potential secondary household workers, faced with fixed or given residential locations. The findings of both models have meaning for the design of transportation systems which may improve access without modifying spatial proximity of home and workplace location.

The overall intent, therefore, is to proceed from the examination of theory, in this paper, to the compilation of data which may be of direct use to municipal officials and to the analysis of these and other data so as to determine certain intra-urban relationships. From these efforts, we hope to contribute to the understanding of urban systems and to the design of policies, strategies and programs related to the urban structure.

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