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A Household Life Cycle Model for Residential Relocation Behaviour

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**A HOUSEHOLD LIFE CYCLE MODEL
FOR RESIDENTIAL RELOCATION BEHAVIOUR**

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ABSTRACT

In this paper a dynamic household model in connection with a comprehensive urban housing market model for Amsterdam is presented. Household dynamics is modelled here by using the methodology of multidimensional demography. A consistent analysis of the components of a dynamic spatial housing market system incorporating various submodules, multiple factors, spatial aggregation levels, and degrees of precision of available data requires the use of an accounting framework. The paper shows the analytical structure and empirical estimation of an accounting model developed for investigating the dynamics on an urban housing market, with a particular focus on changes in household compositions caused by the household life cycle phenomenon. The linkage between the life cycle concept and the demand on the housing market is established by using an explanatory nested logit model. Apart from a few exceptions in a more limited context, this is a rather unique attempt at modelling, in a consistent way, the dynamic allocation of household demand for dwellings in a zonal urban system based on a large-scale socio-economic data set concerning spatial residential relocation behaviour in Amsterdam.

On the basis of the empirical outcomes obtained, of various model testing procedures, and of a comparison of observed and predicted outcomes, this housing market model appears to reproduce housing market developments in the past satisfactorily, so that it can also be used as a tool for predicting future paths of urban housing market demand.

Introduction

Population dynamics, reflected inter alia in a household life cycle model, is crucial in modelling housing market behaviour. As individuals move through various stages of their life cycle, they constantly adjust their housing needs and choices in incremental steps ([29],[30]). It has been observed by many researchers (e.g.,[11],[18]) that the life cycle - rather than economic motives - is the predominant explanatory factor in residential relocation decisions, so that demographic evolution is mirrored in the housing market. Consequently, changes in the life cycle sooner or later trigger relocation decisions in the housing market. For example, Clark et al. ([13]) found evidence in the Netherlands of the effects of the birth of a child on the decision to relocate. Hence, a model that incorporates the concept of the life cycle in housing market behaviour should focus on the dynamics of this process. The model presented in this paper is dynamic in the sense that it is built around the concept of household life cycle transitions and their impact on residential relocation decisions.

The housing market in the Netherlands is highly restricted. Housing supply is, to a large extent, planned by central and local governments, and the price mechanism plays only a minor role in clearing the market ([43]). Housing in the Netherlands is viewed as a merit good. In planning housing facilities, the concept of housing needs is very important, not only in a quantitative sense, but also at a more qualitative level. This means that housing preferences of households are taken into account as well. At the local level, especially in the larger urban areas, housing policy is based on housing needs that are related to the size and composition of households. In Amsterdam, a housing distribution system exists based on household size in relation to dwelling size. Therefore, qualitative aspects of the demographic developments in the Amsterdam housing market are critically important in understanding housing market behaviour. The model presented in this article explores the consequences of household dynamics on a detailed intra-urban zonal level in terms of housing preferences and overall housing market dynamics, by confronting demand and (exogenous) supply. Thus, the need for a dynamic multizonal housing market model focussing on the evolving demand for dwellings in a strictly regulated (and often rationed) housing market is a *sine qua non*.

Dynamic spatial (urban and regional) economic models in a more general sense have increasingly become popular in past years (see, among others, [5],[6],[16],[17]). Such models aim at portraying and predicting the multidimensional, compound and sometimes nested development of a dynamic spatial economic system composed of different sub-systems (housing, transportation, migration, etc.), so that its evolution can be replicated by means of plausible system trajectories. In this context, various explanatory modelling approaches have been previously developed, such as dynamic Lowry models, micro simulation models or dynamic discrete choice models.

A basic distinction of such models can be made between dynamic and quasi-dynamic approaches. In dynamic approaches, the model parameters are treated endogenously, whereas in quasi-dynamic models the parameters are either fixed or treated exogenously during the prediction stage. Based on this distinction, the model developed here may be regarded as quasi-dynamic.

A consistent treatment of (quasi-)dynamic economic models describing different components of a compound spatial economic system characterized by various submodules, multiple actors, different aggregation

levels, and varying degrees of precision of available data requires the use of an equilibrium mechanism in the form of an 'accounting framework' for all objects and actors [14]. This accounting framework is necessary for two reasons: (1) it ensures a coherent and consistent representation of a compound dynamic spatial system, and (2) it ensures a comprehensive and valid treatment of actors operating in varying socio-economic configurations (e.g., individuals, households, socio-economic groups, population as a whole). Such framework may act as a 'niche' in a broader urban economic model, in the same way as an input-output accounting framework can be used in a more comprehensive regional or national model. Unfortunately, the current practice of urban and regional economic modelling has often neglected the consistency conditions associated with such framework.

This paper shows the analytical structure and empirical estimation of an accounting model developed for investigating urban housing market dynamics, with a particular focus on changes in household compositions caused by the household life cycle phenomenon. Apart from a few exceptions in a more limited context, this is a rather unique attempt at modelling, in a consistent way, the dynamic allocation of household demand for dwellings in a zonal urban system, based on a large-scale data set regarding preferences and choices of individual households. The paper is organized as follows. First, the overall framework of the dynamic urban housing market model is presented. A central position in this presentation is given to the accounting framework, that is the link between various submodules in the overall model structure. In subsequent sections, various submodules are presented, viz. the household transition model for analyzing household change, and the household relocation model. The central theme of the relocation model is to represent the effects of household life cycle dynamics for the housing market at the urban level. Two phases can be distinguished in this respect. First, the generation of a housing demand pool as a consequence of household dynamics and related factors. This centers around the decision to want to move, and is triggered by household dynamics related to housing characteristics. This is followed by the decision for the preferred dwelling type. However, such a choice is not made independently of housing market conditions. Households evaluate alternative dwellings not only on the basis of attributes of the dwelling in relation to household and other characteristics, but also with respect to availability of dwellings. This gives rise to dynamic adjustments in the composition of dwelling demand due to market supply and demand relationships.

The main emphasis of the paper is on presenting the overall structure of the model. It is impossible to give a full account of all empirical results in the current context. A presentation of many empirical results can be found in [36] and [42]. A number of illustrative model simulation results of the period 1971-1984 will be presented herein, highlighting the main structural features of the model. The paper concludes with a discussion of feasible future directions in the field of dynamic housing market research.

Dynamics of Households on a Housing Market: An Accounting Framework

Each housing market is characterized by a variety of objects (i.e., dwellings with different size, age and quality categories) and actors (i.e., households with different size, composition and life cycle features). In this paper attention will be focused on the choices at the demand side of the housing market. Especially in the Dutch context, the supply side is an institutionally regulated market in which production, supply and allocation are mainly determined by complicated, planning and rationing schemes, following the expected development of the demand

side without being directly or necessarily connected with a conventional price mechanism (for a discussion of such problems, see also [4]). The supply side of Dutch housing market policy is extremely rigid from an economic viewpoint, so that a 'standard' supply model does not make much sense. Interest here is in household relocation decisions and distribution in the housing market; in particular, a consistent allocation of dwelling choices in an urban housing market as a result of demographic dynamics and market conditions, taking the supply side as determined by given external policies.

The residential relocation model described here is novel in that it contains a multidimensional description of both urban districts and dwelling types. The demand side of our urban housing market model incorporates a detailed zonal subdivision of an urban system, so that the demand effects of household dynamics can be assessed at a zonal level. Furthermore, an extensive set of different dwelling types will be distinguished in order to allow a detailed assessment of the specific demand in each zone. In addition to internal household dynamics caused by life cycle aspects, in- and out-migration may also have a significant impact on the size and composition of actors on the demand side of the housing market. All these elements must be incorporated in a dynamic socio-economic accounting framework in order to achieve a consistent classification of models, variables and data in an organized series (vectors and matrices) describing the demand side of the urban housing market.

[Figure 1 approximately here]

The accounting framework is a book-keeping device for all elements in all time periods in the model. Basically, this framework is needed for two reasons. First, since the model operates at more than one level (viz. the individual level, the household level and the level of the dwelling unit), a mapping is needed to describe the transformation of the distribution of one variable into the other. These mappings are provided by a number of state matrices. For instance, the household composition matrix A provides the link between the population age distribution and the household distribution over the household categories [1]. A typical element, a_{xg} in A, denotes the number of individuals of age x who live in a household type g , multiplied by a factor $(s_g \cdot l_x)^{-1}$, where s_g is the size of a household type g and l_x is the number of persons with age category x . For the moment, we leave household type g unspecified. This will be discussed in the next section. A can only be observed in certain years, whereas the vector l is yearly available at a zonal level. An estimate of the household distribution over all categories in a vector b can be calculated as:

$$\hat{b} = A^T l \quad (1)$$

where $\hat{b}$ denotes the estimate. Another state matrix, the occupancy matrix C plays a similar role in the mapping of households to dwellings, and vice versa. C gives the bivariate distribution of households by category over the various dwelling types.

The second purpose of the accounting framework is to represent the dynamics of each variable over time, by means of a number of transition matrices. These transition matrices are the most important ingredients of the

system and are the result of a number of submodels that operate at different levels in the overall model. This will briefly be described here. The output of the household life cycle model is a period- and zone-specific household transition matrix R , with transitions between pairs of household types. Next, the migration model produces a period- and household-type-specific transition matrix of potential migration between all pairs of zones and dwelling types. This is done in two steps. First, a mover pool of potential relocation is estimated, based on the household's willingness-to-move, indicated by a matrix D . Next, a potential relocation table, W , is estimated from D using information on the intended direction of the move and the preferred dwelling type. Finally, the actual transitions of households between zones and dwelling types in the region are modelled in the allocation model, which produces transition matrix M with the same form as W of observed household relocations between all pairs of zones and dwelling types in the urban area. These three models will be discussed in more detail in the sections to follow. The accounting framework ensures that no person, household or dwelling is 'lost' between years, or in linking one level of the model to the other. Figure 1 gives an overview of all relevant elements in the accounting framework and the corresponding submodels.

The Household Life Cycle Model

Household dynamics is a complex process, not only because of birth, death and ageing, but also because of socio-economic household formation processes: households may split and rejoin in many ways thus affecting the total number of households and their effective demand on the housing market. The modelling of household formation and dissolution is a relatively new topic in demography. It has developed mainly in the 1980s ([24]), and is related to - but different from - the modelling of families and kinship relations, since marital status is not the crucial factor *per se*. (For an overview, see [8], [9], [15]). Households appear in many forms involving both families and non-families. New forms of cohabitation, primarily non-family types, tend to concentrate in urban centers. This underlies why, in the current paper, a household framework was chosen for the modelling of Amsterdam household dynamics. The approach adopted in this research is related to other household models developed in the Netherlands during the 1980s, viz. Primos ([19]) and Lipro ([23],[41]).

Household dynamics may be modelled by means of transition probabilities. In estimating the transition matrix for different household categories (according to size, age and composition) two approaches are relevant (see [22], [25])

- individual transition probabilities for a membership of household class i in period t to i' in $t+1$ ($i, i' = 1, \dots, I$) (cf. [31]), and
- household transition probabilities for different household classes (cf. [45])

The first approach is straightforward and in agreement with many socioeconomic and demographic data bases (e.g., on birth, death, marital status, household membership, etc.). However, a drawback of this approach stems from its inherent consistency problems (e.g., the two-sex problem in the marital status table; see [21]). The second approach corresponds to the need for assessing housing demand at a household level, but faces the problem of defining and measuring households. In this context, the headship rate method is sometimes used ([22]), but is unable to incorporate household dynamics. In our approach, the individual and household levels will be combined

in one model to overcome the consistency problem (cf. [20], [47]).

As a result, our model contains various components, such as the assessment of individual transition probabilities for discrete changes in positions in a given household by means of multidimensional demography (cf. [26],[37],[38],[39],[46],[48]). Explicit continuity rules ([28]) for deriving household events from individual events are incorporated as well. This implies that the existence of a given household is tied to a given member of the household (usually the head), so that continuation of the household unit is also guaranteed when two or more household members are splitting up.

The dynamic household model is based on the premise that age and changes in household size are the most important determinants of a residential relocation decision in the household. In addition, household formation and dissolution, also disaggregated by household size and age, have a strong impact on housing demand and supply. Therefore, the proposed model incorporates three main elements, viz., dynamics in household size, household formation and household dissolution. These processes are disaggregated by age of the head of the household. Such household dynamics are based on a model of individual life cycle transitions. As an individual ages, he or she progresses through a series of phases in the life cycle or household positions; for instance, child, single, head of a two (three, four,...) person household, etc. These transitions at the individual level constitute the basic dynamics of the household model. Individual transitions are aggregated to household transitions. Table 1 contains the individual household positions that are used in the model and the resulting household categories.

[Table 1 approximately here]

The individual transitions are collected in a matrix, T : the individual transition table. It contains individual transition probabilities by position in the household. T is a matrix filled with submatrices $T(x',x)$ ($x, x' = 0, 5, 10, 15, \dots, 65+$)⁽¹⁾. x denotes the 5-year age category at the beginning of the projection interval, while x' denotes the age category at the end of the projection interval. T has the following form:

$$\begin{pmatrix} 0 & \dots & 0 & T(0,\alpha) & \dots & T(0,\beta) & 0 & \dots & 0 \\ T(5,0) & 0 & & & & & & & \\ 0 & T(10,5) & 0 & & & & \dots & & \vdots \\ & 0 & T(15,10) & 0 & & & & & \\ \vdots & & & & & & & & \\ & & & & & & & & 0 \\ 0 & & \dots & & & 0 & T(65,60) & T(65,65) \end{pmatrix} \quad (2)$$

T resembles a Leslie projection matrix, with submatrices replacing matrix elements. In fact, T is an exploded Leslie matrix with dynamics in household positions added. The only non-zero submatrices are the matrices $T(x+5,x)$, $T(65,65)$ and the fertility matrices $T(0,x)$, where $x=15,\dots,45$ is the age category of the mother at the beginning of the projection period. They contain household-position specific fertility probabilities. The subdiagonal

matrices $T(x+5, x)$ can be as abbreviated $T(x)$. $T(x)$ has elements $\{t_{h'h}(x); h, h' = 1, \dots, H, H+1\}$, where the index h denotes the position in the household as defined in Table 1 at the beginning of the projection interval, and h' denotes the position in the household at the end of the projection interval. Category $H+1$ is used for non-household positions. Thus, $\{t_{h', H+1}(x); h' = 1, \dots, H\}$ is the column with transition probabilities from the non-household population to a position in the household h' at age x . Likewise, $\{t_{H+1, h}(x); h = 1, \dots, H\}$ is the row with transition probabilities from a household position h to a non-household position at age x . T enables a complete projection of individuals by age and position in the household.

Let $k(y)$ be a population vector by age and position in the household (the non-household category included) at the beginning of time period y ². k is called the population distribution table ([42]). The following equation projects the population over time:

$$k(y+5) = T k(y) \quad (3)$$

Note that T does not contain migration, so that $k(y+5)$ refers to the population distribution at the beginning of the period $y+5$, of the population who were resident at the beginning of the projection period y . We will deal with change of residence in the next section.

The transition probabilities $t_{h'h}$ are estimated from longitudinal household data using the methodology of multidimensional demography. This involves the estimation of age-specific transition rates $\mu_{h'h}(x)$, for every transition in the table T , where x denotes age. This empirical estimation is carried out by fitting a set of appropriate transition rate functions to empirically observed age-specific transition rates. The rates were calculated from a retrospective survey of 5,000 households that was conducted in 1980, and covered the period 1975-1980 ([32]). Two types of functions were used in our case, viz. the log-normal and the negative-exponential form. The transition rates are organized in matrices, $\mu(x)$, of the following form ([26]):

$$\mu(x) = \begin{bmatrix} \mu_{11}^*(x) & -\mu_{12}(x) & \dots & \dots & -\mu_{1H}(x) \\ -\mu_{21}(x) & \mu_{22}^*(x) & \dots & \dots & \dots \\ \dots & \dots & \ddots & \dots & \dots \\ \dots & \dots & \dots & \mu_{H+1}^*(x) & \dots \\ \dots & \dots & \dots & \dots & \ddots \\ -\mu_{H+1}(x) & \dots & \dots & \dots & \dots & \mu_{H+1H}^*(x) \end{bmatrix} \quad (4)$$

The diagonal elements $\mu_{hh}^*(x)$ denote the total force of mobility out of state h , whereas the off-diagonal elements represent minus the force of mobility from position h to h' , i.e., $-\mu_{h'h}(x)$. The diagonal elements are defined as:

$$\mu_{ab}^*(x) = \sum_{k=1}^K \mu_{abk}(x) + \mu_{ab}(x) \quad (5)$$

where $\mu_{ab}(x)$ is the death rate. The matrix of individual age-specific transition rates can be used to estimate the matrix $T(x)$ of individual transition probabilities between the positions in the household (see also [26], [46])

$$T(x) = \left[I + \frac{1}{2}\mu(x) \right]^{-1} \left[I - \frac{1}{2}\mu(x) \right] \quad (6)$$

While the individual transition probabilities are the basic dynamic elements in the model, for housing market modelling we are more interested in household transitions. The matrix of household transitions $R(y)$ is derived from the matrix $T(y)$ and the population distribution table $k(y)$ by suitable aggregation of the expected number of individual transitions in household positions. Table 2 gives the aggregation of the number of individual transitions in positions in the household to household transitions.

[Table 2 approximately here]

The aggregation rules presented in Table 2 define each household transition in terms of one or more individual transitions in positions in the household. For instance, the transition from a child, partner or non-household position to a single or head position is considered as a household formation, whereas a change from single or head to partner or non-household position is a household dissolution. Further, transition between the states of single or head (of a 2-, 3- or 4+ person household) is a change in size of the existing household. These rules were chosen after detailed study of various alternative aggregation schemes using longitudinal household data. Each submatrix $R(x)$ has elements $\{r_{g'g}(x); g', g=1, \dots, G, G+1\}$. As can be seen from Table 2, the last row $G+1$ of the table gives the expected number of household dissolutions by original household category g while the last column $G+1$ of $R(x)$ gives the expected number of new household formations by resulting household type.

In the next section these household dynamics will be linked to the housing market. Knowledge of the main housing characteristics in conjunction with the present stage and dynamics in the household provides the main input of a behavioural model of intra-urban residential relocation.

The Residential Mobility Model

A large number of authors ([11],[18],[40]) have pointed out that changes in the household life cycle together with the current housing market situation provide the basic stimulus for the residential moving process. This can be incorporated in an accounting framework if we link the household transition table $R(y)$ to the occupancy status of the household, represented by the occupancy table $C(y)$, where $C(y) = \{c_{kg}(y); k=1, \dots, K; g=1, \dots, G\}$ is the complete cross-classification of households by housing submarket k and household type g at the beginning of period y . For ease of notation, g includes here both household categories as defined in Table 1 and age of the head. Housing submarkets or dwelling types are defined in Table 3.

[Table 3 approximately here]

The classification used here combines the main housing dimensions: (1) the number of rooms, (2) tenure (buy versus rent), and (3) housing type (apartment versus single family unit). Housing price was not used in this respect for two reasons. First, as stated before, the housing market is highly regulated, and, as a result of various subsidies and institutional arrangements, housing price only plays a minor role in the urban housing market. Second, the institutionally determined housing price can be generated to a large extent by knowledge of the three above mentioned characteristics.

It should be noted that household category G+I (i.e., the class of new household formations) is not included here, since these households do not yet occupy a dwelling unit. Household dynamics as expressed in the transition table $R(y)$ combined with housing occupancy status in $C(y)$, indexed k , provides all information to calculate the household's willingness to move. For instance, a two-person household currently living in a rented double-room apartment in the city center that changes its size from two to three persons will have, as a result of this change in household composition, an increased stimulus to find another residence. A number of factors account for this phenomenon. First, the stage in the life cycle of the household, indicated by the age of the head has a distinctive effect on residential mobility, with younger households *ceteris paribus* having a relatively high mobility level. Second, room stress is a very important indicator of the willingness to move. This variable was operationalized as the expected number of persons in excess of the number of rooms at the end of the period. Thirdly, the change in household size in the current period is related to the willingness to move. The larger the increase in household size the higher the effect on the desire to change residence. On the other hand, a decrease in household size has a reducing effect on the willingness to move. This effect is measured as the log-odds ratio of household size at the beginning and the end of the current period. Finally, the tenure status and housing type have an effect on the willingness to move. The quantitative effect of these variables on the willingness to move was estimated using a standard binary logit model of the form:

$$P(\text{move}|kzgg') = \frac{\exp A_{kzt}}{1 + \exp A_{kzt}} \quad (7a)$$

where A_{kzt} is equal to:

$$A_{kzt} = \exp \alpha_t + \beta_{1t} \left[\frac{s_t - r_k}{r_k} \right] + \beta_{2t} U_k + \beta_{3t} B_k + \beta_{4t} \log \left[\frac{s_t}{s_{t'}} \right] + \beta_{5t} X_t \quad (7b)$$

Here, s_t and $s_{t'}$ denote household size at the beginning and the end of the period, respectively; r_k is the number of rooms pertaining to dwelling type k ; U_k is housing type of k , with $U_k=1$ denoting an apartment and 0 all other housing types (mostly single family units); B_k is tenure status, where $B_k=1$ means buy and $B_k=0$ means rent. Finally, X_t denotes age of the head at the beginning of the period. Note that all coefficients are zone-specific.

After initial exploratory analysis it was found that households living in the city of Amsterdam attach different weights to these attributes than to households in the suburbs. Estimation of the coefficients in (7) was accomplished using the method of maximum likelihood. The coefficients were estimated separately for the city of Amsterdam and the suburban cities in the Amsterdam region. Table 4 presents the results of this process.

[Table 4 approximately here]

As explained in the previous section, the household transition table, $R(y)$, is an output of the household model. The occupancy table, $C(y)$, on the other hand, is input to the residential mobility model. For simulation purposes, C was only needed for the base year 1971. Given C , specified for each zone in the Amsterdam region in the base year 1971, the housing market and household simulation model could be run for each year in the period 1971-1985. Each year starts with an occupancy table $C(y)$. Each row of C gives the household distribution in a given housing type k . Their household structure is updated using the transition table $R(y)$. In the first year, the observed $C(1)$ is taken and combined with the household events table, $R(1)$, for each zone z in the following way:

$$\begin{aligned} o_{kg'}(1) &= c_{kg}^*(1) + r_{kg'}(1) \\ (k &= 1, \dots, K; g, g' = 1, \dots, G) \end{aligned} \quad (8)$$

where $O(1) = \{o_{kg'}(1)\}$ denotes the extended occupancy table including household transitions from category g to g' in dwelling type k in year 1, and where $c_{kg}^*(1)$ is equal to $c_{kg}(1)$ scaled such that the sum of each column equals 1. In general, table $O(y)$ is the complete multivariable frequency distribution of all households in terms of dwelling type characteristics k and household transitions (g, g') in year y .

Applying equation (7) to each cell of $O(y)$, we can construct a potential movers table, $D(y)$. The cell entries in $D(y)$ give the total number of households who are of type g at the end of year y and lived in a dwelling type k at the beginning of year y . Note that we have dropped the household composition index at the beginning of year y in D and that (for ease of notation) index g is now used for the household composition at the *end* of year y . Note also that all these matrices are zone-specific, but, in order to make the notation less complicated, we have left out the zone index z . Household dynamics was important in the estimation of the potential movers pool D but it is no longer needed in the sequel of the modelling steps. $D(y)$ has elements $\{d_{kg}(y)\}$. So, the residential mobility model results in a pool of households who are willing to move; a willingness triggered by household dynamics coupled with housing characteristics.

There is one additional group of households: those who are forced to move due to housing demolitions. In the model, this group is taken into account using exogenous yearly information on housing demolitions. However, in the sequel we will focus attention on the large group of voluntary movers. The next section will deal with the modelling of housing demand.

The Housing Demand Model

The mover pool, D , exerts a demand for dwelling types k' in zone z' in the market. Thus k and z (k' and z') define the housing submarket. The choice process for submarkets (k', z') is modelled here by means of a nested multinomial logit structure. For ease of exposition, the indices g , k and z , which describe the current characteristics of the household, will be replaced by the single index j unless explicitly needed. The choice probabilities therefore

have the following form:

$$P_{k'j} = P_{z'|k'j} * P_{k'|z'} \quad (9)$$

where $P_{z'|k'j}$ is the choice for the new zone z' for a household with characteristics j , and $P_{k'|z'}$ is the choice of dwelling type k' for a household type j , conditional on an intended move to zone z' (see e.g., [3], [12]). The interdependence between the two levels of decisions is modelled through the inclusive value of dwelling types in the choice for the preferred zone z' . This model structure can be derived from the assumption of random utility maximization and a specific error distribution.

There is a third level of choice, conditional on zonal and dwelling type preference. This is the choice for an available dwelling unit w in submarket (k', z') . The total number of available dwelling units in submarket (k', z') , $N_{k'z'}$, equals the number of vacancies plus the number of newly constructed dwellings. By assumption, however, all such units in a given specific submarket are regarded as homogeneous. So, the probability of choosing an individual dwelling unit w in (k', z') is $P_{w|k'z'} = 1/N_{k'z'}$, while the expected maximum utility derived from choosing an individual dwelling unit in (k', z') is $\lambda \log N_{k'z'}$. Technically, in the nested logit specification this term is the inclusive value associated with the lowest level of choosing an individual dwelling unit, w , within a submarket (k', z') . To be consistent with utility maximization, λ should fall between 0 and 1. Thus, the total demand for submarket (k', z') is *inter alia* a function of the available dwellings $N_{k'z'}$. The weight, λ , can be estimated as a coefficient in the multinomial logit model. The probability of choosing a dwelling of type k' in year y for a household type j -given that it intends to move to zone z' - can be expressed in the following multinomial logit formulation:

$$P(k' | z'j) = \frac{\exp(V_{jk'z'})}{\sum_{k'=1}^K \exp(V_{jk'z'})} \quad (10a)$$

Here, the term $V_{jk'z'}$ is the indirect utility associated with dwelling type alternative k' for a household type j that intends to move to zone z' . $V_{jk'z'}$ is assumed to have the following form:

$$V_{jk'z'} = V_{jk'z'} = \gamma_{0k'} + \gamma_1 Q_{k'z'} + \gamma_2 Y_{jkz'} + \gamma_3 F_{jkz'} + \lambda \log N_{k'z'} \quad (10b)$$

The parameter $\tau_{k'}$ is an alternative specific constant, measuring the base level utility not accounted for in the exogenous variables; $Q_{k'z'}$ is a set of variables related to the characteristics of dwelling type k' in zone z' ; $Y_{jkz'}$ relates to household and current housing situation, as well as to attributes of the original zone. In addition, a term $F_{jkz'}$ has been added to describe the distance between current and intended dwelling type. This reflects the fact that households usually change their housing consumption in small steps. Here, it was defined as a dummy with $F_{jkz'} = 1$

if $k=k'$ and 0 otherwise. $N_{k'}$ has already been defined above.

The choice for zone z' is the highest choice level in the nested structure. In choosing among the alternative zones, z' , the characteristics of the dwelling types within each z' are taken into account as well through the inclusive value, $L_{k'}$, the expected maximum utility associated with choosing a dwelling type in zone z' for a household type j :

$$\begin{aligned} L_{k'} &= \log \left\{ \sum_{i=1}^K \exp(V_{jk'}) \right\} \\ &= \log \left\{ \sum_{i=1}^K N_{k'}^{\lambda} \exp(\gamma_0 + \gamma_1 Q_{k'} + \gamma_2 Y_{jk'} + \gamma_3 F_{jk'}) \right\} \end{aligned} \quad (11)$$

Thus, in choosing among the various zones, the number of available dwellings is important through this inclusive value. Note that the term $N_{k'}$ has been placed outside the exponential operator. The choice model for choosing among the alternative zones is given by:

$$P(z' | j) = \frac{\exp(W_{jk'})}{\sum_{i=1}^Z \exp(W_{ji})} \quad (12a)$$

where $W_{jk'}$ is equal to:

$$W_{jk'} = W_{jk'} = \theta_{jk'} + \theta_1 X_{k'} + \theta_2 D_{z'} + \theta_3 L_{jk'} \quad (12b)$$

where $\theta_{jk'}$ is an alternative specific constant; $X_{k'}$ is a set of attributes pertaining to zone z' , and $D_{z'}$ is the distance between origin and destination zone. $L_{jk'}$ is the inclusive value pertaining to the lower level dwelling type choice in the nested framework. This model formulation has two advantages. First, it recognizes the impact of market disequilibrium on housing preferences. If the number of available dwellings is low, then the preferred demand for submarket ($k'z'$) will be low relative to submarkets with a larger supply. This is clearly an economic balancing mechanism in the market. Highly attractive dwelling types will be relatively less favoured if the number of available units is low; unattractive dwellings, but in excess supply, will be relatively more valued than would be the case if zonal and dwelling characteristics alone were taken into account. A second advantage is that the impact of new housing construction on housing choice can be measured directly with this model. Estimation results have been reported elsewhere ([42], p.160-7) and will not be repeated here.

In the model simulations, $N_{k'}$ is endogenous. It consists of the total number of (exogenously given) newly constructed dwellings in each year, plus the number of vacancies that occur as a result of realized outmigration. The accounting framework ensures a constant updating of individual households and dwellings in each period, while the structure of housing demand is adjusted dynamically in each period to reflect changes in market conditions. An example of this adjustment process will be given in the empirical section, below.

Missing data in Tables

In order to apply our dynamic model empirically, a large number of data requirements had to be met. Two types of data were used in the modelling effort for the housing market of the Greater Amsterdam Area:

1. Sample data to estimate model parameters, and
2. Census data to provide starting values for the model simulations and the assessment of model fit.

The sample data came from two sources. First, a longitudinal household survey, the so-called "North Wing Study" ([32]-[35]) was used to estimate the household life cycle transition intensities and the relation between life cycle transitions and residential relocation decisions. Second, the Dutch National Housing Survey ([44]) provided the basic information to estimate the decision to move and housing preferences by using a nested logit model.

The census data were composed of three categories. The national 1971 census data [10] were used to provide starting values for model simulations in the period 1971-1985. Further, census data on population and housing for each zone in the urban system at yearly intervals were used to compare aggregate model performance against observed figures and to obtain data on housing supply. Thirdly, data on household composition for the city of Amsterdam related to a number of housing characteristics were obtained for a number of years from municipal statistics [2]. These were used to assess, at a detailed level, the model's performance.

Given the level of detail and disaggregation of the model, it was unlikely that all informational needs could be completely fulfilled by existing data sources. Therefore, whenever necessary, use was made of a data pooling technique by combining different sources of information together and by estimating the most probable distribution, given these data. A maximum likelihood method was developed that estimated expected cell frequencies of a table with known marginal and other partial information. The estimation method used was essentially based on the Generalized Linear Model (GLM) methodology (see [27]). In this framework, information can be included in the form of constraints on the data (e.g., marginal and other hybrid types of information) or prior information on the multivariate distribution. This data pooling technique was applied at various stages in estimating the model.

As an example, we consider the estimation of the initial occupancy table, $C(1)$ (i.e. for the year 1971), for each zone in the system using all relevant published census information. The position of the occupancy table in the overall model structure has been described above. The occupancy table is the complete five-dimensional distribution of households by housing type U (flat versus single family unit), tenure B (buy versus rent), number of rooms r , age of the head x (six categories), and size of the household s (with categories 1, 2, 3 and 4+ persons).

It is convenient here to specify a multivariate discrete distribution using a shorthand notation developed in log-linear modelling (see e.g. [7]). In this notation, $[U]$ denotes the table given by the marginal total of the discrete variable U ; $[U][B]$ is the two-way table completely determined by the marginal distributions of the two variables U and B . This means that the cell entries x_{ij} in the table are equal to $x_{i+}x_{+j}/N$, where the '+' sign means 'summation over the relevant index', corresponding to the hypothesis of independence between variables U and B . If U and B are not independent, however, the marginal totals are not sufficient to determine the complete table. Instead, an additional interaction term is needed. In that case, the complete table is given by $[UB]$.

In general, for a table of any dimension, the cell entries can be determined using the marginal totals of all terms included, plus all higher-order interaction terms of all variables within the same brackets. Likewise, the

complete five-way occupancy table can be described as [UBRAS]. Using this notation, the information available from the published tables of the 1971 census for each zone is: [AR][AS][AB][RS][BSU]. Using the housing needs sample for the year 1981 ([44]), and assuming that the structure among the variables had not changed in the time interval between 1971 and 1981, a test was employed to determine whether this information was sufficient to estimate the complete table [UBRAS]. Results indicated that the difference between the estimated and observed tables in the sample was too large to be attributable to chance. Still, the percentage 'explained' variance accounted for by these marginal totals was 96.9% for Amsterdam and 91.6% for the suburbs. In addition, it was found, in the 1981 sample, that the most important missing piece of information was the bivariate table [RU], viz. the breakdown of households by housing type and number of rooms. Therefore, an improved estimate of the complete occupancy table was made by using the observed 1981 sample distribution in addition to the 1971 marginal totals. If we denote the 1981 sample distribution by {UBRAS}, the estimate of the initial occupancy table for each zone was as follows:

$$\text{est}[UBRAS] = [AR][AS][AB][RS][BSU]\{UBRAS\} \quad (13)$$

This model combines, in an optimal way (in terms of the minimum information principle), the marginal information of the 1971 census with *a priori* information of the multivariate distribution of the joint variables in 1981. This method was used throughout the simulations in order to estimate annual multivariate distributions where only partial information was available.

Empirical Results

In this section, a number of illustrative results of the model simulations for the period 1971-1984 for the agglomeration of Amsterdam will be presented. First, a short description of the agglomeration is given, followed by an overview of the simulation structure. A number of steps in the simulation model will be illustrated empirically. However, it is not possible to give a full account of the complete model results within the framework of this article. For more information, the reader is referred to [42].

The study area

The agglomeration of Amsterdam occupies about 83,000 hectares (350 square miles). This region was subdivided into 20 zones (see figure 2): 11 zones within the municipality of Amsterdam and 9 zones in the suburban communities. The total population of the region in 1971 was 1,23 million, of which 66% lived in the city of Amsterdam. In 1985, the agglomeration inhabited 1,29 million people and the share of the city of Amsterdam was reduced to 53%. In absolute terms, the Amsterdam population dropped from 820 thousand to 676 thousand. The number of households in the agglomeration was 450 thousand of which 72%, or 324 thousand, were in Amsterdam. In 1982, the number of households in the agglomeration had grown to 522 thousand, with a share of 64% (337 thousand) for Amsterdam. So, in absolute terms, the number of households in the city increased slightly despite a significant decrease in population size. Household composition also changed dramatically. In Amsterdam the share of one person households increased from 31% in 1971, to 39% in 1982, and to 46% in 1984, while that of three-

plus person households declined from 39% in 1971, to 28% in 1982, and to 24% in 1984. In the suburbs, changes were less dramatic: one person households increased their share from 13 to 17% between 1971 and 1982 while that of three-plus person household decreased from 63 to 55%.

[Figure 2 approximately here]

Step 1: *Simulation*

Simulations were run for the period 1971-1984, in a sequence of 14 yearly runs. In each run, the following steps were performed (see also Figure 1 for an overview):

1. Initialization: read in all starting data for all zones:
 1. The occupancy matrix $C(y)$,
 2. The total number of (exogenous) external migrants from and to the agglomeration by age,
 3. The total number of newly constructed dwelling units by type
 4. The total number of vacancies,
 5. Model parameters pertaining to year y .
2. Household transitions: calculate the number of household transitions in the table $R(y)$; apply this model to each zone and dwelling type and store it in the extended occupancy matrix $O(y)$.
3. Potential movers pool: calculate the potential movers pool $D(y)$ from $O(y)$ using equation (7).
4. Housing demand: calculate total housing demand $M(y)$ by zone and dwelling category using equations (10)-(12) and using the available supply $N(y)$ per zone and dwelling type; $N(y)$ is calculated from the (exogenous) total new construction plus (endogenous) vacancies minus (exogenous) demolitions.
5. Allocation: confront demand $M(y)$ with supply $N(y)$ in a number of rounds; in each round demand is allocated proportionally to the available supply, taking into account a number of *allocation rules* reflecting the institutional constraints within the housing market; these allocations result in new vacancies and, according to equation (10), a new demand structure over the zones and dwelling types. Demand will be attracted to submarkets with a large excess supply and will move away from submarkets with excess demand. The allocation process stops if the total number of simulated moves equals the number of observed moves in the agglomeration.
6. Updating: update the occupancy table $C(y)$ to $C(y+1)$ and the population distribution table $k(y)$ to $k(+1)$ using the accounting framework; calculate the number of vacancies at the end of year y .

A number of selective results are presented below.

Step 2: *the household transition table $R(y)$ and the extended occupancy table $O(y)$*

Table 5 shows the individual transition matrix T between positions in the household and the aggregated household transition table R for the city of Amsterdam as estimated by the household model for the year 1984. These

transitions pertain to the population alive and resident in the city of Amsterdam at the beginning of 1984. If the city were a closed system, this table could be used for population and household forecasts. However, the population and household composition will also change as a result of in- and out-migration.

A closer look at the marginal totals of the transitions in Table 5 reveals the net change in the population, while Table 6 depicts the corresponding changes in household composition. Table 6 shows a net increase in the total number of households of 1.3 percent. The change in the number of households in the city is inversely related to household size: the only increasing category is the singles group (2 percent) while all other category decrease in number, with the 4+ household size category showing the largest decrease (-1.6 percent). Another interesting feature is the stability of the household categories. A simple measure of stability is the percentage of all households that do not change (i.e., the main diagonal entries as a percentage of the column totals). It is noteworthy that singles are the most stable group: 93.9 percent remained single in 1984. Three person households tended to change the most; only 88.5 percent didn't change during the year.

[Tables 5 & 6 approximately here]

Combining the household transition table R with the housing market situation of the household, reflected in the occupancy table C, is now straightforward (equation (8)) and results in the extended occupancy table O. This is a large table, since it contains a separate table R for each housing submarket in the system. For example, table 7 is the estimated subtable corresponding to all households living in small (one or two room) apartments in the rental sector in the city of Amsterdam in 1984.

Step 3: The potential movers pool

Table O can be used to predict residential mobility at a highly disaggregate level. The household transitions have a direct impact on the propensity to move. This is shown in the estimated coefficient related to the variable household growth in Table 4. The negative value of this coefficient implies that household growth has a positive impact on the propensity to move. This is depicted as an illustration in Table 8 for the households in one or two room-rental apartments (dwelling type 1) in Amsterdam. Here, the estimated probabilities of households which are willing to move are given as a function of household transitions. These probabilities have been calculated by combining the estimated coefficients specified in equation (8) and presented in Table 4 with the values of the exogenous variables of households living in this specific dwelling type. Multiplication of the extended occupancy matrix O with the probabilities to move gives the movers table D. The figures presented here pertain to the smallest and lowest quality dwellings in the city so that here the estimated probabilities are quite high. A decrease in household size appears to have a diminishing effect on the willingness to move.

The effect of dwelling size versus household size is clear if we compare the entries on the main diagonal. The propensity to change residence increases if household size increases relative to dwelling size.

[Tables 7 & 8 approximately here]

Step 4: Housing demand

Applying equations (10)-(12) to the potential movers pool results in a demand vector for each housing submarket. Figure 3 presents the development in the supply/demand ratio for a number of selected dwelling types in zone 11 within the municipality of Amsterdam, the *Bijlmermeer*. The *Bijlmermeer* is a newly constructed residential area built in the 1970s and 1980s. A ratio larger than 1 indicates a submarket with excess supply. Given the chronic housing shortage problem in the city during this period, excess supply is very rare. Despite this, the model estimated a large share of vacant dwellings in this zone for large rental apartments for most years of the simulation period.

[Table 9 approximately here]

Indeed, in reality, this zone has been characterized by a large vacancy problem, especially in these dwelling types, while there were fewer problems in finding occupants for the single family units.

[Figure 3 approximately here]

Step 5: Allocation

In Figure 4, total intrazonal migration within Amsterdam is depicted for the period 1971-1984. The model outcomes reflect strongly the observed trend: a sharp decrease in mobility at the end of the 1970s, followed by a strong increase in the 1980s. On the basis of the results shown in Figure 4 (and many additional results at a disaggregate level), it may be concluded that the housing market model (which is only presented in a concise way in this paper) is capable of replicating past developments within the housing market of Amsterdam.

[Figure 4 approximately here]

Next, Figure 5 shows the model outcomes for the development of households by size and age class of the head in the period 1971-1984 for the city of Amsterdam.

[Figure 5 approximately here]

Assessing the fit of the simulation for the period 1971-1982

[Table 10 approximately here]

Observed household information at such a disaggregate level as depicted in Figure 5 was available exclusively for the year 1982. So, only for this year, could the goodness-of-fit of the model be tested. Table 10 shows the results of this comparison between predicted and observed figures. The model outcomes result from

simulations of the period 1971-1982. It appears that results for Amsterdam as a whole were quite satisfactory. Both the simulated total number of individuals and the number of households match closely the observed figures. In terms of household size, the simulated distribution is also quite close to the observed one, taking into account that the size distribution of the starting year 1971 was very different from the 1982 distribution.

The age distribution is less satisfactory, especially for the two youngest "age of head" groups. The percentage households with a head under 25 years of age is overpredicted by 4 percent, whereas that of the age category 25-34 is underpredicted by 6 percent. Taken together, the category heads under 35 years of age is only underpredicted by 2 percent. The other age groups match very closely. One of the reasons for these discrepancies is that the population census data are in five year age groups, while the simulation interval is a single year. Assumptions thus had to be made with respect to the distribution of the ages within each age interval. For the highly mobile and dynamic age group under 35 years of age, this may have had a strong effect on the yearly outcomes.

Epilogue

In this paper, some theoretical aspects and empirical results of a dynamic household model developed within the context of the housing market were presented. Design of an operational accounting model for a variety of households, dwellings and urban zones is a substantial task, from the standpoint of both consistent model building and computer programming, data gathering and data handling. On the basis of empirical outcomes, model testing and comparison of observed and predicted outcomes however, the final result appear to be rather satisfactory. The model was able to reproduce fairly precisely past housing market developments. As such, the model, we feel, can be used for policy questions at different zonal levels and for forecasting future housing market developments.

The implications of such a model are essentially twofold. First, local governments (which have a very strong influence on the supply side of the Dutch housing market) may receive detailed information on (1) long-term demographic developments and (2) the implications of life cycle phenomena for housing markets at the urban district level. Second, the consequences of various policy measures (e.g., supply of specific new dwelling types) on demand by various categories of households can be evaluated. This implies that the model is suitable for a wide spectrum of scenario experiments through which the effects of exogenous and policy developments can be identified.

It can be concluded that the life cycle concept is useful for predicting household mobility. The household life cycle, modelled here by means of multidimensional demography, proved important for studying the household development process. The multidimensional life table is well-suited at the micro scale of household dynamics. The level of analysis in the household model is the individual. The transition probabilities can thus be derived at the individual level, while consequences for the household level can be constructed via the household composition matrix.

A second conclusion to be drawn concerns the allocation of housing demand over available dwellings. Our model indicates that housing market conditions have a strong impact on housing preferences. Demand adjusts dynamically to the changing structure of dwelling availability. This has a strong equilibrating effect, since highly

preferred submarkets become less favoured, due to low supply relative to demand, while less preferred submarkets become more attractive, since they are in excess supply.

The multidimensional life table focuses on the age- and time-dependency of household transitions. Further progress could be made by endogenizing the transition rates. This would make the model fully dynamic since the transition intensities would then change over time endogenously. As a consequence, the rate $\mu(x)$ (x being age, see model (1)) might be replaced by a more general formulation, $\mu(z)$, where z is a vector of relevant explanatory variables evolving over time (e.g., relative population abundance in each cohort). If such a function could be specified and estimated, those problems in the household model involving the time-variance of demographic intensities, could, in principle, be eliminated.

Another interesting development would be to extend the state space of the demographic model to include aspects of the housing market. A simultaneous treatment of housing market and life cycle decisions would be feasible in such a model. However, the micro-economic theory underlying random utility models such as the logit model would have to be translated into a multidimensional form.

The data requirements of a dynamic household model are large in that the applicability of multidimensional demography in modelling household dynamics is based on the availability of accurate data. In the absence of census information on household dynamics, we employed data estimation techniques. A longitudinal survey might, in principle, provide transition rates that otherwise could not be observed in a cross-sectional survey. If such data sources were available, use of a multidimensional model is appropriate for household modelling on a micro scale. In this respect, the availability of a longitudinal data set in which the transition rates can be distinguished by both time period and zone would likely stimulate further research efforts and empirical testing of sophisticated demographic modelling.

Notes

1. Note that the projection interval in the model is one year, whereas the age intervals are five years. For presentation purposes the necessary but trivial transformations that are present in the model have been left out here.

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Position in the household	Household categories
1. Child	
2. Single	1. Single
3. Head of a 2-person household	2. 2-person household
4. Head of a 3-person household	3. 3-person household
5. Head of a 4 + person household	4. 4 + person household
6. Partner of head	5. Non-household
7. Other (non-household)	

Table 1 Positions in the household and household categories in the household model (for each 5-year age interval)

$t = 1$						
$t = 2$		single	2-person hh.	3-person hh.	4+ person hh.	hh. formation
single 2-person household 3-person household 4+ person household	single	$n[S,S]$	$n[S,H2] + n[d,H2]$	$n[S,H3]$	$n[S,H4]$	$n[S,C] + n[S,P] + n[S,N] - n[d,H2]$
	2-person household	$n[H2,S]$	$n[H2,H2]$	$n[H2,H3] + n[H3,d]$	$n[H2,H4]$	$n[H2,C] + n[H2,P] + n[H2,N] - n[d,H3]$
	3-person household	$n[H3,S]$	$n[H3,H2]$	$n[H3,H3]$	$n[H3,H4] + n[d,H4]$	$n[H3,C] + n[H3,P] + n[H3,N] - n[d,H4]$
	4+ person household	$n[H4,S]$	$n[H4,H2]$	$n[H4,H3]$	$n[H4,H4] + n[d,H5]$	$n[H4,C] + n[H4,P] + n[H4,N] - n[d,H5]$
household dissolutions		$n[d,S] + n[P,S] + n[N,S]$	$n[P,H2] + n[N,H2]$	$n[P,H3] + n[N,H3]$	$n[P,H4] + n[N,H4]$	0

Table 2 The aggregation rules of the expected number of individual transitions to the expected number of household transitions in the matrix R. $n[a,b]$ is the expected number of individual transitions from household category b to household category a.
Legend: C Child; S single; P partner; N non-household position; H2 head 2-person household; H3 head 3-person household; H4 head 4-person household; H4+ head 4+ person household; H5 head 5-person household; d death

dwelling type	number of rooms			
	1-2	3	4	5+
rented apartment	1	5	6	9
owner occupier apartment	2	2	2	2
rented single family	3	3	7	10
owner occupier single family	4	4	8	11

Table 3 **The definition of the 11 dwelling types**

Variable	Mnemonic/ formula	Amsterdam	Suburbs
Roomstress	$(s_o - r_k)/r_k$	0.660 (0.153)	0.475 (0.204)
Housing type (1 = apartment; 0 = single fam. unit)	U_k	0.658 (0.232)	1.741 (0.187)
Tenure status (1 = buy; 0 = other)	B_k	-0.546 (0.257)	-0.524 (0.202)
Household growth	$\log(s_o/s_o')$	-1.495 (1.002)	0.011 (1.321)
Age	X_o	-0.027 (0.004)	-0.025 (0.006)
Rho ²		0.41	0.66
N		1679	1300

Table 4 **Estimated coefficients of the willingness to move model for the city of Amsterdam and the suburbs (estimated using the WBO-1981 survey) (standard-errors in parentheses)**

	january 1 1984						
january 1 1985	child	single	head 2p	head 3p	head 4 + p	partner	non-hh
child	129927	0	0	0	0	0	6241 *
single	5826	137786	1590	221	74	4039	28
head 2p	1984	2277	86979	2581	112	215	27
head 3p	121	1139	2413	42234	1473	140	26
head 4 + p	20	38	158	1741	34620	84	26
partner	2316	2025	199	101	77	165052	27
non-hh	3	759	1119	102	126	226	23381
dead	112	2668	1797	372	397	682	1174
total 1-1- 1985	136168	149564	94175	47546	36687	169797	25716
total 1-1- 1984	140139	146692	94255	47352	36879	170438	24689
% change	97.1	102.0	99.9	100.4	99.5	99.6	104.2

* births

Table 5 Expected number of individual transitions in position in the household in 1984 of the population resident in Amsterdam on 1-1-1984 summed over all age categories and all residential zones

january 1 1984

january 1 1985	single	head 2 persons	head 3 persons	head 4+ persons	new households
single	137786	3387	221	74	8096
head 2 persons	2277	86979	2953	112	1854
head 3 persons	1139	2423	42243	1760	29
head 4+ persons	38	158	1741	34810	0
dissolutions	5452	1318	575	600	
total 1-1-1985	149564	94175	47594	36747	328989
total 1-1-1984	146692	92947	47733	37356	324728
% change	102.0	101.3	99.7	98.4	101.3

Table 6 Expected number of household transitions based upon the individual transitions given in Table 5

size primo 1984	size ultimo 1984					total
	single	2 persons	3 persons	4 + persons	dissolution	
single	14813	319	154	2	53	15841
2 persons	55	1533	50	1	31	1670
3 persons	0	0	195	8	7	215
4 + persons	0	0	0	10	2	12
total	14868	1852	399	21	93	17738

Table 7. Estimated household transitions for households in one or two room-rental apartments (dwelling type 1) in Amsterdam (part of the matrix O)

size primo 1984	size ultimo 1984			
	single	2 persons	3 persons	4 + persons
single	0.41	0.93	0.99	1.00
2 persons	0.05	0.49	0.86	0.96
3 persons	0.01	0.18	0.58	0.58
4 + persons	0.00	0.07	0.32	0.32

Table 8. Estimated propensity to move for households in one or two room-rental apartments (dwelling type 1) by transition category.

Variable	Predicted	Observed
1. Totals (thousands)		
population	697	701
households	325	330
2. Size (percentages)		
single	43	42-44
two persons	29	31-33
three persons	15	12-13
four + persons	12	12-15
3. Age of head (percentages)		
0-24 years	13	9
25-34 years	19	25
35-44 years	15	15
45-54 years	14	13
55-64 years	14	15
65 + years	24	24

Table 9. Observed and predicted outcomes for total population, total households and households by size and age of head in Amsterdam (1982)

*: Two complementary (but not always mutually consistent) data sources were used to derive observed figures on household size. Here the range of the figures is given.

Figure 1 Accounting framework for the housing market model

Figure 2 The study area divided into 20 zones

Figure 3 Supply/Demand ratios for selected dwelling types in the urban district Bijlmermeer 1971-1984

Figure 4 **Observed and simulated intra-urban moves within Amsterdam 1971-1984**
(persons)

Figure 5 Simulated developments in household size and age categories in Amsterdam 1972-1984

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