Chapter 2
Employment and Labour in Urban Markets in the IRPUD Model

Michael Wegener

Abstract The IRPUD model is a simulation model of intraregional location and mobility decisions in a metropolitan area. Employment and labour in the model are affected by developments in other submodels: The supply of jobs results from growth and decline, location and relocation of firms and their demand for labour by skill. The demand for jobs results from population and immigration and outmigration by age, education and skill. Intraregional labour mobility results from decisions of firms to hire or release workers and decisions of workers to start or end a job. These decisions affect commuting patterns and residential and firm location and the associated construction and real estate markets. This chapter presents the parts of the model affecting regional employment and labour and the remaining submodels as far as necessary for understanding these. The paper closes by summarising calibration results and an example application of the model.

2.1 The IRPUD Model

The IRPUD model is a simulation model of intraregional location and mobility decisions in a metropolitan area (Wegener 1982, 1983, 1985, 1986, 1994, 1996, 1998, 2011). It receives its spatial dimension by the subdivision of the study area into *zones* connected by transport networks containing the most important links of the public transport and road networks coded as an integrated, multimodal network including all past and future network changes. It receives its temporal dimension by the subdivision of time into *periods* of one or more years' duration.

M. Wegener (✉)
Spiekermann & Wegener Urban and Regional Research (S&W), Dortmund, Germany
e-mail: mw@spiekermann-wegener.de

F. Pagliara et al. (eds.), *Employment Location in Cities and Regions*,
Advances in Spatial Science, DOI 10.1007/978-3-642-31779-8_2,

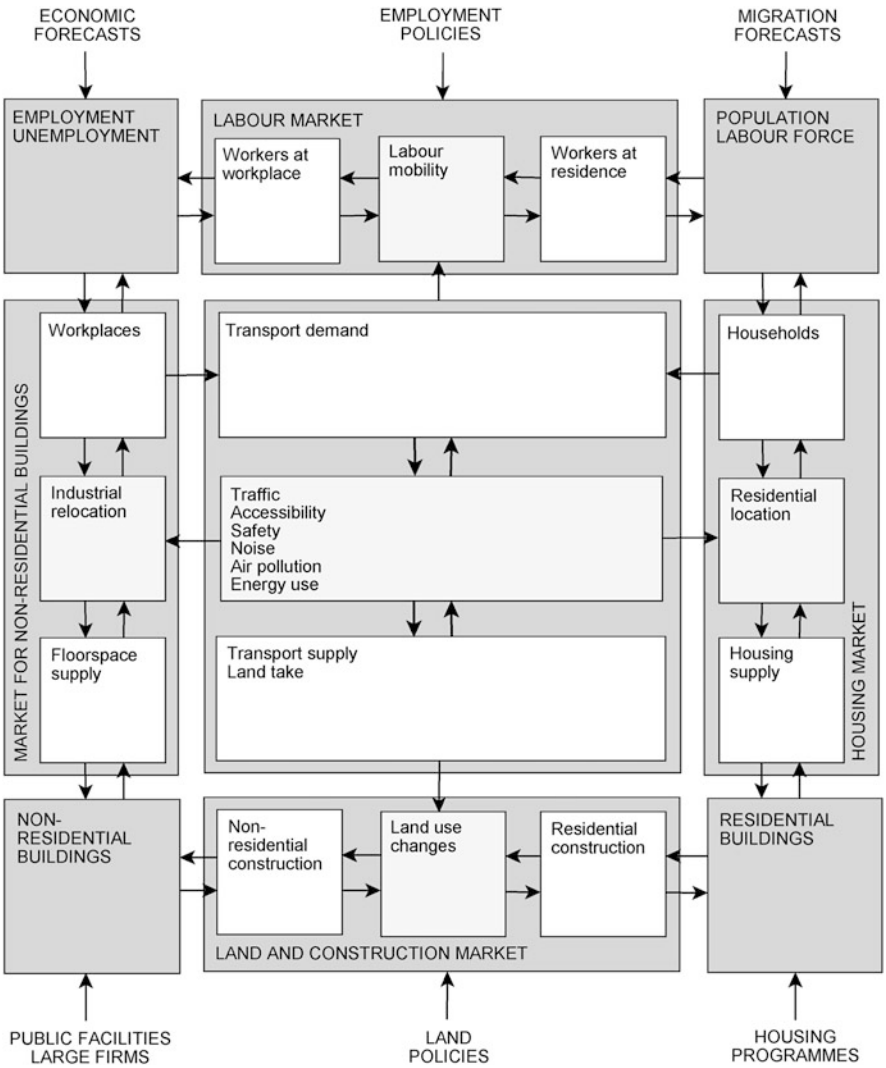

Fig. 2.1 The IRPUD model

2.1.1 Model Structure

The model predicts for each simulation period intraregional *location decisions* of industry, residential developers and households, the resulting *migration* and *travel* patterns, *construction* activity and *land-use* development and the impacts of *public policies* in the fields of industrial development, housing, public facilities and transport.

Figure 2.1 is a schematic diagram of the major subsystems considered in the model and their interactions and of the most important policy instruments.

The four square boxes in the corners of the diagram show the major stock variables of the model: *population*, *employment*, *residential buildings* (housing) and *non-residential buildings* (industrial and commercial workplaces and public facilities). The actors representing these stocks are *individuals or households*, *workers*, *housing investors* and *firms*.

These actors interact on five *submarkets* of urban development. The five submarkets treated in the model and the market transactions occurring on them are:

- *Labour market*: new jobs and redundancies,
- The *market for non-residential buildings*: new firms and firm relocations,
- The *housing market*: immigration, outmigration, new households and moves,
- The *land and construction market*: changes of land use through new construction, modernisation or demolition,
- The *transport market*: trips.

For each submarket, the diagram shows *supply* and *demand* and the resulting *market transactions*. Choice in the submarkets is constrained by supply (jobs, vacant housing, vacant land, vacant industrial or commercial floorspace) and guided by attractiveness, which in general terms is an actor-specific aggregate of *neighbourhood quality*, *accessibility* and *price*.

The large arrows in the diagram indicate exogenous inputs: these are either *forecasts* of regional employment and population subject to long-term economic and demographic trends or *policies* in the fields of industrial development, housing, public facilities and transport.

2.1.2 Submodels

The IRPUD model has a modular structure and consists of six interlinked submodels operating in a recursive fashion on a common spatio-temporal database:

1. The *Transport Submodel* calculates work, shopping, services/social and education trips for four socioeconomic groups and three modes, walking/cycling, public transport and car. It determines a user-optimum set of flows where car ownership, trip rates and destination, mode and route choice are in equilibrium subject to congestion in the road network.
2. The *Ageing Submodel* computes all changes of the stock variables of the model which are assumed to result from biological, technological or long-term socio-economic trends originating outside the model (i.e. which are not treated as decision-based). These changes are effected in the model by probabilistic ageing or updating models of the Markov type with dynamic transition rates. There are three such models, for employment, population and households/housing.

3. The *Public Programmes Submodel* processes a large variety of public programmes specified by the model user in the fields of employment, housing, health, welfare, education, recreation and transport.
4. The *Private Construction Submodel* considers investment and location decisions of private developers, i.e. of enterprises erecting new industrial or commercial buildings, and of residential developers who build flats or houses for sale or rent or for their own use. Thus the submodel is a model of the regional land and construction market.
5. The *Labour Market Submodel* models intraregional labour mobility as decisions of workers to change their job location in the regional labour market.
6. The *Housing Market Submodel* simulates intraregional migration decisions of households as search processes in the regional housing market. Housing search is modelled in a stochastic microsimulation framework. The results of the Housing Market Submodel are intraregional migration flows by household category between housing by category in the zones.

Figure 2.2 visualises the recursive processing of the six submodels. The Transport Submodel is an equilibrium model referring to a *point in time*. All other submodels are incremental and refer to a *period of time*. Submodels (2) to (6) are executed once in each simulation period, while the Transport Submodel (1) is processed at the beginning and the end of each simulation period. Each submodel passes information to the next submodel in the same period and to its own next iteration in the following period.

2.1.3 Employment and Labour in the Submodels

In the IRPUD model employment and labour are not modelled in one integrated model but in several interacting submodels. Change of zonal employment occurs in three different submodels:

1. Decline of zonal employment due to sectoral decline, lack of building space and intraregional relocation of firms is modelled in the *Ageing Submodel*.
2. Changes of zonal employment due to the location or removal of large plants exogenously specified by the user are executed in the *Public Programmes Submodel*.
3. Changes of zonal employment due to new jobs in vacant industrial or commercial buildings, in newly built industrial or commercial buildings or in converted residential buildings are modelled in the *Private Construction Submodel*.

Changes of zonal labour force are modelled in five different submodels:

1. Ageing of households and housing and other demographic changes of household status are modelled in the *Ageing Submodel*.
2. Public housing programmes specified by the model user are executed in the *Public Programmes Submodel*.

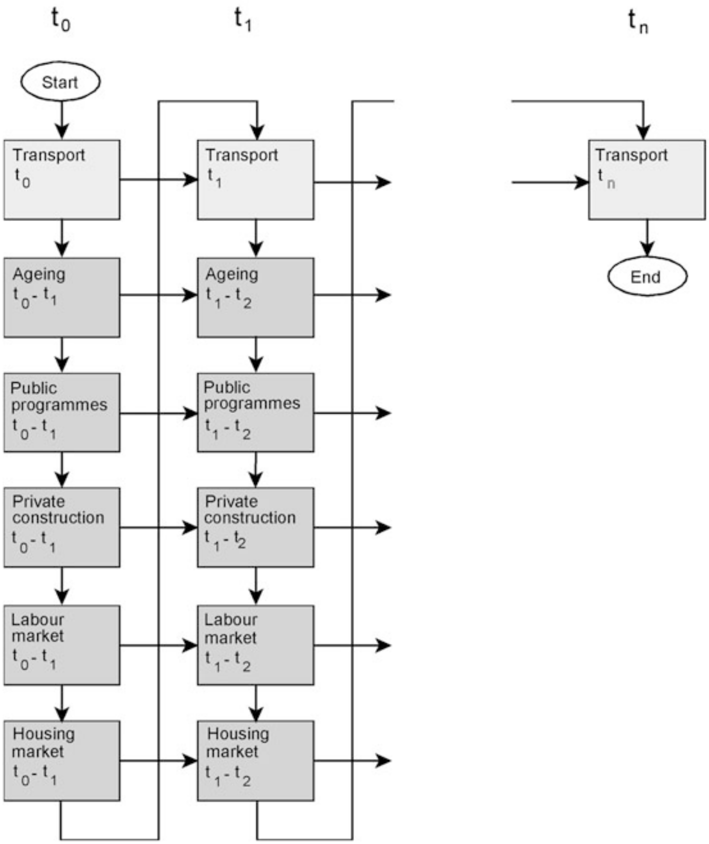

Fig. 2.2 Recursive processing of submodels

3. Private housing maintenance/upgrading and new construction investments and the resulting changes in housing and land prices are modelled in the *Private Construction Submodel*.
4. Labour mobility and the resulting changes of household income are modelled in the *Labour Market Submodel*.
5. Changes of the association of households with housing are modelled in the *Housing Market Submodel*.

2.2 Ageing Submodel

In the *Ageing Submodel* all changes of zonal stock variables are modelled which are assumed to result from biological, technological or long-term socio-economic trends or originating outside of the model, i.e. which are not treated as *decision-based*. These changes are effected by probabilistic ageing or updating, or semi-Markov, models with dynamic transition rates. There are three such models for employment, population and households and housing. Here only changes of employment are discussed.

In the Ageing Submodel decline of zonal employment due to sectoral decline, lack of building space and intraregional relocation of firms is modelled. Each of the 40 industries of the model is considered a separate submarket. The model starts from existing employment $E_{slj}(t)$ of industry s situated on land use category l in zone j at time t. There are three different ways for E_{slj} to change in this submodel:

2.2.1 Sectoral Decline

Declining industries make workers redundant. This occurs not necessarily at the same rate all over the region, but is more likely where locational conditions are less favourable:

$$R_{slj}(t, t+1) = \frac{E_{slj}(t) \exp[-\alpha_s \, u_{slj}(t)]}{\sum_{jl} E_{slj}(t) \exp[-\alpha_s \, u_{slj}(t)]} \; [E_s(t+1) - E_s(t)] \tag{2.1}$$

is the number of workers in industry s made redundant on land-use category l in zone j between t and $t + 1$. $E_s(t)$ indicates total employment of industry s in the region and $E_s(t + 1)$ is the exogenous projection of total regional employment for time $t + 1$. The utility $u_{slj}(t)$ expresses the attractiveness of land-use category l in zone j for industry s (see Eq. 2.7 below). R_{slj} is set to zero for growing industries.

2.2.2 Relocation

Some industries are very stationary, while others easily move from one location to another. If $r_s(t,t + 1)$ is a sectoral mobility rate, then

$$M_{slj}(t, t+1) = \frac{E_{slj}(t) \exp[-\alpha_s \, u_{slj}(t)]}{\sum_{jl} E_{slj}(t) \exp[-\alpha_s \, u_{slj}(t)]} \; r_s(t, t+1) \, E_s(t) \tag{2.2}$$

is the number of workplaces relocated from land-use category l in zone j during the period. The mobility rate $r_s(t,t + 1)$ is exogenous.

2.2.3 Lack of Building Space

In most industries, mechanisation and automation tend to increase the building floorspace per workplace. Accordingly, in each period, a number of jobs S_{slj} have to be relocated because of lack of space:

$$S_{slj}(t, t+1) = E_{slj}(t)\left[1 - \frac{b_{sj}(t)}{b_{sj}(t+1)}\right] - R_{slj}(t, t+1) \tag{2.3}$$

where $b_{sj}(t+1)$ is the projected floor space per workplace in industry s in zone j at time $t+1$, which will be always greater than or equal to its value at time t. Where redundancies exceed relocations due to lack of space, S_{slj} is set to zero. For the workers made redundant, later new buildings will be provided in the *Public Programmes* or *Private Construction Submodels*. Where decline of employment is large, buildings remain vacant, but may be reused by other industries later.

2.3 Public Programmes

In the *Public Programmes Submodel* public programmes assumed to be implemented during the simulation are processed.

Public programmes in the IRPUD model are events entered exogenously by the model user. They represent primarily public policy measures such as infrastructure investments or public housing programmes, where local, state or national governments directly intervene into the process of spatial urban development. In addition they represent "singular historical events" that are caused by private market decisions but are too unique and too large to be predicted by a model, such as the location or closure of large industrial plants, large commercial developments, such shopping malls, or large private housing developments.

Regulatory or monetary policies such as land-use plans, building regulations, taxes, public transport fares or parking fees are not part of the Public Programmes Submodel but are entered exogenously by the model user. Transport infrastructure changes are entered as dynamic transport network scenarios.

In the Public Programmes Submodel three types of events are executed: changes of *employment*, changes of *housing* and changes of *infrastructure*. Here only changes of employment are discussed.

Exogenously specified changes of employment such as the location or closure of large industrial plants or large shopping malls are entered as a code specifying the kind of change (removal or location), the number and category (industry) of jobs to be removed or located and the year and zone in which this is to take place. In the case of removal, a distinction is made whether the associated buildings are to be torn down or are to remain vacant for later use by other industries. In the case of a new location also the industrial or commercial buildings required for the new facility are constructed. If there is not enough vacant industrial land in the zone, a limited percentage of housing of low quality, if available, may be torn down. If also this is not sufficient, the number of jobs to be located is reduced.

In addition, the impact of the removal or addition of employment on household incomes in the region is calculated using the method described in the *Labour Market Submodel* below.

2.4 Private Construction

The *Private Construction* submodel considers investment and location decisions by private developers, i.e. by enterprises which erect new industrial or commercial buildings and by residential developers who build flats or houses for sale or rent or for their own use. Thus the submodel is a model of the regional land and construction market. Here only industrial or commercial construction is discussed.

The industrial location submodel makes no distinction between basic and non-basic industries, i.e. all industries are located or relocated endogenously subject to sectoral employment projections for the whole region. The model locates industrial or commercial floor space suitable as workplaces in the 40 industries considered in the model. However, as the amount of floor space occupied per worker is not constant over time and certain types of floor space can be used by several industries, the model actually locates *workplaces* or employment, which are subsequently converted to floor space. The location of workplaces of all industries may also be controlled exogenously by the user in the *Public Programmes Submodel* in order to reflect major events such as the location or closure of large plants in particular zones. Changes of zonal employment due to new jobs in vacant industrial or commercial buildings, in newly built industrial or commercial buildings or converted residential buildings are modelled in this submodel.

New workplaces are either located in existing vacant industrial or commercial buildings, in newly constructed industrial or commercial buildings or in converted residential buildings.

Before starting the location process, industries are sorted by decreasing floorspace productivity, or rent paying ability, and processed in that order. The total demand for new workplaces of industry s in the region is

$$N_s(t, t+1) = E_s(t+1) - E_s(t) + \sum_{jl} \Delta E_{slj}(t, t+1) \tag{2.4}$$

where $\Delta E_{slj}(t,t+1)$ are net changes in employment of industry s on land use category l in zone j modelled in previous submodels resulting from sectoral decline, lack of building space and intraregional relocation of firms as well as from exogenously specified public programmes.

2.4.1 New Jobs in Vacant Buildings

Declining industries or relocating firms leave buildings vacant that may be used by other industries. For this purpose, the 40 industries have been divided into groups with similar space requirements.

If this demand is less than the total supply of suitable floor space, it is allocated to vacant floor space with the following allocation function:

$$V_{slj}(t,t+1) = \frac{K_{slj}\exp[\gamma_s\ u_{slj}(t)]}{\sum_{jl} K_{slj}\exp[\gamma_s\ u_{slj}(t)]}\ N_s(t,t+1) \tag{2.5}$$

where K_{slj} is the capacity of existing buildings on land-use category l in zone j for workplaces in industry s. V_{slj} is the number of jobs accommodated.

2.4.2 New Jobs in New Buildings

For any remaining demand, new industrial or commercial buildings have to be provided. This demand is allocated to vacant industrial or commercial land with the allocation function

$$C_{slj}(t,t+1) = \frac{L_{slj}\exp[\gamma_s\ u_{slj}(t)]}{\sum_{jl} L_{slj}\exp[\gamma_s\ u_{slj}(t)]}\ \left[N_s(t,t+1) - \sum_{jl} V_{slj}(t,t+1)\right] \tag{2.6}$$

where C_{slj} are new workplaces in industry s built on land-use category l in zone j between t and $t+1$. L_{slj} is the current capacity of land of land-use category l for such workplaces in zone j; since it is continuously reduced during the simulation period, it bears no time label.

The utility $u_{slj}(t)$ used in Eqs. 2.5 and 2.6 is the attractiveness of land-use category l in zone j for industry s and has three components:

$$u_{slj}(t) = [u_{sj}(t)]^{v_s}\ [u_{sl}(t)]^{w_s}\ [u_s(c_{lj})(t)]^{1-v_s-w_s} \tag{2.7}$$

where $u_{sj}(t)$ is the attractiveness of zone j as a location for industry s, $u_{sl}(t)$ is the attractiveness of land-use category l for industry s, and $u_s(c_{lj})(t)$ is the attractiveness of the land price of land-use category l in zone j in relation to the expected profit of economic activity s. The v_s, w_s, and $1 - v_s - w_s$ are multiplicative importance weights adding up to unity. The three component utilities are constructed similarly to the components of the housing utility $u_{hki}(t)$ (see *Housing Market Submodel*). Like all utilities in the model, the $u_{slj}(t)$ remain unchanged during the simulation period as calculated at time t. The price or rent of industrial or commercial buildings is presently not represented in the model.

The land capacity L_{slj} is normally taken as being fixed as specified in the zoning plan. If a piece of land was formerly in a built-up area, its development implies the demolition of existing buildings. In addition, under certain restrictions in zones of high demand, the capacity L_{slj} may be extended by demolition of existing buildings with less profitable building uses to represent displacement processes going on within existing neighbourhoods. As L_{slj} is updated after the location of each industry, it bears no time label. All workplaces or dwellings displaced by demolition during a simulation period are replaced in the same period by iterating the industrial and residential submodels several times.

Retailing is treated like any other industry in the model except that the zonal attractiveness $u_{sj}(t)$ (see Eq. 2.7) for retailing includes a fourth attribute

$$u_{sjn}(t) = v_n \left[\frac{\sum_{qim} t_{q2ijm}(t) \;\; y_{qi}(t) \;/\; E_{rj}(t)}{\sum_{qijm} t_{q2ijm}(t) \;\; y_{qi}(t) \;/\; E_r(t)} \right] \tag{2.8}$$

where $t_{q2ijm}(t)$ are shopping trips (trip purpose $g = 2$) of households of income group q from residential zone i to shopping zone j using mode m, $y_{qi}(t)$ are retail expenses of households of income group q in zone i at time t, $E_{rj}(t)$ is retail employment in zone j at time t, $E_r(t)$ total regional retail employment, and $v_n(.)$ the value function mapping attribute n to utility. This attribute indicates retail sales per retail employee in zone j expressed in units of average turnover per retail employee in the whole region.

2.4.3 Conversion of Existing Dwellings

In the case of service workplaces, the capacity of a zone may also be extended by conversion of existing dwellings to offices where the demand for office space is high in relation to supply in order to represent the displacement of dwellings by offices observed within or near the CBD. All dwellings converted to offices during a simulation period are replaced in the same period by iterating the industrial and residential location submodels several times.

2.5 Labour Market

The urban economy is represented in the model by employment (workers at place of work) and industrial and commercial buildings classified by 40 industries. Labour force is represented by workers and unemployed persons at place of residence classified by four skill levels and by sex and nationality (native or foreign). The four skill levels correspond to the four income levels of the classification of households (see *Housing Market Submodel*). There is no distinction between employed and self-employed persons. The distribution of skill levels of workers by industry is assumed to change over time according to exogenous assumptions.

The labour market is assumed to be demand-driven; firms employ and release workers according to their needs, and this influences the distribution of employment, labour, unemployment and household incomes in the region.

2.5.1 Labour Mobility

For a variety of reasons workers change their workplace each year. If both workplace and residence are in the region, this does not normally imply a change of residence so that neither the distribution of workplaces nor the distribution of residences is changed. However, the pattern of work trips in the region is changed.

As nothing is known about work-related reasons of intraregional labour mobility, only reasons related to the work trip are modelled. It is assumed that, everything else being equal, a job nearer to home is more preferable than one farther away, so that the propensity to change job is inversely related to the trip utility of the work trip:

$$M_{qj}(t,t+1) = \sum_i \frac{t_{q1ij}(t) \;\; \exp\left[-\alpha \;\; u_{qij}(t)\right]}{\sum\limits_{ij} t_{q1ij}(t) \;\; \exp\left[-\alpha \, u_{qij}(t)\right]} \;\; a_q(t,t+1)\, E_q(t) \tag{2.9}$$

where $M_{qj}(t,t+1)$ are workers of skill level q working in zone j considering a change of job between time t and time $t+1$, $t_{q1ij}(t)$ are work trips (trip purpose g = 1) of workers of skill level (income group) q between residences in zones i and workplaces in zones j at time t and $u_{qij}(t)$ is the trip utility of work trips between zones i and j for workers of skill level q aggregated over modes m:

$$u_{qij}(t) = \frac{1}{\lambda} \sum_{m \in \mathbf{M}_h} \exp\left[\lambda \;\; u_{qijm}(t)\right] \tag{2.10}$$

The mobility rate $a_q(t,t+1)$ indicating how many workers of total workers $E_q(t)$ of skill level q are likely to change their jobs between t and $t+1$ is exogenous. It is assumed that when selecting a new job, again everything else being equal, also the distance between the old and the new job plays a role (see Fig. 2.3).

Therefore a *change-of-job utility* similar to the migration utility used in the *Housing Market Submodel* (see Eq. 2.24) was defined:

$$\underline{u}_{qjj'}(t) = {u'}_{qij'}(t)^{w_q} \; u_{qjj}(t)^{1-w_q} \tag{2.11}$$

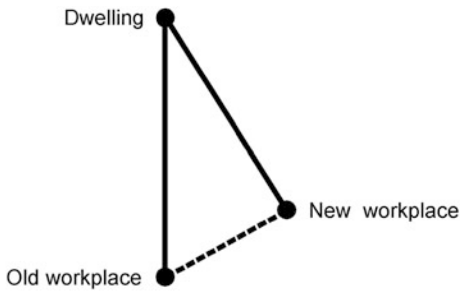

Fig. 2.3 Change of job

with

$$u'_{qij'}(t) = \frac{1}{\beta}\ \ ln \sum_i \frac{t_{q1ij}(t)\ \ \exp\left[\alpha\ \ u_{qij}(t)\right]}{\sum_i t_{q1ij}(t)\ \ \exp\left[\alpha\ \ u_{qij}(t)\right]}\ \ \exp\left[\beta\ \ u_{qij'}(t)\right] \tag{2.12}$$

The first part of the change-of-job utility Eq. 2.11 is the expected utility of a work trip from the old housing zone i to the new work zone j' after the move weighted by the probability that the worker lives in zone i (Eq. 2.12), the second part evaluates the utility of a trip between the old and the new workplace. The w_q and $1 - w_q$ are multiplicative weights adding up to unity.

With the above components a doubly constrained spatial interaction model is used to model job changes between work zones j:

$$M_{qjj'}(t, t+1) = M_{qj}(t, t+1)\ \ A_{qj}\ M_{qj'}(t, t+1)\ \ B_{qj'}\ \exp\left[\ \gamma\ \ \underline{u}_{qjj'}(t)\right] \tag{2.13}$$

where A_{qj} and $B_{qj'}$ are balancing factors.

2.5.2 *Change of Income*

Household incomes are classified into four household income groups (low, medium, high, very high) corresponding to the four skill levels of workers. It is assumed that all households within one of the four income groups have the same income irrespective of their location in the region. Household incomes also determine housing budgets (used in the *Housing Market Submodel*) and travel budgets (used in the *Transport Submodel*) as well as disposable income for shopping (used in the retail location part of the *Private Construction Submodel*). Household incomes and housing, travel and shopping budgets of the four income groups are updated according to exogenously specified projections.

Changes of the income distribution of households are induced by changes of employment (see above). It is assumed that in the case of unemployment a household drops from one income group to the next lower one. Conversely, in the case of new employment the household is promoted by one income group. Changes of employment are calculated as redundancies or new jobs at places of work. It is assumed that workers are released or hired without regard of their place of residence. Therefore, using the work trip matrix (trip purpose $g = 1$) calculated for each period in the *Transport Submodel*, changes of employment at places of residence can be inferred:

$$R'_{qi}(t, t+1) = \sum_j \frac{t_{q1ij}(t)}{\sum_{ij} t_{q1ij}(t)} \sum_s R_{sqj}(t, t+1) \tag{2.14}$$

$$N'_{qi}(t, t+1) = \sum_j \frac{t_{q1ij}(t)}{\sum_{ij} t_{q1ij}(t)} \sum_s N_{sqj}(t, t+1) \tag{2.15}$$

where $R'_{qi}(t,t+1)$ are workers made redundant and $N'_{qi}(t,t+1)$ newly employed workers of skill level q at places of residence i between time t and time $t+1$, $R_{sqj}(t,t+1)$ are workers of skill level q made redundant in industry s in work zones j in that period due to sectoral decline, lack of building space, intraregional relocation or exogenous user specification, and $N_{sqj}(t,t+1)$ are new jobs of skill level q created in industry s in work zone j in vacant or new buildings.

As the four skill levels correspond to the four household income groups, it is assumed that workers of skill level q belong to a household of the set of household types belonging to income group q. With this assumption, for each zone a 4×4 matrix of transition rates between household income groups is calculated and used for updating all household distributions of the model.

2.6 Housing Market

As the supply of labour and the demand for jobs on the regional labour market are determined by the location and relocation of households, also the *Housing Market Submodel* of the IRPUD model is briefly presented here. In the Housing Market Submodel all changes of association of households with housing and the resulting changes in housing prices are modelled.

2.6.1 Household Moves

The Housing Market Submodel simulates intraregional migration decisions of households as search processes in the regional housing market. Thus it is at the same time an intraregional migration model. Housing search is modelled in a stochastic microsimulation framework. The results of the Housing Market Submodel are intraregional migration flows by household category between housing by category in the zones.

Households are represented in the model as a four-dimensional distribution classified by nationality (native, foreign), age of head (16–29, 30–59, 60+), income/skill (low, medium, high, very high) and size (1, 2, 3, 4, 5+ persons). Similarly, housing of each zone is represented as a four-dimensional distribution of dwellings classified by type of building (single-family, multi-family), tenure (owner-occupied, rented, public), quality (very low, low, medium, high) and size (1, 2, 3, 4, 5+ rooms). All changes of households and housing during the simulation are computed for these 120 household types and 120 housing types. However, where households and housing are cross-classified together, these households and housing types are aggregated to H household and K housing types, with H and K not exceeding 30.

Technically, the migration submodel is a Monte Carlo micro simulation of a sample of representative housing market *transactions*. However, it differs from other, 'list-oriented', micro simulations in that (a) sampling and aggregation are part of the simulation and (b) stocks (households and dwellings) are classified, i.e. aggregate, data. A market transaction is any successfully completed operation by which a migration occurs, i.e. a household moves into or out of a dwelling or both.

A market transaction has a *sampling phase*, a *search phase*, a *choice phase* and an *aggregation phase* (Wegener 1985; Wegener and Spiekermann 1996):

- In the *sampling phase* a household looking for a dwelling or a landlord looking for a tenant is sampled for being simulated.
- In the *search phase* the household looks for a suitable dwelling, or the landlord looks for a tenant.
- In the *choice phase* the household decides whether to accept the dwelling or not.
- In the *aggregation phase* all changes of households and dwellings resulting from the transaction, multiplied by the sampling factor, are performed.

The sampling phase and the search phase are controlled by multinomial logit choice functions. For instance, for a household looking for a dwelling,

$$p_{k|hi} = \frac{R_{hki}\ \exp[-\alpha_h\ u_{hki}(t)]}{\sum_k R_{hki}\ \exp[-\alpha_h\ u_{hki}(t)]} \tag{2.16}$$

is the probability that of all households of type h living in zone i, one occupying a dwelling of type k will be sampled for simulation,

$$p_{i'|hki} = \frac{\sum_{k'} D_{k'i'}\ \exp[\beta_h\ \underline{u}_{hii'}(t)]}{\sum_{i'k'} D_{k'i'}\ \exp[\beta_h\ \underline{u}_{hii'}(t)]} \tag{2.17}$$

is the probability that the household searches in zone i' for a new dwelling and

$$p_{k'|hkii'} = \frac{D_{k'i'}\ \exp[\gamma_h\ u_{hk'i'}(t)]}{\sum_{k'} D_{k'i'}\ \exp[\gamma_h\ u_{hk'i'}(t)]} \tag{2.18}$$

is the probability that it inspects a dwelling of type k' there before making a choice. In these equations R_{hki} is the number of households of type h living in a dwelling of type k in zone i, and $D_{k'i'}$ is the number of vacant dwellings of type k' in zone i'. The $u_{hki}(t)$ and the $\underline{u}_{hii'}(t)$ are two different kinds of utility measures expressing the attractiveness of a dwelling or a zone for a household considering a move. They are discussed in Eqs. 2.19 and 2.24. The two utilities carry the time label t, i.e. are unchanged since the beginning of the simulation period, while R_{hki} and $D_{k'i'}$ carry no time label as they are continuously updated during the microsimulation.

In the choice phase, the household decides whether to accept the inspected dwelling or not. It is assumed that it behaves as a satisficer, i.e. that it accepts the dwelling if this will improve its housing situation by a certain margin. Otherwise, it enters another search phase to find a dwelling, but after a number of unsuccessful attempts it abandons the idea of a move. The amount of improvement necessary to make a household move is assumed to depend on its prior search experience, i.e. go up with each successful and down with each unsuccessful search. In other words, households are assumed to adapt their aspiration levels to supply conditions on the market.

The results of the migration submodel are intraregional migration flows of households (including starter households and inmigrant and outmigrant households) by household type between dwellings by type in the zone.

The attractiveness of a dwelling of type k in zone i for a household of type h, $u_{hki}(t)$, is a weighted aggregate of housing attributes:

$$u_{hki}(t) = [u_{hi}(t)]^{v_h}\ [u_{hk}(t)]^{w_h}\ [u_{q(h)h}(c_{ki})(t)]^{1-v_h-w_h} \tag{2.19}$$

where $u_{hi}(t)$ is the attractiveness of zone i as a housing location for household type h, $u_{hk}(t)$ is the attractiveness of housing type k for household type h, and $\mathrm{u}_{q(h)}(c_{ki})$ is the attractiveness of the rent or price of the dwelling in relation to the household's housing budget, which is a function of its income group $q(h)$. The v_h, w_h and $1 - v_h - w_h$ are multiplicative importance weights adding up to unity.

Both $u_{hi}(t)$ and $u_{hk}(t)$ are themselves multiattribute encompassing relevant attributes of the neighbourhood:

$$u_{hi}(t) = \sum_n a_n v_n\, \mathrm{f}_n[\mathbf{X}_i(t), \mathbf{U}_{q(h)i}(t)] \tag{2.20}$$

or of the dwelling:

$$u_{hk}(t) = \sum_n b_n\ w_n\ g_n[\mathbf{X}_k(t)] \tag{2.21}$$

where subscript n indicates attribute n. The a_n and b_n are importance weights adding up to unity, the $v_n(.)$ and $w_n(.)$ are value functions mapping attributes to utility, and the $f_n(.)$ and $g_n(.)$ are generation functions specifying how to calculate attributes from one or more elements of vectors $\mathbf{X}_i(t)$ or $\mathbf{X}_k(t)$ of raw attributes of zone i or dwelling type k or vectors of accessibility indices $\mathbf{U}_{q(h)i}(t)$ of zone i (see below). The housing price attractiveness $u_{q(h)}(c_{ki})$ is calculated as

$$u_{q(h)}(c_{ki}) = u_{q(h)}(c_{ki}/y_{q(h)k}) \tag{2.22}$$

where c_{ki} is rent, or imputed rent, of dwelling type k in zone i, and $y_{q(h)k}$ is the monthly housing budget of household type h belonging to income group q for this dwelling type. The housing budgets include housing allowances and other public subsidies and are therefore different for rented and owner-occupied dwellings.

The $\mathbf{U}_{q(h)i}(t)$ are household income-group specific vectors of accessibility indices describing the location of zone i in the region with respect to activities $W_{nj}(t)$ in zones j:

$$u_{qni}(t) = \sum_{j,m\in\mathbf{M}q} \frac{W_{nj}(t)\exp\left[\beta_n u_{qijm}(t)\right]}{\sum\limits_{j,m\in\mathbf{M}_q} W_{nj}(t)\ \exp\left[\beta_n u_{qijm}(t)\right]}\quad u_{qijm}(t) \tag{2.23}$$

The accessibility is expressed in terms of mean trip utility, i.e. as a weighted average of potential trips from zone i to activities or facilities $W_{nj}(t)$ of type n in zone j using mode m with trip utility $u_{qijm}(t)$ for household income group q. The set $\mathbf{M}_q$ includes all transport modes accessible to households of income group q depending on its car ownership level.

The attractiveness measure $\underline{u}_{hii'}(t)$ used in Eq. 2.17 is a relational utility describing the attractiveness of a zone i' as a new housing location for a household of type q now living in zone i and working in any of the zones near i (see Fig. 2.4).

Corresponding to the *change-of-job* utility in Eq. 2.11, it is called *migration utility*:

$$\underline{u}_{hii'}(t) = {u'}_{hi'j}(t)^{w_q}\ u_{q(h)hii'}(t)^{1-w_q} \tag{2.24}$$

with

$${u'}_{hi'j}(t) = \frac{1}{\beta}\ \ ln\ \sum_j \frac{t_{q(h)1ij}(t)\ \ \exp\left[\alpha\ \ u_{q(h)ij}(t)\right]}{\sum\limits_j t_{q(h)1ij}(t)\ \ \exp\left[\alpha\ \ u_{q(h)ij}(t)\right]}\ \ \exp\left[\beta\ \ u_{q(h)i'j}(t)\right] \tag{2.25}$$

and

Fig. 2.4 Change of residence

$$u_{q(h)ij}(t) = \frac{1}{\lambda} \sum_{m \in \mathbf{M}_h} \exp \left[\lambda \;\; u_{q(h)ijm}(t)\right] \tag{2.26}$$

The first part of the migration utility Eq. 2.24 is the expected utility of a work trip from the new housing zone i' to work zone j after the move weighted by the probability that the household works in j (Eq. 2.25) aggregated across modes (Eq. 2.26), the second part evaluates the utility of a trip between the old and the new housing zone. The w_q and $1 - w_q$ are multiplicative weights adding up to unity.

2.6.2 Price Adjustment

At the end of each simulation period housing prices and rents are adjusted to reflect changes in housing demand in the previous housing market simulation. Changes of housing prices and rents due to changes in the composition of the housing stock are dealt with in the *Private Construction Submodel*, price increases through inflation in the *Ageing SubmodeI*.

Housing prices and rents by housing type and zone are adjusted as a function of the demand for housing in that submarket in the period expressed by the proportion of vacant units:

$$p_{ki}(t+1) = p_{ki}(t) \left[1 + \mathrm{f}\left(\frac{V_{ki}(t+1)}{D_{ki}(t+1)}\right)\right] \tag{2.27}$$

where $p_{ki}(t)$ is monthly rent or imputed rent per square metre of housing floorspace of dwelling type k in zone i at time t, $V_{ki}(\mathrm{t}+1)$ is the number of vacant dwellings of housing type k in zone i at time $\mathrm{t}+1$, and $D_{ki}(t)$ is the total number of dwellings of that type in the zone at time $\mathrm{t}+1$. The function f(.) is an inverted S-shaped elasticity curve entered exogenously resulting in a reduction of housing prices and rents if there is a large percentage of vacant dwellings of that kind not bought or rented in the previous housing market simulation, and in a price or rent increase if there are no or only few vacant dwellings left. No attempt is made to determine equilibrium housing prices or rents. The price adjustment model reflects price adjustment behaviour by landlords. If they reduce or increase prices or rents too much, this will be corrected in the subsequent simulation period.

2.7 Calibration and Validation

The calibration and validation of the IRPUD model cannot be presented in detail here. Due to the large number of its submodels not all of them could be estimated statistically using maximum likelihood techniques because of lack of data.

In addition, the intended use of the model to assess scenarios quite different from past experiences made estimation of the model based on past behaviour less meaningful. Instead most attention was paid to capturing the constraints on mobility and location behaviour imposed by household disposable incomes, in particular travel and housing budgets. Accordingly the utility functions of firms, households and developers were largely determined by expert judgment based on theory and the available literature.

In the absence of calibration data, validation of the model becomes all important. This is why the model simulations always start in the year 1970 in order to iteratively adjust model parameters until the major spatial processes observed in the past are adequately reproduced.

As an example for the successful reproduction of characteristics of the labour market of the region, observed and modelled travel times and travel distances of commuter trips are compared in Fig. 2.5. The Figure shows cumulated frequencies of travel times (left) and travel distances (right) of work trips in the year 2000 aggregated for municipalities. The grey line shows travel times and distances between internal municipalities and to and from external municipalities (i.e. without internal travel times and work trips between external municipalities) forecast by the model, whereas the black lines show the empirically observed work trips of the North-Rhine Westphalia State Statistical Office multiplied by the travel times and travel distances of the *Transport Submodel*.

Figure 2.6 shows a comparison of population and employment of the municipalities of the study area as forecast by the model with observed population and employment data. The two diagrams show the quality of the forecasts based only on 1970 base year data. In particular the population data of the large cities Dortmund and Bochum were matched almost exactly, whereas Hagen is somewhat over- and Hamm and Herten somewhat underestimated.

The employment numbers of Dortmund were reproduced well, whereas those of Bochum, Hagen and Iserlohn were slightly overestimated. The examples demonstrate that the model is able to reproduce the essential spatial processes in the region. The small deviations from reality have no influence on the relevance of the results, as in their interpretation not absolute values but differences between scenarios are analysed.

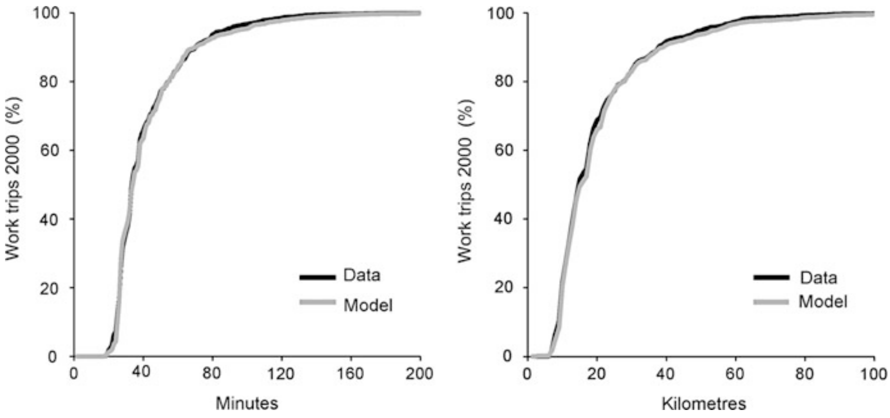

Fig. 2.5 Observed and modelled cumulated travel times and travel distances of work trips 2000

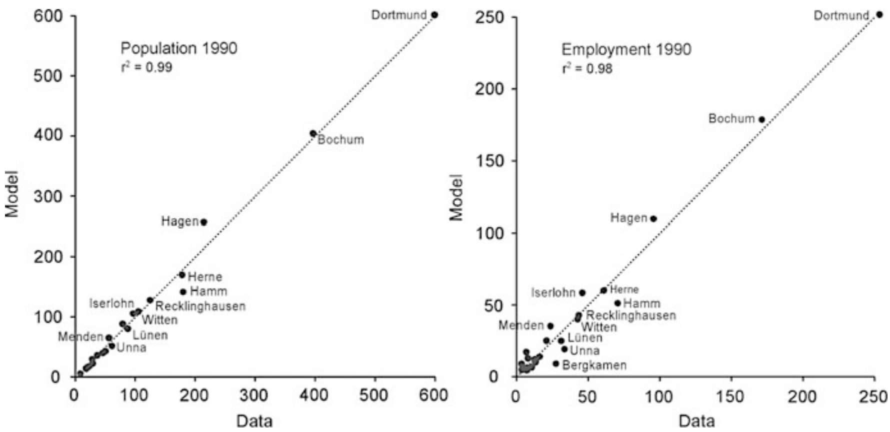

Fig. 2.6 Observed and modelled population and employment 1990

2.8 Model Applications

The IRPUD model has been applied in projects for the European Commission and regional authorities, such as the EU projects PROPOLIS: Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability (Lautso et al. 2004) and STEPs: Scenarios for the Transport System and Energy Supply and their Potential Effects (Fiorello et al. 2006) and a project for the State government of North-Rhine Westphalia (Spiekermann and Wegener 2005) and is presently extended to the whole Ruhr area (Huber et al. 2011).

It is impossible to show in this chapter the full range of policy issues investigated with the model in these projects. Here only one example will be given.

In the STEPs project it was explored what impact on travel behaviour would result from a combination of travel demand management and land use policies on the location of households and firms (Fiorello et al. 2006).

Fig. 2.7 Scenarios of concentration of population and employment at public transport stations

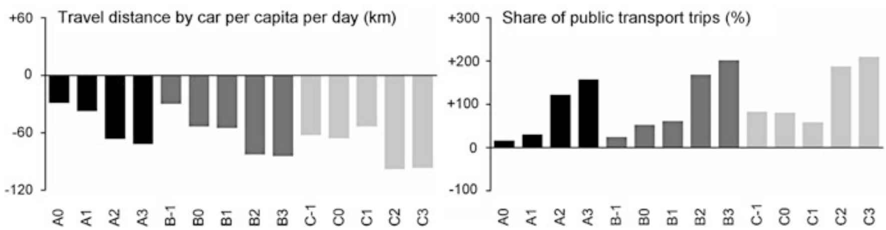

Fig. 2.8 The impacts of ant-sprawl land-use policies and other transport policies on travel distances by car and share of public transport trips

Figure 2.7 shows the effects of a scenario in which transport-related policies, such as higher fuel taxes and parking restrictions are combined with a land use plan restricting development to locations near rail stations. The two surfaces in the upper part of the figure show the effects on population and employment location as differences to the reference scenario.

Figure 2.8 shows the impacts of a range of scenarios on total distances travelled by car and modal shares. It can be seen that the scenarios with anti-sprawl land use controls (A2, A3, B2, B3 and C2 and C3) perform better in terms of environmental quality, energy conservation and reduction of greenhouse gas emissions.

2.9 Conclusions

This chapter presented a model of the urban labour market which is distinct from other models by its close integration between demand for labour by firms and the supply of labour by households.

Employment and labour in the model are affected by developments in other submodels: The supply of jobs results from growth and decline, location and relocation of firms and their demand for labour by skill. The demand for jobs results from population and immigration and outmigration by age, education and skill. Intraregional labour mobility results from decisions of firms to hire or release workers and decisions of workers to start or end a job. These decisions affect commuting patterns and residential and firm location and the associated construction and real estate markets.

It was demonstrated that the model could be calibrated with a minimum of data and produces relevant answers to urgent current urban problems.

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http://www.springer.com/978-3-642-31778-1

Employment Location in Cities and Regions
Models and Applications
Pagliara, F.; de Bok, M.; Simmonds, D.; Wilson, A. (Eds.)
2013, VIII, 296 p., Hardcover
ISBN: 978-3-642-31778-1