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How does the household structure shape the urban economy?

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How does the household structure shape the urban economy?

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Abstract:

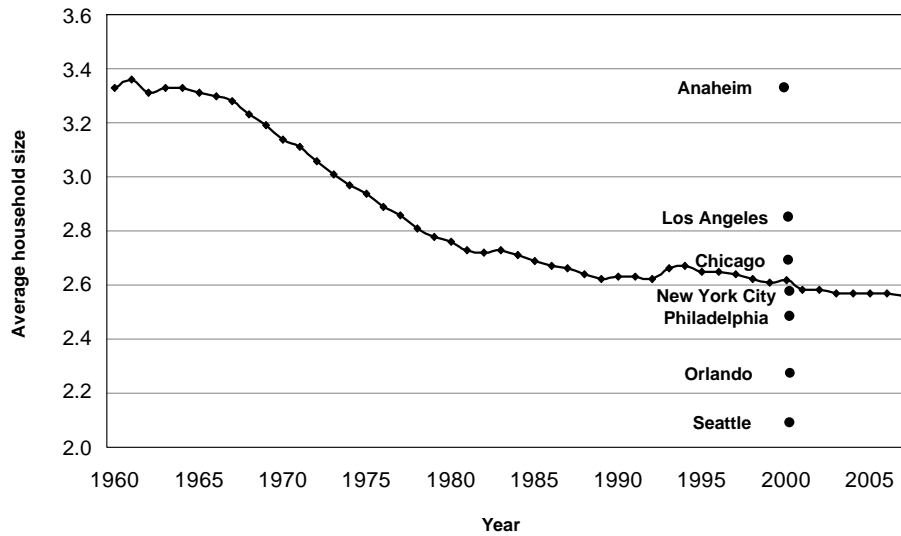
Households in real cities are heterogeneous regarding their size and composition. This implies that the household structure - i.e. the (average) household size, the composition, the relative share of different household types, and the number of households - differs across cities. This aspect is usually neglected in urban models used to study economic and policy issues that arise in today's cities. Furthermore, the household structure might change over time. For instance, over the last decades average household size has decreased in many countries. Several implications of this change have been discussed, but usually not in regard to an urban economy with its interdependencies. We develop an applied urban general equilibrium model which explicitly takes the household structure into account and thus allows studying the impacts of changes in the household structure on an urban economy and its spatial pattern. The paper shows that changes in the household structure affect an urban economy in various ways and may contribute to explain economic and spatial effects on cities. Compared to a 'Base City' which reflects the actual household structure in the United States, urban labor force participation, housing demand, rents, wages as well as urban commuting and shopping patterns are considerably affected by, e.g., changes in the average household size in a city. For instance, wage inequality between differently skilled workers rises and extreme cross commuting drops to almost zero when the city turns into a pure 'Singles City'.

JEL-Classification: C 68; R12; R13; R14; R20

Keywords: General equilibrium; Household structure; Household size; Location; Commuting

1 Introduction

The household is the fundamental basic economic unit in the society. But the structure of households varies across cities because households are heterogeneous and differ in size as well as their composition. Furthermore, the household structure – i.e. the (average) household size, the composition, the relative share of different household types, and the number of households – changes over time. For instance, in many countries households have become smaller in recent decades. Between 1970 and 2000, the average number of persons in households in less developed countries fell from 5.1 to 4.4. In more developed nations, it decreased from 3.2 to 2.5 persons per household over the same period (Keilman, 2003). Figure 1 shows the development in the United States.



Source: U.S. Census Bureau, 2007 (Cities: 2000)

Figure 1: Average household size in the United States (1960 - 2007) and some cities (2000)

In the U.S. the level of the average number of persons in households declined to 2.57 (2007), whereas total population and thus the number of households grew. Furthermore, the average household size differs considerably across cities (see for instance the year 2000). The development is similar in countries of the European Union, as shown in Table 1.

Table 1: Average household size in countries and cities of the European Union

| Country | Average household size | | | |
|---------|------------------------|------|------------|------|
| | 1982 | 2002 | City | 2004 |
| UK | 2.7 | 2.3 | Manchester | 2.24 |
| Germany | 2.5 | 2.2 | Berlin | 1.80 |
| Italy | 3.0 | 2.6 | Milan | 1.95 |
| Spain | 3.6 | 3.0 | Barcelona | 2.50 |
| Finland | 2.3 | 1.9 | Helsinki | 1.88 |

Source: European Commission - Living conditions in Europe (2003); Eurostat - Urban Audit (2009)

For example in Germany, the average number of persons per household fell from 2.5 in 1982 to 2.2 in 2002 for the whole country, whereas the number of households increased in the same period. Taking into account only the city of Berlin, the average number of persons in households is only 1.8. In addition, in the U.S. the growth in single-parent and single-person households has increased the share of adults in all age groups heading independent households. For instance, 26% of all households consisted of a person living alone in 2006, up from 17% in 1970 (U.S. Census Bureau, 2007a). *What do these changes in the household structure imply for an urban economy?* This is the issue we explore in this paper.

A differentiated understanding of the interplay between the household structure and the city is important from an urban economic perspective because the number of households located in urban areas is expected to increase over the next decades (United Nations, 2008). Therefore, effects of differences and changes in the household structure mainly arise on the level of cities, such as changes in rents, locations, commuting and shopping patterns with all its consequences. In the literature, there are several effects that have been discussed, but usually not in regard to an urban economy with its miscellaneous interdependencies, such as the interactions between different markets (products, labor, land), households and firms.

On the one hand, an increase in the number of households rises the demand for housing units. On the other hand, smaller households are less efficient concerning the per capita use of resources, because goods and services are shared by more people in larger households.

Thus, even when the population remains constant, a higher share of small households induces a larger demand for resources. In other words, the prevailing trend towards a smaller average household size means that economies of scale are being lost. As Ironmonger et al. (1995) suggest, energy use and expenditures per adult decrease with an increase in household size. Thus, economies of scale arise with respect to the number of persons per household. Concerning this matter, a similar result is found by Nelson (1988), who empirically determined economies of scale in housing. Logan (2008) provides evidence that increases in household size are correlated with decreases in the share of expenditure devoted to housing. That is, if two adults unite to form one household, they will be better off as they can share a household internal public good such as housing. In addition, many taxation schemes treat single-persons and larger households differently. Therefore, to examine, for instance, the impact of income taxation on an urban economy, it is necessary to incorporate a more complex and heterogeneous household structure. Other examples are the effects of the household structure on urban labor force participation, gender issues and public transport. But heterogeneity in the household structure is usually neglected in the literature. Most urban models used to study economic and policy issues that arise in today's cities focus almost entirely on different consumer types, for example rich and poor persons, but not on differences in the household structure, i.g. the number of equally or differently skilled working household members.

There are only a few urban models taking into account a more complex household structure. For instance, models used to examine the more complex process of location decision concerning households with two working members were developed by Curran et al. (1982) and White (1977). But these models ignore the interactions between different markets, households and firms in the city. Another model which incorporates a more complex household structure was developed by Hotchkiss and White (1993). However, they also do not consider the production sector of the urban economy. Hence, shopping trips required to buy the consumption goods in the city are ignored. But shopping trips are an important aspect when considering different household types. Imagine a household with two working members. Assume there is a wage differential among the household members. Then, the value of time of both household

members can differ implying differences in full economic shopping costs, i.e. monetary costs plus opportunity costs of travel time. As a consequence, the heterogeneous household can benefit from internal division of shopping activities. Hence, full economic shopping costs of a two-worker household may differ from those of two identical single-worker households, resulting in economies scale in shopping. This might affect its location decision. A similar conclusion occurs with regard to full economic commuting costs. Because workers optimally choose their number of daily working hours in the model of Hotchkiss and White, commuting costs remain unaffected as long as there is a minimum fraction of working hours supplied per day. As a result, changes in commuting costs only occur if the number of working hours supplied per day fall to zero and, hence, commuting costs drop to zero. Thus, in their model gains from an optimal internal division of labor in a two-worker household cannot arise with respect to commuting. In contrast, because of the complementarity of working days and full economic commuting costs (excepting for telecommuting), such gains could be realized when workers are allowed to choose their supply of working days. Furthermore, their model treats wages as exogenously given. This means, a more complex income taxation scheme that treats different households differently cannot be considered, because income taxation influences labor decisions and thus wages in the city. Aside from these issues, their model does not incorporate non-working households, although in reality the share of non-working households is substantial, as Table 2 shows.

Table 2: Number of workers per household in the United States 2007

| Number of workers per household | Share [%] |
|---------------------------------|-----------|
| No workers | 26 |
| 1 worker | 39 |
| 2 workers | 29 |
| 3 or more workers | 6 |

Source: U.S. Census Bureau

To explore the impact of changes in the household structure on an urban economy, we modify the urban general equilibrium model of Anas and Xu (1999) or Anas and Rhee (2006)

in various ways. The most important innovation is the differentiated household structure we implement. This allows to examine, to our knowledge for the first time within an urban general equilibrium framework, the impact of differences in the household structure on an urban economy and its spatial pattern. The model treats the interactions of product, labor and land markets as well as linkages between firms and different consumer types living in different household types. Households differ not only in endowments and preferences, but also in size and in the composition regarding their members. Referring to real-world observations, we implement the following consumer and household types: non-working single-person households and non-working two-person households, i.e. non-working couples; low-skilled and high-skilled single-worker households; low-skilled and high-skilled homogeneous two-worker households each composed of two potentially employed adults each with the same skill level; and heterogeneous two-worker households each composed of one potentially employed adult with a lower skill level and one potentially employed adult with a higher skill level.¹

The persons are potentially employed because the work decision is endogenous in the model and, as we will see later, depends also on the household type the persons belong to. Households decide where to reside, where to work (if working), where and how much to shop, how much labor to supply and how much land to rent in the urban area bearing in mind full economic travel costs. The labor supply decision concerns the choice of the number of working days, so potential savings of full economic commuting costs in two-worker households can arise. All prices, i.e. commodity prices, wages, rents, as well as location decisions are determined endogenously in the model. Since households can vary in idiosyncratic tastes for locations within the urban area, decisions of households create mixed land use and various possible commuting patterns, a result which is commonly observed in real cities. The crucial aspect in the case of homogeneous as well as heterogeneous two-worker households is that their household members make a joint decision regarding the residential location and the potential work location of both members. These decisions are interdependent in real decision

¹Although Table 1 shows a small share of households composed of three or more workers, for simplicity, we subsume such households to two-worker households.

processes, as observed, for instance, by Freedman and Kern (1997) or Singell and Lillydahl (1986) using empirical approaches. In addition, the members of these household types not only have to decide where to shop in the urban area, but also who shall execute the shopping trips. Hence, internal economies of scale in shopping can be realized by a two-worker household compared to the usually assumed single-worker household. There are no predetermined residential or employment locations in the city, so the spatial pattern can exhibit a polycentric structure. Making employment locations endogenous is important in order to reflect real-world land use patterns with a remarkable fraction of dispersed job locations (see e.g. Anas et al., 1998; Center on Urban & Metropolitan Policy, 2001; Wheaton, 2004).

The paper is organized as follows: Section 2 presents the model. In Section 3 we describe the model calibration and the results of the numerical 'Base City' simulation which constitutes our benchmark and reflects the actual household structure in the U.S. In Section 4 we provide results and discuss the findings of the numerical simulations of changes in the household structure. The paper shows that changes in the household structure contribute to explain economic and spatial effects on cities. The main findings are that compared to the 'Base City' urban labor force participation, housing demand, rents, wages as well as commuting and shopping patterns are considerably affected by changes in the household structure. For instance, wage inequality between differently skilled workers increases and extreme cross commuting drops to almost zero when the city turns into a pure 'Singles City'. However, overall commuting travel might even increase. Section 5 provides sensitivity analyses and Section 6 offers conclusions and some ideas of possible further model extensions and applications.

2 The model

2.1 The general setting

The urban area is partitioned into I zones. The zones are linked via an exogenously given transport network with distance d_{ij} . At each zone i ($i \in I$), a fixed land area A_i is available for

the development of residences and establishments. The land area in each zone i is homogeneous. Hence, from the perspective of city residents and firms, land within the same zone is identical but land of different zones is viewed as an imperfect substitute. At each zone i , the land rent is endogenously determined² and firms produce a composite commodity using land and labor supplied by high-skilled and low-skilled city residents. The zone specific local markets for the composite commodity and the production factors are competitive. Commodities produced in different zones are product varieties, hence, there is spatial product differentiation and consumers have the opportunity to shop at different locations in the city to satisfy their taste for shopping variety.

Households with working members are differentiated in regard to the skill levels of their members either as high-skilled, low-skilled or mixed-skilled, i.e. heterogeneous, households. Household members are free to choose home zones (residence) and work zones (employment) within the urban area. They derive utility from consumption of the spatially differentiated commodities, housing and leisure. Household members might have to commute to work and make shopping trips to the selling points of the commodities. In order to determine trip distances and travel times, commuting and shopping trips are assumed to originate from the center of a zone.

It is assumed that the urban economy is closed in the sense that the total population in the urban area is fixed and exogenously given, that is there is no interurban migration and utility levels of households are endogenously determined.³ Apart from this, the city is partly open in the sense that some share of the urban production will be exported to balance rents paid to absentee landowners and travel expenses which implicitly flow to an external transport sector.

²One can imagine that the urban area has already reached its natural boundary or the urban area is surrounded by land that is not convertible into urban land due to political restrictions. Hence, land rent at the edge of the city can differ from land rent beyond the city boundary.

³The assumption that no interurban migration occurs is appropriate if it is assumed that consequences arising in the city, for instance based on policy or demographic changes, also affect the other cities in the (national) economy.

2.2 Households

There are 4 different household types y ($y \in Y$) in the urban economy: non-working households ($y = 1$), single-worker households ($y = 2$), homogeneous two-worker households ($y = 3$), and heterogeneous two-worker households ($y = 4$). In addition, non-working households are differentiated in regard to the number of household members, where $g = 1$ denotes a non-working single household and $g = 2$ denotes a non-working couple household. Furthermore, households with working members are differentiated according to their composition of skill types h ($h \in H$), where $h = 1$ denotes a lower skill level and $h = 2$ denotes a higher skill level. That means, there are two different non-working household types, two different single-worker household types, two different homogeneous two-worker household types composed of two employed persons each with the same skill level, and one heterogeneous (mixed) two-worker household type composed of one employed lower-skilled person and one employed higher-skilled person. Let N be the number of households belonging to a specific household type, the total number of households in the urban area is then $\sum_{\forall g} N^{g,1} + \sum_{\forall h} N^{h,2} + \sum_{\forall h} N^{h,3} + N^4$. In this paper we treat children in the households as dependents who do not cause any trip purpose, e.g. trips to child care facilities or schools, or child related expenditures, e.g. expenditures on child care or education.

Each household resides in some zone i . In the case of single-worker households, the household member is employed in zone j ($j \in I$). In the case of two-worker households, the first member is employed in zone j while the second member is employed in zone l ($l \in I$). Therefore, the location choice set of non-working households is $\{i\}$, the choice set of single-worker households is $\{i, j\}$, and the choice set of two-worker households is $\{i, j, l\}$. This implies commuting from residential location i to work zone j or l . Each household type has to pay a rent r_i per square meter of lot size for a residence in zone i . There are zone specific local markets for the composite commodity, land and different labor skills. The latter implies hourly wage rates w_j^h or w_l^h differing according to skill level h and work zone j or l . In addition, since travel costs, travel time, rents and wages depend on the location choice set, utility U of each household type also depends on either $\{i\}$, $\{i, j\}$ or $\{i, j, l\}$.

In the next subsections we present the two-stage decision process of a typical, homogeneous or heterogeneous, two-worker household with location choice set $\{i, j, l\}$. All other household types face equivalent decision problems, depending on the specific location choice set.⁴ In the first stage, the household decides on consumption quantities, i.e. commodities, housing and leisure, given its location choice set. In the second stage, the two-worker household chooses its joint home location and the work locations of household members considering deterministic utility levels associated with each location choice set as well as idiosyncratic tastes reflected by a stochastic utility component.

In the following, the lower indices are used to denote locations. The upper indices s ($s \in S$), where $s = \{f^h, m^h\}$, denote a specific member of the household with skill level $h \in H$. In general, f is the first member in a two-worker household (or the only member in a single-worker household) and m is the second member in a two-worker household. To simplify notation, we only use f, m in the following.

2.2.1 Utility maximization

Using $\iota \equiv \{i, j, l\}$, the random utility function of a typical two-worker household is

$$U_\iota = u(Z_\iota, q_\iota, F_\iota) + \epsilon_\iota = \alpha \ln Z_\iota + \beta \ln q_\iota + \gamma \ln F_\iota + \epsilon_\iota, \quad (1)$$

where the deterministic part $u(Z_\iota, q_\iota, F_\iota)$ is a Cobb-Douglas utility function on demand of the composite commodity Z_ι , lot size q_ι as a approximation for housing and aggregate leisure F_ι . The idiosyncratic taste constant ϵ_ι presents the stochastic part of the random utility function and varies among the households for each location choice set ι .⁵

The shopping subutility function Z_ι for visiting different shopping locations over a certain

⁴The full specification of the model including decisions of other household types can be found in Tscharaktschiew and Hirte (2009).

⁵One can imagine that households differ in tastes for specific attributes regarding the choice set ι and these attributes are not observable by the researchers. Hence, they can determine only a choice probability of the household's decision on ι .

period of time is a two-stage nested C.E.S. utility function:

$$Z_i = \left[\left(\sum_{k=1}^I a_k \left(z_{ik}^f \right)^\eta \right)^{\frac{\omega}{\eta}} + \left(\sum_{k=1}^I b_k \left(z_{ik}^m \right)^\eta \right)^{\frac{\omega}{\eta}} \right]^{\frac{1}{\omega}}. \quad (2a)$$

The household members s residing at i , working at j or l , travel from zone i to every zone k ($k \in I$) to purchase the composite commodity z_k produced there, taking into account full economic shopping costs, i.e. the commodity price plus monetary travel cost and opportunity cost of travel time. We assume that Z_i is produced by shopping activities of both household members. Each member s might be active in home production, i.e. collects an amount of each of the product varieties to produce a share of the composite commodity. However, whether both household members go shopping depends on the relation of individual full economic shopping costs as well as on the elasticity of substitution. The constants $a_k, b_k \geq 0$ measure the relative attractiveness of shopping location k to household member f and m compared to other locations.

The constant elasticity of substitution $1/(1-\eta)$, $\eta < 1$ reflects spatial taste variety in shopping (Dixit and Stiglitz, 1977). As $\eta \rightarrow 1$, shopping locations and therefore goods sold at different zones are perfect substitutes. In this case the household members shop only at the zone where full economic shopping costs are the lowest. As $\eta \rightarrow -\infty$, the household members prefer to shop at each zone where shopping is possible regardless of the commodity price, travel costs and travel time of making such a trip. We assume that separate trips are made to each production (shopping) zone, purchasing one unit of the local good per trip. Hence, we ignore trip chaining.

Besides the fact that both household members value spatial variety in shopping, they have a taste for an internal task sharing concerning shopping trips, reflected by the elasticity of substitution $1/(1-\omega)$, $\omega < 1$. As $\omega \rightarrow 1$, shopping trips within the household are perfect substitutes, so the household member with the lower full economic shopping costs is making all shopping in the respective zone. Hence, full economic shopping costs per capita in a two-worker household can be lower compared to an identical single-worker household. This

implies that the two-worker household might realize internal economies of scale in shopping. As $\omega \rightarrow -\infty$, there is an extreme taste to spread shopping trips over both household members s , regardless of differences in full economic shopping costs.⁶

In addition, the household derives utility from lot size q_ι and leisure consumption ℓ_ι^s of each household member s . The leisure C.E.S. subutility function of the household is

$$F_\iota = [(\ell_\iota^f)^\rho + (\ell_\iota^m)^\rho]^{\frac{1}{\rho}}. \quad (2b)$$

The constant elasticity of substitution between leisure of both household members is $1/(1-\rho)$, $\rho < 1$ and reflects the preference to spread leisure over both household members.

Assuming that travel cost and travel time per unit of distance are identical for each person the monetary budget constraint of the household is

$$\sum_{k=1}^I P_{ik} z_{ik}^f + \sum_{k=1}^I P_{ik} z_{ik}^m + r_i q_\iota = W_{ij}^f D_\iota^f + W_{il}^m D_\iota^m + R, \quad (3)$$

where $P_{ik} = p_k + c_{ik}$ is the full monetary consumer price including the price of the composite commodity p_k and two-way monetary shopping trip costs c_{ik} , $W_{i\zeta}^s = (w_\zeta^h L - c_{i\zeta}^s)$ is the net daily wage of household member s working in zone $\zeta \in [j, l]$. D_ι^s is the number of working days supplied by household member s . Travel costs are determined by multiplying distance d_{ij} from zone i to zone j by travel cost per unit of distance c . The monetary budget states that consumption expenditure including monetary shopping trip costs of both household members plus joint housing expenditure equal disposable income. The latter is the sum of wage income of both working members of the household plus non-working income R , i.e. rent dividend income, minus aggregate commuting costs. L are exogenously given daily working hours assumed to be constant for all working individuals.

⁶As usual, in reality the truth lies somewhere in the middle. Hence, $-\infty < \sigma < 1$. One can imagine that in some cases, the physical presence of a specific household member s is necessary to buy a certain commodity such that s buys the consumption good in zone k despite higher full economic shopping costs. Alternatively, it is plausible to assume that, although household member s has higher full economic shopping costs, the member s simply loves to do some shopping on its own.

Each household member s is also subject to the following time constraint:

$$D_\iota^s L + \ell_\iota^s + T_\iota^s = E, \forall s = f, m \quad (4)$$

where E is the total time endowment per period, $T_\iota^f = \sum_{k=1}^I t_{ik} z_{ik}^f + t_{ij}^f D_\iota^f$ is total travel time per period of household member f and $T_\iota^m = \sum_{k=1}^I t_{ik} z_{ik}^m + t_{il}^m D_\iota^m$ is total travel time per period of household member m . The two-way travel time for a shopping trip from i to k is denoted by t_{ik} and the two-way commuting time is denoted by t_{ij}^f or t_{il}^m , where travel times do not depend on traffic volume. Travel time is determined by dividing distance d_{ij} by travel speed v . Total time endowment E can be allocated to work, leisure and travelling.

Maximizing household utility (1) subject to the monetary budget constraint (3) and the time constraints (4) yields the first-order conditions:

$$\begin{aligned} \frac{\partial u_\iota}{\partial z_{ik}^s} &= \lambda_\iota P_{ik} + \mu_\iota^s t_{ik}, \forall s, k \\ \frac{\partial u_\iota}{\partial q_i} &= \lambda_\iota r_i & \frac{\partial u_\iota}{\partial \ell_\iota^f} &= \mu_\iota^f & \frac{\partial u_\iota}{\partial \ell_\iota^m} &= \mu_\iota^m \\ (L + t_{ij}^f) \mu_\iota^f &= W_{ij}^f \lambda_\iota & (L + t_{il}^m) \mu_\iota^m &= W_{il}^m \lambda_\iota, \end{aligned} \quad (5)$$

where μ_ι^s is the marginal utility of time of household member s and λ_ι is the marginal utility of joint monetary household income.

The last equations are used to derive the value of time θ_ι^s of household member s :

$$\theta_\iota^f \equiv \frac{\mu_\iota^f}{\lambda_\iota} = \frac{L w_j^h - c_{ij}^f}{L + t_{ij}^f} \quad \theta_\iota^m \equiv \frac{\mu_\iota^m}{\lambda_\iota} = \frac{L w_l^h - c_{il}^m}{L + t_{il}^m}. \quad (6)$$

The value of time, which is the effective hourly wage rate, decreases with an increase in monetary travel cost and travel time. If monetary transport cost and/or travel time differ between the household members because of different work locations, effective hourly wage

rates can differ even though gross wage rates paid by firms are equal, as in a homogeneous two-worker household. However, if $j = l$ (work locations of both household members are identical), the value of time does not differ between the household members of a homogeneous two-worker household, because gross wage rates earned by two equally skilled city workers are the same.

Rearranging the first-order conditions gives a first intuition on some important effects:

$$\begin{aligned} \frac{\partial u_l / \partial z_{lk}^s}{\partial u_l / \partial q_l} &= \frac{p_k + c_{lk} + \theta^s t_{lk}}{r_i} & \frac{\partial u_l / \partial z_{lk}^s}{\partial u_l / \partial \ell_l^s} &= \frac{p_k + c_{lk} + \theta^s t_{lk}}{\theta^s} \\ \frac{\partial u_l / \partial z_{lk}^f}{\partial u_l / \partial z_{lk}^m} &= \frac{p_k + c_{lk} + \theta_{ij}^f t_{lk}}{p_k + c_{lk} + \theta_{il}^m t_{lk}} & \frac{\partial u_l / \partial \ell_l^f}{\partial u_l / \partial \ell_l^m} &= \frac{\theta_{ij}^f}{\theta_{il}^m} \end{aligned} \tag{7}$$

The value of time enters all prices, except for housing demand. A higher value of time rises the relative price of consumption or leisure with respect to housing. Hence, *ceteris paribus*, high-wage households demand relatively more housing and less consumption or leisure, i.e. they supply more labor. The same occurs with respect to the division of activities within a two-worker household. If the members are heterogeneous concerning their value of time, *ceteris paribus* the household member with the higher value of time is doing less shopping trips and consumes less leisure, hence, he is working more. With identical household members these effects are absent, and the household cannot benefit from the internal division of working or shopping activities.⁷ Concerning the location decision there are several opposite forces. If rents decrease with distance from the center housing demand is a centrifugal force. In contrast, commuting and shopping trip costs constitute a centripetal force, since a central residential location reduces aggregate full economic travel costs of the household. Since wages of high-skilled individuals are higher than those of low-skilled individuals, high-skilled households demand more land and at the same time have a higher value of time. Hence, both forces are stronger for high-skilled households. The net effect is *a priori* ambiguous.

⁷There is evidence that in many countries women earn less than men, even in the same jobs. This implies that women work less hours or days and bear a larger share of shopping activities.

2.2.2 Location decision

Insertion of the demand functions which can be derived from the first-order conditions (5) yields the complete indirect random utility function

$$\tilde{U}_\iota = \tilde{u} \left(\tilde{z}_{\iota k}^f, \tilde{z}_{\iota k}^m \forall k, \tilde{q}_\iota, \tilde{\ell}_\iota^f, \tilde{\ell}_\iota^m \right) + \varepsilon_\iota.$$

The household compares all location choice sets and chooses the most preferred combination of locations, in other words, chooses the choice set ι which offers the highest utility given optimized consumption, housing demand and leisure demand, as well as idiosyncratic tastes. These are stochastically distributed among households within the two-worker household type for each ι . Hence, choices are described probabilistically and, as a consequence, a discrete choice model can be applied to model this decision.

The probability of a two-worker household to choose the specific location choice set $\iota \equiv \{i, j, l\}$ is

$$\Psi_\iota = \text{Prob} \left[\tilde{U}_\iota > \tilde{U}_{\tilde{\iota}}, \forall \tilde{\iota} \neq \iota \right] \quad (8a)$$

$$= \text{Prob} \left[\tilde{u}_\iota + \varepsilon_\iota > \tilde{u}_{\tilde{\iota}} + \varepsilon_{\tilde{\iota}}, \forall \tilde{\iota} \neq \iota \right], \quad (8b)$$

where Ψ_ι is the probability that a randomly selected two-worker household prefers the location choice set ι . Assuming that each ε_ι is i.i.d. Gumbel distributed with $E[\varepsilon_\iota] = 0$, variance σ^2 and dispersion parameter $\Lambda = \pi / (\sigma\sqrt{6})$, the choice probabilities are given by the multinomial logit model (see e.g. McFadden, 1973; Train, 2003):

$$\Psi_\iota = \frac{\exp(\Lambda \tilde{u}_\iota)}{\sum_{a=1}^I \sum_{b=1}^I \sum_{c=1}^I \exp(\Lambda \tilde{u}_{abc})}. \quad (9)$$

The logit probabilities exhibit several desirable properties (Train, 2003). First, Ψ_ι is between zero and one, as required for a probability. Second, the choice probabilities for all alternatives sum to one: $\sum_{\forall(i,j,l)} \Psi_{ijl} = 1$. The denominator in (9) is simply the sum of the numerator

over all location choice sets, which gives this summing-up property automatically.

Further, the dispersion parameter, Λ , is important (Anas, 1990). At one extreme, as $\Lambda \rightarrow \infty$ $\sigma \rightarrow 0$, there is taste homogeneity since taste idiosyncrasies vanish and all households within the two-worker household type choose identically. In this case, the Ψ_ℓ corresponding to the highest \tilde{u}_ℓ approaches one and all others converge to zero. At the other extreme, as $\Lambda \rightarrow 0$ $\sigma \rightarrow \infty$, there is infinite taste heterogeneity since idiosyncrasies swamp the deterministic and systematic part of utility and two-worker households choose randomly ($\Psi_\ell = 1/I^3$). The case of finite Λ has empirical validity and is in line with the hypothesis of wasteful commuting (first noted by Hamilton, 1982; for further studies see e.g. Small and Song, 1992; Kim, 1995; Van Ommeren and Van der Straaten, 2005; Ng, 2008). In reality, many possible commuting patterns can be observed (see e.g. Anas and Rhee, 2007; Glaeser et al., 2001).⁸ Such differentiated commuting patterns are explained by assuming idiosyncratic tastes, but cannot be explained using the assumption of uniform tastes (which means $\Lambda = \infty$ or $\sigma = 0$). Hence, if $\Lambda < \infty$, at equilibrium different household types can choose the same location choice set, as is observed in real cities.

2.3 Producers (firms)

Within each zone i competitive firms in the input and output markets employ a Cobb–Douglas production function that combines land and labor to produce a zone specific composite commodity. Each commodity is sold at the zone in which it is produced. Firms producing at the same zone i are identical. To simplify matters we drop the zone index i . Let M^h be the aggregate labor input of skill level h [hours/period] in i and let Q be the aggregate land input in i , the production function of the zone specific aggregate output X can then be written as follows:

$$X = BQ^\phi \prod_{h=1}^H (M^h)^{\delta^h}, \quad (10)$$

⁸For example, commuters who live in the suburbs and work in central cities and commuters who live in central cities and work in the suburbs (known as reverse commuting).

where B is the productivity (scale-) parameter, δ^h is the output elasticity with respect to labor of skill level h , ϕ is the output elasticity with respect to land and $\sum_{h=1}^H \delta^h + \phi = 1 \forall i$. Given the production technology, profit maximization

$$\max_{M^h(\forall h), Q} \pi = pBQ^\phi \prod_{h=1}^H (M^h)^{\delta^h} - \sum_h w^h M^h - rQ \quad (11)$$

yields profit maximizing input demands $\tilde{M}^h \forall h$ and \tilde{Q} with corresponding first order conditions:

$$p\delta^h X/M^h = w^h, \quad p\phi X/Q = r. \quad (12)$$

The zone specific commodity prices are determined from the zero profit condition

$$p = \frac{\partial C(w^h \forall h, r, X)}{\partial X} = \frac{C(w^h \forall h, r, X)}{X}, \quad (13)$$

since free entry in each zone insures that profit maximizing firms make zero economic profit in the competitive market. Hence, price equals marginal (and average) cost, where $C(w^h \forall h, r, X)$ is the cost function of a typical firm located in the city.

2.4 Equilibrium conditions

In addition to the utility and profit maximization conditions, several other conditions are necessary to close the model. At general equilibrium, the factor markets for land and labor with respect to skill level h and the market for the locally produced composite commodity must clear in each zone i . Furthermore, firms in each zone must make zero economic profits.

In each zone i , market clearing in the local land market requires

$$\begin{aligned} & \sum_{\forall g} \Psi_i^{g,1} N^{g,1} \tilde{q}_i^{g,1} + \sum_{\forall (h,j)} \Psi_{ij}^{h,2} N^{h,2} \tilde{q}_{ij}^{h,2} + \sum_{\forall (h,j,l)} \Psi_l^{h,3} N^{h,3} \tilde{q}_l^{h,3} \\ & + \sum_{\forall (j,l)} \Psi_l^4 N^4 \tilde{q}_l^4 + \tilde{Q}_i = A_i \end{aligned} \quad (14)$$

The left-hand side is the sum of lot size demands of all households of all household types residing in zone i and commuting to all zones plus land demands of all the firms in zone i . The right-hand side is the available developable land in zone i .

Equilibrium in the local labor market regarding skill level h in zone i requires

$$\sum_{\forall a} \Psi_{ai}^{h,2} N^{h,2} \tilde{D}_{ai}^{h,2} L + \sum_{\forall(a,c)} \Psi_{aic}^{h,3} N^{h,3} \tilde{D}_{aic}^{h,3,f} L + \sum_{\forall(a,b)} \Psi_{abi}^{h,3} N^{h,3} \tilde{D}_{abi}^{h,3,m} L + \{\cdot\} = \tilde{M}_i^h, \quad (15)$$

$$\text{where } \{\cdot\} = \begin{cases} \sum_{\forall(a,c)} \Psi_{aic}^4 N^4 \tilde{D}_{aic}^{4,f} L & \text{if } h = 1 \\ \sum_{\forall(a,b)} \Psi_{abi}^4 N^4 \tilde{D}_{abi}^{4,m} L & \text{if } h = 2 \end{cases}.$$

The left-hand side is the supply of labor by all household members (household types 2-4) working in zone i and the right-hand side is the demand for labor by all the firms producing and selling in zone i . Note that in the case of the heterogeneous two-worker household (Type $y = 4$), only one household member supplies labor in a specific labor market h .

In the local market i for the composite commodity, market clearing requires

$$\begin{aligned} & \sum_{\forall(g,a)} \Psi_a^{g,1} N^{g,1} \tilde{z}_{ai}^{g,1} + \sum_{\forall(h,a,b)} \Psi_{a,b}^{h,2} N^{h,2} \tilde{z}_{abi}^{h,2} + \sum_{\forall(h,s,a,b,c)} \Psi_{a,b,c}^{h,3} N^{h,3} \tilde{z}_{a,b,c,i}^{h,3,s} \\ & + \sum_{\forall(s,a,b,c)} \Psi_{abc}^4 N^4 \tilde{z}_{abci}^{4,s} + EX_i = \tilde{X}_i \end{aligned} \quad (16)$$

The left-hand side is the quantity of the composite commodity purchased in zone i by all household members of all household types y who live and work in all the zones in the urban area plus the quantity of the composite commodity that must be exported to balance rents paid to absentee landowners and travel expenses. It is assumed that the composite commodity produced in a zone i can be exported at price p_i at zero transport costs. Therefore, the following condition must be met such that the urban economy is in equilibrium:

$$p_i EX_i = \frac{1}{I} ATC + \frac{1}{I} \sum_{\forall i} ALR_i, \quad (17)$$

where ATC are aggregate monetary travel costs paid by all city residents per period for two-way shopping trips and two-way commuting, and $ALR_i = (1 - \Theta_i) A_i r_i$ is aggregate land rent generated in zone i but not owned by households in the city with Θ_i as the share of rents generated in zone i and redistributed to the residents. Hence, $\Theta_i A_i r_i$ is the sum of rent dividends generated in zone i and earned by all city residents. The local zone specific production not exported, $X_i - EX_i$, is consumed locally. It is assumed that an equal share of aggregate monetary transport costs and aggregate land rent is distributed to zones.⁹

According to the conditions described above, the task is to find for each zone i land rents, wages with respect to skill level h , commodity prices, firm outputs, export quantities and, based on it, the entire set of endogenous variables. Relative prices can be determined, but the price level is arbitrary.¹⁰ We solve the optimization problems of all household types y and the city firms which yields utility maximizing demands and profit maximizing factor demands. Then, we substitute these solutions into the equilibrium conditions, solving them simultaneously. The system (13)-(17) is non-linear and cannot be solved analytically. Therefore we have to rely on numerical simulations and proceed with computational analysis.¹¹ See for instance the complexity of the decision process of a typical two-worker household. In order to find the optimal location pattern within the city, i.e. the joint residential location in zone i , work zone j of household member f and work zone l of household member m , it is necessary to compare $i \times j \times l = I^3$ choice alternatives.

In the next sections we use the model to examine the long run effects of changes in the

⁹Note that if $\Theta_i = 1 \forall i$ and $ATC = 0$, it follows that $EX_i = 0$ for each zone.

¹⁰Testing the model we found the expected result that multiplying all prices by a constant factor remains all aggregate values as well as the individual optimized household demands and factor demands of the firms unchanged.

¹¹Under the parameter values and the city geography we describe in the next section, the algorithm that solves for the general equilibrium finds an equilibrium in 2-5 minutes (once starting values are set appropriately) by means of an accurate iterative procedure using a pc with a 2.40 GHz processor. We have checked the successful iterative solutions in order to ensure that all excess demands equal zero and that the monetary and full economic budget constraints of all households as well as the time constraints of all household members in the city and the zero profit condition of all city firms are met (generally with a small tolerance of $10^{-8}\%$). In addition, we have explored the uniqueness of the equilibrium numerically. Using a broad range of different starting values, the solution algorithm converges to the same equilibrium under the same city geography and parameters.

household structure – particularly changes in the household size, the relative share of different household types, and the number of households – on an urban economy and its spatial pattern. First, we describe the parameter values used to simulate a 'Base City' which reflects the actual pattern of the household structure in the U. S. Then, we describe and discuss some properties of the 'Base City'. After this, we compute the entire path of discrete changes in the household structure. Starting with the 'Base City', we show how the urban economy can change when the city turns into a 'Singles City' and a 'Couples City', which are the extreme cases in the simulations. However, we also determine intermediate developments.

3 Model calibration and the 'Base City'

The city characteristics and the chosen parameters for all simulations are shown in Table 3. The urban area is partitioned into 5 zones, where zone $i = 3$ is assumed to be the city center. The area developable for residences and establishments, A_i , increases with distance from the city center.

We assume that the number of households in the 'Base City' is 1 million. Then we use U.S. data (U.S. Census Bureau) to calculate the number of households within a specific household type y (see Table 2). Accordingly, there are 260,000 non-working households, 390,000 single-worker households and 350,000 two-worker households which is a share of 0.35 of all households. This corresponds to the share of all households with more than two workers in the U.S. In addition, we assume that non-working households are equally distributed among singles and larger households. Summing up, total (adult) city population is 1,480,000 while the labor force encompasses 1,090,000 city residents. Following the American Community Survey (U.S. Census Bureau, 2007b) we define a percentage of 30 of the labor force as high-skilled, referring to an educational attainment of a Bachelor degree or higher. Hence, there are 327,000 higher-skilled and 763,000 lower-skilled working persons in the city. Parameters of the utility functions are chosen to fit real-world observations. Since housing is

Table 3: Calibrated values of parameters

| City Geography | | | | | | |
|---|--------------------------------|---------------|-------------------------------|------------------|--------|---------------------------|
| Distance | | | | | | Area A_i |
| d_{ij} [km] | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 | [million m ²] |
| Zone 1 | 4 | 9 | 18 | 27 | 36 | 65.0 |
| Zone 2 | 9 | 2 | 9 | 18 | 27 | 30.0 |
| Zone 3 | 18 | 9 | 1 | 9 | 18 | 15.0 |
| Zone 4 | 27 | 18 | 9 | 2 | 9 | 30.0 |
| Zone 5 | 36 | 27 | 18 | 9 | 4 | 65.0 |
| Households (Consumers) | | | | | | |
| Total city population: 1,480,000 | | | Non-working persons: 390,000 | | | |
| Low-skilled persons: 763,000 | | | High-skilled persons: 327,000 | | | |
| Utility function | SNW | CNW | SW $\forall h$ | HoTW $\forall h$ | HeTW | |
| α (Consumption) | 0.45 | 0.45 | 0.35 | 0.35 | 0.35 | |
| β (Housing) | 0.20 | 0.17 | 0.20 | 0.17 | 0.17 | |
| γ (Leisure) | 0.35 | 0.38 | 0.45 | 0.48 | 0.48 | |
| η | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | |
| ω | - | 0.95 | - | 0.95 | 0.95 | |
| ρ | - | 0.30 | - | 0.30 | 0.30 | |
| $a_k, b_k \forall k$ | 1 | 1 | 1 | 1 | 1 | |
| $L = 8$ hours/day | $\Lambda = 10$ | $p_3 = \$125$ | $c = 0.35$ \$/km | $v = 30$ km/hour | | |
| $E = 3520$ hours/year (220 operating days per year \times 16 hours per day) | | | | | | |
| Production (City firms) | | | | | | |
| $\delta^{low-skilled} = 0.35$ | $\delta^{high-skilled} = 0.45$ | $\phi = 0.2$ | $B = 0.6$ | | | |
| SW: Single-worker: SNW: Non-working single CNW: Non-working couple Ho(e)TW: Homogeneous (Heterogeneous) two-worker | | | | | | |

a public good within households, single households have higher expenditure shares of housing compared to larger households, i.e. non-working couple and two-worker households. This refers to results of several empirical studies founding that increases in household size are correlated with decreases in the share of expenditure devoted to housing (see e.g. Nelson, 1988; Logan, 2008).

As Table 3 shows, we assume that leisure enters the utility function of non-working households. So even the members of non-working households take into account travel time for shopping. The value of time for non-working singles, derived from the Lagrangian, is then,

$\mu_i^1/\lambda_i^1 = \gamma^1 r_i q_i^1/\beta^1 \ell_i^1$. The preference for leisure is assumed to be slightly higher in larger households (non-working couple and two-worker households), reflecting the intention that both household members are more interested in spending time together. By setting $\eta = 0.70$ we assume that there is some spatial taste variety in shopping. Furthermore, we choose $\omega = 0.95$ so that shopping trips are imperfect substitutes within households. Equivalently, leisure hours of both household members are also considered to be imperfect substitutes. Hence, ρ which represents the preference to spread leisure over both household members is set at 0.3, following the assumption that both household members are interested in enjoying some leisure.

The Travel cost rate is $c = 0.35$ \$/km. This approximates the average cost of owning and operating an automobile in the U.S. (U.S. Department of Transportation, 2007). Hence, we ignore mode choice for the time being. Urban travel speed is assumed to be 30 km/hour for each city resident.

It is assumed that the non-working household type is the only one that earns non-wage income from land rents generated in the city. This implies the assumption that the non-working households benefit from an increase in land rents (or suffer from decreasing land rents) while the other household types do not.¹² The aggregate share of land rents $\sum_{\forall g} \Theta_i^{g,1}$ redistributed to households of the non-working household type is 0.5 for each zone i . However, since the number of households within subtype g (single or couple household) differs among the simulation path, for instance $N^{1,1} = 260,000$ (SNW) and $N^{2,1} = 0$ (CNW) in a pure 'Singles City', the individual share $\Theta_i^{g,1}$ is adjusted such that the per capita share is equal in all simulations. According to the American Time Use Survey 2007 (U.S. Bureau of Labor Statistics, 2007), working time per day, L , is 8 hours. The dispersion parameter is set at 10 for all households. The output elasticity of firms in the city is taken to be 0.45 with respect to higher-skilled workers and 0.35 with respect to lower-skilled workers. Finally, to ensure flexible wages, rents and incomes, we set the commodity price at the city center as

¹²One can think of retired households earning capital income from shares in real-estate firms, or non-working landowners, or people receiving inflation adjusted benefits.

the numeraire and choose a level such that reasonable results can be obtained. Using this base calibration, we obtain the 'Base City'. The main results of the 'Base City' equilibrium simulation are shown in Table 4.

Table 4: Some results of the 'Base City' simulation

| | | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 |
|---|--------------|-----------------|----------------------------------|-----------|---------|---------|
| Rent [$\$/\text{m}^2/\text{year}$] | | 70.06 | 110.03 | 159.28 | 110.03 | 70.06 |
| Wage | low-skilled | 11.56 | 11.34 | 11.26 | 11.34 | 11.56 |
| | high-skilled | 23.62 | 23.08 | 22.70 | 23.08 | 23.62 |
| Price [$\$/\text{unit}$] | | 108.72 | 116.99 | 125.00 | 116.99 | 108.72 |
| Output/resident [units/year] | | 42.24 | 37.98 | 33.09 | 37.98 | 42.24 |
| Shopping/resident [units/year] | | 27.18 | 23.99 | 20.00 | 23.99 | 27.18 |
| Jobs | low-skilled | 154,906 | 153,197 | 146,794 | 153,197 | 154,906 |
| | high-skilled | 66,466 | 65,758 | 62,552 | 65,758 | 66,466 |
| Location decision [% HH of HH-Typ y] | | | | | | |
| SNW | | 31.6 | 14.7 | 7.4 | 14.7 | 31.6 |
| CNW | | 29.7 | 15.9 | 8.8 | 15.9 | 29.7 |
| SW | low-skilled | 28.3 | 17.0 | 9.4 | 17.0 | 28.3 |
| | high-skilled | 28.5 | 16.9 | 9.2 | 16.9 | 28.5 |
| HoTW | low-skilled | 25.8 | 18.4 | 11.6 | 18.4 | 25.8 |
| | high-skilled | 26.3 | 18.1 | 11.2 | 18.1 | 26.3 |
| HeTW | | 27.0 | 17.7 | 10.6 | 17.7 | 27.0 |
| Income [$\$/\text{year}$] | | | Housing [lot size m^2] | | | |
| SNW | | 23,203 | | 46 - 104 | | |
| CNW | | 46,405 | | 81 - 186 | | |
| SW | low-skilled | 19,655 - 19,964 | | 44 - 99 | | |
| | high-skilled | 38,024 - 39,110 | | 92 - 205 | | |
| HoTW | low-skilled | 35,522 - 37,182 | | 74 - 158 | | |
| | high-skilled | 69,591 - 73,181 | | 155 - 335 | | |
| HeTW | | 54,015 - 55,414 | | 115 - 255 | | |

The supply of developable land is inelastic in the urban area. It increases with distance from the city center, i.e. zone 3. The central location is relatively attractive for households and firms due to good accessibility. This is the reason why rents decline steeply with distance

from the center. In contrast, the wage gradient is almost flat since labor is very mobile. Because commodity prices depend on both, rents and wages, the price gradient is steeper than the wage gradient but flatter than the rent gradient.

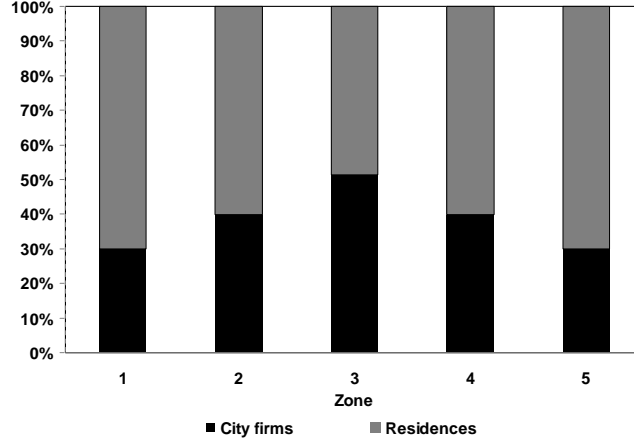


Figure 2: Land use pattern in the 'Base city'

The prices affect and reflect the land use pattern of firms and households which is displayed in Figure 2. Although production and selling take place everywhere in the city, land use for production and selling is higher in the central district. Residential land use shows the opposite pattern. In the suburbs, i.e. zones 1 and 5, 70 % of the developable land area is allocated to housing. Nonetheless, land is used more intensely in the city center: population density as well as employment density decrease with distance from the center as shown in Figure 3. Here, gross residential (employment) density in zone i is measured as the ratio of the number of residents (workers) in this zone to the developable total land area in that zone i . Net residential (employment) density is measured as the ratio of the number of residents (workers) in a zone i to the land in that zone i developed for residences (production/selling). Net residential (employment) density falls from 2.0 residents (2.7 workers) per 100 m² to 0.9 residents (1.1 workers) in the edge zones.

In the 'Base City' average one-way commuting time per worker is about 23.5 minutes per working day. This is close to average daily commuting time in the U.S. which is about

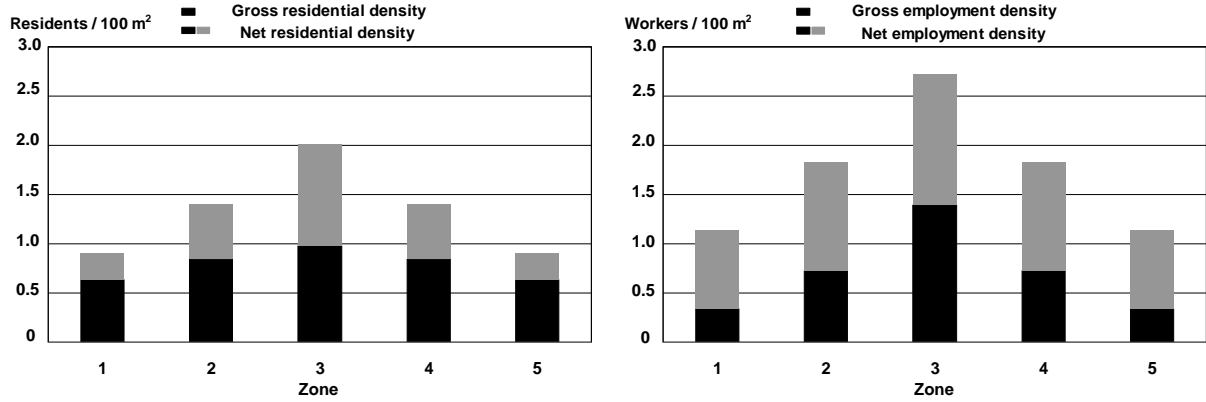


Figure 3: Residential and employment density

24.3 minutes in 2003 (U.S. Census Bureau, 2005a). Average monetary commuting (shopping trip) cost is \$1315 per worker and year (\$1104 per resident and year). Average full economic commuting (shopping trip) cost is \$2967 per worker and year (\$2150 per resident and year).

When one considers different household types, a more differentiated pattern emerges. For instance, 48% of all households centrally located are singles compared to 52% of larger households.¹³ In general, working singles are able to lowering full economic commuting cost by residing near their working place. Since they can work in each district there is no need to live only in the center. Hence, single-worker households (SW) commute on average shorter distances than other household types (see Table 5). In contrast, due to idiosyncratic tastes work locations of household members of many two-worker households are located in different districts. Since these households are limited in their abilities to locate near both work places, they face higher average commuting distances (see Table 5). Hence, on average the attraction force of the work location is weaker and they choose more centralized locations. Furthermore, the city center is even less attractive for non-working households. Since full economic commuting costs do not influence their location decision, the centrifugal force of

¹³In the U.S., the share of larger households centrally located is higher in largely white metro areas (Center on Urban & Metropolitan Policy, 2002). Non-family households, e.g. singles, were the fastest growing household type in major metropolitan suburbs in the 1990s. So household types traditionally associated with more central locations are becoming more common in suburbs.

Table 5: Average two-way commuting distance in the 'Base City'

| | | Average two-way commuting distance [km] | |
|------|--------------|---|----------------------|
| | | Household member f | Household member m |
| SW | low-skilled | 18.3 | - |
| | high-skilled | 21.8 | - |
| HoTW | low-skilled | 24.7 | 24.7 |
| | high-skilled | 26.8 | 26.8 |
| HeTW | | 31.5 | 22.5 |

housing demand is more important and they prefer more decentralized locations. The percentage of non-working households living in the city center is lower compared to households with working city residents (see Table 4). Interestingly, concerning single-worker and homogeneous two-worker households, average commuting distances of low-skilled workers are lower compared to high-skilled workers. What are the reasons for this? On the one hand, the wage and thus the value of time of a low-skilled worker is lower. Therefore, the worker is willing to accept longer commuting trips. On the other hand, income of a low-skilled worker is lower. Hence, monetary commuting cost takes up a larger fraction of income, forcing the worker to travel shorter distances.¹⁴ In our case the latter effect is dominant and the lower income worker commutes shorter distances (for empirical evidence see e.g. Kim, 1995).

In addition, there are some major differences between homogeneous and heterogeneous two-worker households.

In a homogeneous household, both working members face the same value of time. For this reason, this household is not able to reduce aggregate full economic commuting cost by re-locating. Rather, the household is indifferent between all locations lying in between both

¹⁴In the 'Base City' the low-skilled single-worker spends on average about 6.5% of income on commuting. This is more compared to all the other workers in the city. In comparison, in the U.S. the median percentage of personal income spent on commuting is 5.6 (U.S. Department of Transportation, 2003) with respect to income group \$15,000–\$21,999. This income group is equivalent to the income group of the low-skilled single-worker households in the 'Base City'. Furthermore, the high-skilled single-worker spends on average about 3.9% of income (\$38,024–\$39,110, see Table 4) on commuting. In comparison, in the U.S. the median percentage of personal income spent on commuting is 4.2 with respect to income group \$30,000 to \$40,999.

working places. In addition, concerning the low-skilled household, aggregate monetary commuting costs take up a large fraction of joint income. Concerning the high-skilled household, both household members value commuting time at a high rate. As a consequence, homogeneous two-worker households are more centrally located. Table 4 shows that the percentage of the low-skilled homogeneous households living in the center is the highest, 11.6, followed by the percentage of the high-skilled homogeneous households which is 11.2. In contrast, aggregate full economic commuting costs of a heterogeneous household depend on its location. This household comprises a high-skilled and a low-skilled worker. Since both face different wages and thus a different value of time, the household can benefit from internal division of labor. Its aggregate income increases if the high-wage member works more. As a consequence, the low-wage member is working less on the labor market but more in household production, i.e. is doing more shopping activities (see below). This low-skilled member is working even less than any other group of workers in the city. These labor supply behaviors are reflected by the number of commuting trips. The high-skilled member of the heterogeneous household commutes on average 280 times per year, i.e. he is doing 280 working shifts, which is more than any other group of workers.¹⁵ On account of this labor division, the heterogeneous household can lower full economic commuting cost by residing closer to the working place of its high-wage member. As a result (see Table 5), the average two-way commuting distance of the high-skilled member of this household type is on average lower (22.5 km), compared to the low-skilled member (31.5 km). So, we generalize the results of White (1977),¹⁶ found in a partial equilibrium approach, to the case of a general equilibrium model of a dispersed urban area including spatial taste variety in shopping, endogenously determined supply of working days and interactions between different markets and household types.

¹⁵Based on the assumption of 220 operating days with 16 hours per day and 8 hours per working day, theoretical number of commuting trips is 440. But this number can not be realized in practice because each commuting trip requires travel time and total time constraint must hold.

¹⁶White found that if the wage of the better earning member (the male worker in her model) in the two-worker household is sufficiently high relative to the wage of the other member, the two-worker household would be willing to reside nearer to the work location of the better earning member (which is the city center in her model). Then, the better earning member can reduce commuting time, even though this caused increasing commuting time for the other member (the female with a exogenously given suburban work location) and the payment of a premium for a central location.

Summing up, heterogeneous two-worker households are more likely to live farther away from the central district compared to homogeneous two-worker households.¹⁷ As can be seen in Table 4, 10.6% of the heterogeneous two-worker households prefer residing in the city center, which is only more preferred by homogeneous two-worker households.

In addition, specialization in shopping is another important issue arising when considering a complex household structure. Let us consider Table 6 which presents average full economic shopping cost (per unit, trip and person), i.e. the average full consumer price, of homogeneous and heterogeneous two-worker households.

Table 6: Economies of scale in shopping

| | | Average full economic shopping price per person [\$/unit/trip/person] | | | | |
|----------------------|--------------|--|--------|--------|--------|--------|
| Two-Worker Household | | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 |
| Homogeneous | low-skilled | 127.39 | 132.89 | 140.56 | 132.89 | 127.39 |
| | high-skilled | 133.58 | 139.68 | 148.08 | 139.68 | 133.58 |
| Heterogeneous | | 130.50 | 136.41 | 144.53 | 136.41 | 130.50 |

Because the household member with the lower value of time, i.e. the low-skilled member, is specializing in shopping, the heterogeneous household faces lower average full economic shopping cost than a homogeneous household with two high-skilled members. But, remember the assumption that shopping trips within a household are imperfect substitutes. This is the reason why even the high-wage member of the heterogeneous household is doing some shopping. As a consequence, average full economic shopping cost of this household type is higher compared to the average full consumer price of a homogeneous household with only

¹⁷Using a Logit model, Freedman and Kern (1997) found that a wife living in a two-worker household working full time at an uninterrupted professional career (like the husband) substantially increases the probability of choosing a central city location compared to a two-worker household with a wife working at an interrupted non-professional career (in contrast to the husband). However, they argued that it would be interesting to use a general equilibrium approach to see whether the effect remains the same. In fact, our general equilibrium approach indirectly yields the same result. Assuming that the wife working at an interrupted non-professional career is the lower skilled (not full time working) member in the heterogeneous two-worker household, the probability of choosing a central city location is higher for a homogeneous two-worker household (where both members working full time at an uninterrupted professional career).

low-skilled members. In contrast, since both members of the homogeneous household face the same value of time, homogeneous households would not benefit from specialization in shopping.¹⁸

In the following we simulate a number of cities which differ in the household structure, discuss the results and compare them to the 'Base City' simulation. This provides various interesting relationships between the household structure and the urban economy.

4 Other cities: results

The cities we consider in our simulations differ in the household structure, i.e. they differ in the average household size, the composition of household types, the relative share of different household types and the number of households. However, the total city population as well as the proportion of low-skilled and high-skilled persons in the city remain unchanged. This allows us to focus on the pure effects of differences in the household structure. Table 7 gives the household structure for the different simulations we carried out.

Table 7: Simulation scheme

| City | | Workers living in | | | Non-Workers living in | | City HH | [1] |
|------|----------------|-------------------|------|------|-----------------------|-----|-----------|------|
| | | SW | HoTW | HeTW | SNW | CNW | [million] | |
| | | Household [%] | | | Household [%] | | | |
| 1 | 'Singles City' | 100 | 0 | 0 | 100 | 0 | 1.480 | 1.00 |
| 2 | | 80 | 10 | 10 | 80 | 20 | 1.332 | 1.11 |
| 3 | | 60 | 20 | 20 | 60 | 40 | 1.184 | 1.25 |
| 4 | | 40 | 30 | 30 | 40 | 60 | 1.036 | 1.43 |
| 5 | 'Base City' | 36 | 30 | 34 | 33 | 67 | 1.000 | 1.48 |
| 6 | | 20 | 40 | 40 | 20 | 80 | 0.888 | 1.67 |
| 7 | 'Couples City' | 0 | 50 | 50 | 0 | 100 | 0.740 | 2.00 |

Note: [1]: Average household size [Adult city residents per household]

| | | |
|---------------------|----------------------------------|-------------------------------|
| In all simulations: | Total city population: 1,480,000 | Non-working persons: 390,000 |
| | Low-skilled persons: 763,000 | High-skilled persons: 327,000 |

¹⁸However, when modeling mode choice with different mode availability, the value of time might differ even in a homogeneous two-worker household.

Simulation 1 denotes the 'Singles City', consisting only of single-person households which are either non-working or working. In this 'Singles City' the total number of households is the highest and equals the total number of city residents, whereas average household size is the lowest. In contrast, in the 'Couples City', where all non-working residents live in non-working couple households and the whole labor force lives only in two-worker households, the total number of households is the lowest, whereas average household size is the highest. Note that we do not consider children in our simulation. Taking children (dependents) explicitly into account, average household size in Table 7 would be higher.

Table 8: Changes in rents, wages, prices, output, shopping

| | Zone 1 or 5 | Zone 2 or 4 | Zone 3 |
|---------------------------------------|-----------------|------------------|-----------------|
| Rent [$\$/\text{m}^2/\text{year}$] | | | |
| 'Singles City' | 76.46 (+9.14 %) | 116.89 (+6.23 %) | 165.78 (+4.08%) |
| 'Couples City' | 66.76 (-4.71%) | 107.00 (-2.75%) | 156.84 (-1.53%) |
| Wage - low-skilled [$\$/\text{h}$] | | | |
| 'Singles City' | 8.72 (-24.57%) | 8.63 (-23.90%) | 8.63 (-23.36%) |
| 'Couples City' | 12.81 (+10.81%) | 12.42 (+9.52%) | 12.23 (+8.61%) |
| Wage - high-skilled [$\$/\text{h}$] | | | |
| 'Singles City' | 28.46 (+20.49%) | 27.85 (+20.67%) | 27.56 (+20.82%) |
| 'Couples City' | 22.26 (-5.76%) | 21.78 (-5.63%) | 21.54 (-5.57%) |
| Prices [$\$$] | | | |
| 'Singles City' | 109.04 (+0.29%) | 117.10 (+0.09%) | 125.00 |
| 'Couples City' | 108.70 (-0.02%) | 117.01 (+0.02%) | 125.00 |
| Output/resident [units/year] | | | |
| 'Singles City' | 42.49 (+0.59%) | 38.34 (+0.95%) | 33.47 (+1.14%) |
| 'Couples City' | 41.92 (-0.75%) | 37.71 (-0.71%) | 32.88 (-0.66%) |
| Shopping/resident [units/year] | | | |
| 'Singles City' | 26.72(-1.71%) | 23.65(-1.39%) | 19.71 (-1.42%) |
| 'Couples City' | 27.20 (+0.07%) | 24.03 (+0.19%) | 20.07 (+0.39%) |

Note: In parentheses: Changes in relation to 'Base City'

As Table 8 shows, in the 'Singles City' rents are higher everywhere, whereas in the 'Couples City' rents are lower compared to the 'Base City'. The reason for this is that economies of scale in housing disappear (arise) when the city turns into a pure 'Singles City' ('Couples

City’). Hence, the demand for housing increases with a growing number of singles in the city, while the supply of developable land is perfectly inelastic.

The development of wage rates is different with respect to the skill level. While the wage rate for high-skilled workers increases when the city turns into a pure ‘Singles City’, the wage rate for low-skilled workers decreases significantly. This is caused by the change in urban labor supply which is displayed in Figure 4. Note that the letters ‘A’ or ‘B’ in this and the subsequent Figure refer to sensitivity analyses we performed (see the next section).

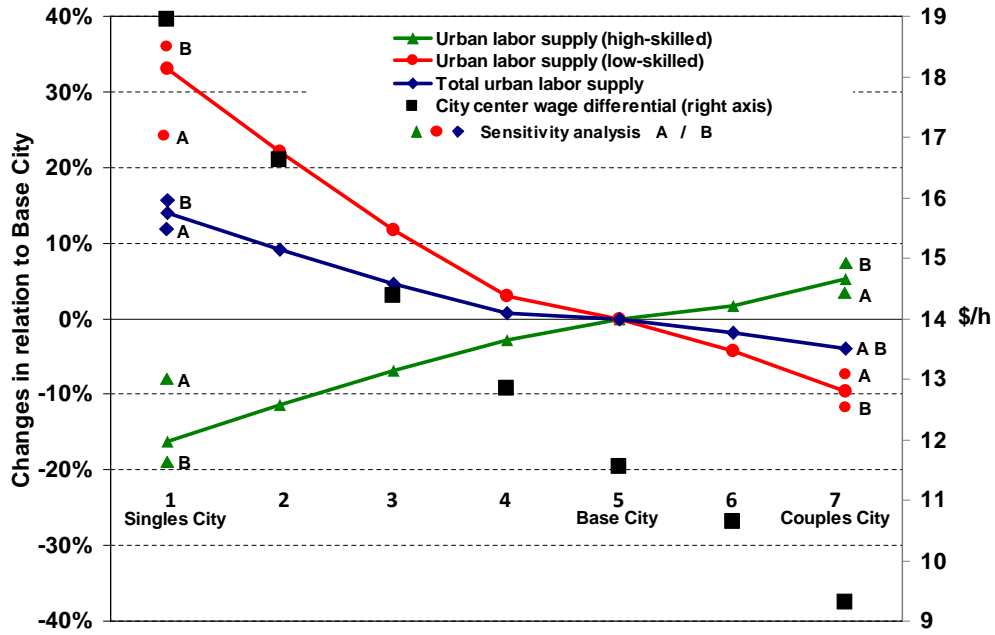


Figure 4: Changes in urban labor supply

If more workers live in single-person households the supply of low-skilled labor, measured in working days per year, increases but the supply of high-skilled labor decreases. The reason is that internal labor division is not feasible for a single-person household. Therefore, low-skilled singles work more while high-skilled singles work less compared to equivalent individuals living in larger households. All in all in the simulations urban labor supply of low-skilled workers rises by 33% compared to the ‘Base City’ when the city turns into a ‘Singles City’, while labor supply of high-skilled workers drops by 16%. The maximum number of

commutes (=working shifts) is 221 in the 'Singles City', now realized by the lower-skilled worker. In contrast, in the 'Couples City' the maximum number of commutes (=working shifts) is 270. Here realized by the higher-skilled worker. Moreover, there is a remarkable increase in the urban wage differential between skill levels. The wage differential in the city center nearly doubles from \$9.31 to \$18.93 when the city turns from the 'Couples City' into the 'Singles City'. As a consequence, inequality between skill groups rises remarkably. Interestingly, the maximal number of commutes realized by a working city resident is the highest in the 'Base City'. If there are only households with more than one member in the city, wage differential is the lowest. Hence, the incentive for internal labor division decreases in heterogeneous two-worker households. To sum up: the household structure affects urban labor force participation of differently skilled workers and thus city wages (and vice versa).

Commodity prices remain almost unaffected. This can be explained by considering input costs which are reflected by prices. There is a strong increase in rents and high-skilled wages when moving to the 'Singles City' which is evidently offset by the reduction in low-skilled wages.

Commuting and shopping patterns are also affected by differences in the household structure. Figure 5 depicts changes in the number of extreme cross commuters, where extreme cross commuting is defined as commuting from zone 1 (5) to Zone 5 (1), thus, crossing the whole city. The number of commuters doing extreme cross commuting drops by 62% to almost zero when moving from the 'Basic City' to the 'Singles City'. Here, extreme cross commuters amount to a percentage of only 1.88 of all commuters, whereas this percentage is 5.01 in the 'Base City'.¹⁹ In the 'Singles City' the average two-way commuting distance is 5.2 kilometers lower than in the 'Base City'. Consider a heterogeneous household whose joint residential location decision takes into account work locations of both household members. Since full economic commuting costs of the higher-skilled member exceed full economic commuting

¹⁹For comparison only, the share of workers of age 16 and higher doing extreme commuting (> 90 minutes according to the U.S. Census Bureau (2005b) for some cities is as follows: Baltimore 5.6%, New York 5.6%, Los Angeles 3%.

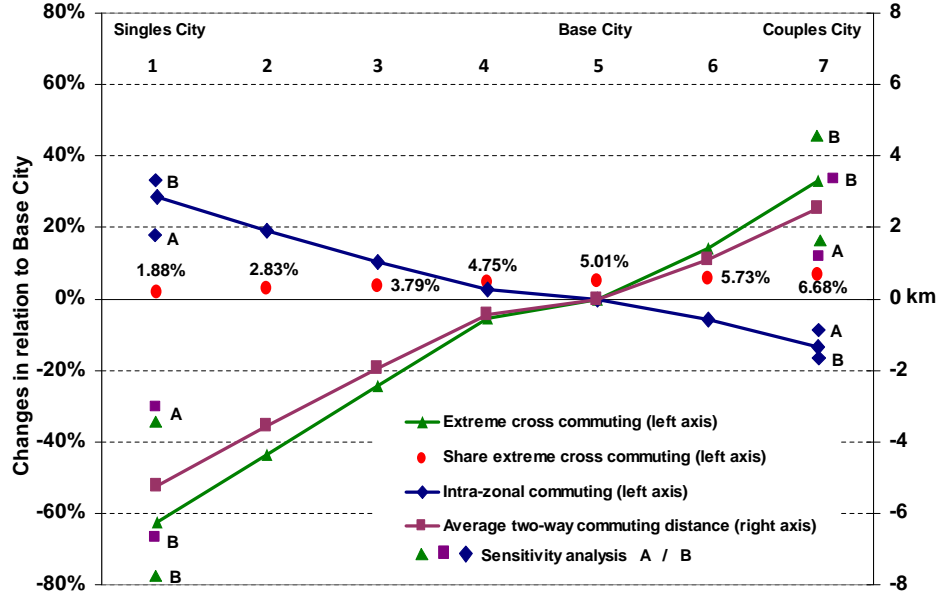


Figure 5: Changes in commuting patterns

costs of the lower-skilled member, the household primarily wants to reduce the commuting distance of the higher-skilled member. The work location of the lower-skilled member is less important and joint household utility is less sensitive with respect to that work location. This induces a higher extent of extreme commuting. In contrast, if there are only singles in the city, utility is very sensitive with respect to each joint work-home location decision. Therefore, the share of extreme commuting is smaller in the 'Singles City'. In addition, the number of commuters doing intrazonal commuting (home zone = work zone) is by about 28% higher in the 'Singles City' compared to the 'Base City'.

Changes in total commuting trips per year (total number of commutes made by all workers) are shown in Table 9. The number of intrazonal commuting trips per year is significantly higher in the 'Singles City'. This results from two effects: the increase in total urban labor supply (Figure 4) and the increase in the number of intrazonal commuters (Figure 5). Consequently, the average one-way commuting time of working household members is only about 18.3 minutes per day compared to 23.5 minutes in the 'Base City'. In the 'Couples City', the reverse pattern occurs: the number of intrazonal commuting trips per year is lower.

Table 9: Changes in commuting trips in percent

| | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 |
|--------|---------------|---------------|---------------|---------------|---------------|
| Zone 1 | +28.4 (-12.6) | +19.3 (-7.6) | +0.6 (+0.7) | -19.9 (+11.7) | -33.8 (+22.3) |
| Zone 2 | +10.2 (-1.6) | +28.1 (-10.0) | +15.9 (-3.5) | -8.1 (+8.6) | -26.5 (+17.6) |
| Zone 3 | -13.4 (+13.9) | +7.9 (+0.8) | +33.0 (-10.3) | +7.9 (+0.8) | -13.4 (+13.9) |
| Zone 4 | -26.5 (+17.6) | -8.1 (+8.6) | +15.9 (-3.5) | +28.1 (-10.0) | +10.2 (-1.6) |
| Zone 5 | -33.8 (+22.3) | -19.9 (+11.7) | +0.6 (+0.7) | +19.3 (-7.6) | +28.4 (-12.6) |

Note: In parentheses: 'Couples City' changes in relation to 'Base City'

Changes in the total number of shopping trips per year made by all city residents are shown in Table 10.

Table 10: Changes in shopping trips in percent

| | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 |
|--------|-------------|-------------|-------------|-------------|-------------|
| Zone 1 | +3.6 (-1.2) | +1.5 (-1.0) | -1.3 (-0.5) | -3.9 (-0.2) | -5.9 (+0.1) |
| Zone 2 | -3.4 (+1.1) | +0.9 (+0.6) | -2.0 (+1.0) | -5.7 (+1.2) | -8.3 (+1.4) |
| Zone 3 | -9.2 (+2.6) | -5.4 (+2.3) | -0.5 (+2.0) | -5.4 (+2.3) | -9.2 (+2.6) |
| Zone 4 | -8.3 (+1.4) | -5.7 (+1.2) | -2.0 (+1.0) | +0.9 (+0.6) | -3.4 (+1.1) |
| Zone 5 | -5.9 (+0.1) | -3.9 (-0.2) | -1.3 (-0.3) | +1.5 (-1.0) | +3.6 (-1.2) |

Note: In parentheses: 'Couples City' changes in relation to 'Base City'

Compared to the 'Base City', the number of shopping trips originating in the city center is smaller in the 'Singles City' and larger in the 'Couples City', reflecting the centralizing advantage the city center provides for two-worker households. Furthermore, in the 'Couples City' more shopping trips are made to stores farther away from home. Two-worker households economize on full economic shopping costs by internal partitioning of shopping trips. This allows them to satisfy their spatial taste variety in shopping on a larger scale. In contrast, in the 'Singles City' less trips are made to locations farther away from home. The reasons for this are: first, economizing on full economic shopping cost is not possible because each single person has to do shopping trips on its own; second, in the 'Singles City' all low-skilled workers live in single-person households and suffer from lower wages associated with a smaller disposable income. As a consequence, in the 'Singles City' monetary transport

costs take up a large fraction of income, i.e. 10% if living in the city center and 13% if living in zone 1 or 5. These are the highest numbers compared to all the other households in all simulations. This lowers the willingness to purchase commodities at stores farther away from home. Accordingly, average distance travelled for shopping decreases with an increase in the number of single-person households.

Summarizing the impact of changes in the household structure on the spatial pattern of commuting and shopping, we found in regard to both trip purposes: an increase in the number of single-person households *ceteris paribus* lowers average distance travelled by workers (commuting) and residents (shopping). However, concerning the total distance travelled per period there is a considerable difference (see Figure 6).

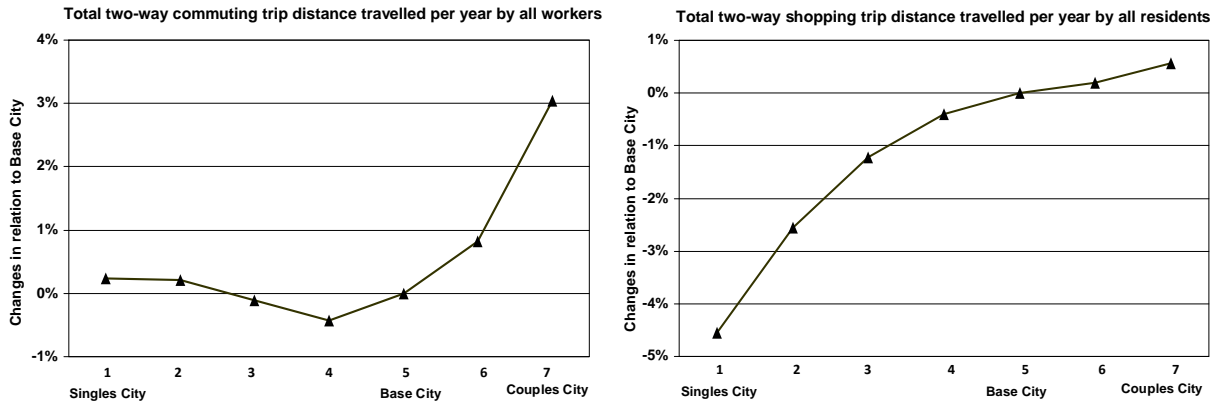


Figure 6: Changes in total travelled distances

In the 'Couples City' total two-way commuting distance travelled by all workers per year is the highest (about 4,000 million kilometers). Total kilometers travelled decrease with an increase in the number of single-person households up to the point where 40 percent of all workers live in single-worker households (city simulation 4). One reason is that the number of extreme cross commuters decreases with an increase in the number of single-person households (see Figure 5). Beyond the threshold of 40% of workers living as single-persons, the total commuting distance travelled by all workers per year increases. This in turn is conditional on the increase in the total labor force participation (total urban labor supply)

caused by the growth in the number of single-person households (see Figure 4). So, there is a trade off between a decline in extreme cross commuting and a rise in the total labor force participation. While the former is dominant if less than 40% of all workers live in single-person households (or if more than 60 % of all workers live in larger households), the latter dominates if more than 40% of all workers live in single-person households. As a result, total kilometers travelled by all workers in the city are higher in the 'Singles City' as well as in the 'Couples City', but even more in the latter. However, with respect to the trip purpose shopping, there is no difference in the development between average and total distance travelled. As shown on the right panel in Figure 6, the run of the curve tends downwards, starting from the 'Couples City'.

Finally, these results are also reflected by changes in average monetary commuting and shopping trip costs in comparison with the 'Base City'. In the 'Singles City' average monetary commuting cost is about \$1318 per worker and year which is only \$3 more. Average monetary shopping trip cost is about \$1063 per resident and year which is \$41 less. In the "Couples City" average monetary commuting cost is about \$1355 per worker and year and thus \$40 higher. Average monetary shopping trip cost are about \$1120 per resident and year, which is \$16 more than in the 'Base City'.

5 Robustness: sensitivity analyses

In addition to the simulations discussed above (base case) Figure 4 and the subsequent Figure 5 also depict some results of the sensitivity analyses we performed (see Appendix A for sensitivity analyses A and B). We varied some parameters determining individual behavior: the parameter determining the taste for spatial variety in shopping, η ; the parameter affecting the distribution of shopping activities in larger households, ω ; the parameter determining the preference to spread leisure over both household members, ρ ; and the parameter Λ which reflects the taste heterogeneity concerning a specific location choice set.

In *sensitivity analysis A*, parameter values are lowered ($\eta = 0.1$, $\omega = 0.2$, $\rho = -0.5$, $\Lambda = 5$). This implies that responses to prices are less important while taste heterogeneity becomes more important. Hence, deterministic utility becomes less important and the probability to choose a specific location is less sensitive to economic effects. An alternative interpretation is that more households are willing to accept a location choice set associated with a lower deterministic utility level, because stronger "hidden" tastes make this location more preferable compared to other locations.

In *sensitivity analysis B*, parameters influencing responses to prices are increased compared to the base case ($\eta = 0.9$, $\omega = 0.99$, $\rho = 0.5$, $\Lambda = 15$). Therefore, price based behavior becomes more important in relation to taste heterogeneity. Hence, deterministic utility components become more important and the probability to choose a specific location is more sensitive to economic effects.

Performing sensitivity analyses A and B hardly affects the results qualitatively concerning changes in urban labor supply (see Figure 4), commuting patterns (see Figure 5) as well as commuting and shopping trips (see Appendix A) found in the base case. There are only some changes in the magnitude of effects. This suggests that the effects of changes in the household structure are robust with respect to changes in parameters of individual behavior. However, some notable results occur with respect to changes in total distance travelled (see Figure 7).

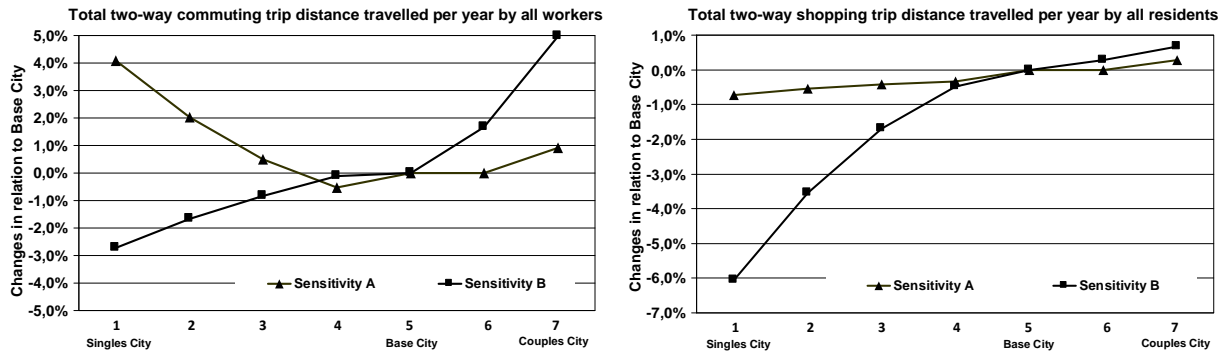


Figure 7: Changes in total travelled distances (Sensitivity analysis)

In sensitivity analysis A, the reversal in total commuting distance travelled by all city workers occurring when moving to the 'Singles City' is strengthened. Since in this simulation households location choice is less responsive to changes in the household structure, households do not relocate to reduce full economic commuting costs. Hence, cross commuting declines much less than in the base case. Instead, the increase in total urban labor supply dominates and thus the aggregate travel distances increase to the left of the 'Base City' (see the left panel in Figure 7). In contrast, in sensitivity analysis B, the number of commuters doing extreme cross commuting as well as the number of extreme commuting trips drop much more when more city workers live in single-person households. Since this is dominant the total commuting distance falls almost continuously when moving to the 'Singles City'.

Regarding shopping costs, the run of the curve of total shopping distances travelled by all city residents per year is basically the same in sensitivity analyses A and B. However, the decrease is less strong in simulation A. In the 'Base City' of sensitivity analysis A, both household members want doing shopping trips due to a strong taste for splitting shopping trips. Hence, the effect of economizing on full economic shopping cost is less strong. When more residents live in single-person households, the only household member is also doing shopping trips on its own. In sensitivity analysis B, the incentive to reduce travelling concerning shopping is even larger than in the base case implying a reduction in total shopping trip distances travelled per year by all residents.

6 Model extensions, applications and conclusions

We have analyzed the impacts of changes in the household structure on an urban economy by applying an urban model which explicitly considers a complex household structure. Besides the usually assumed single-worker household, we have implemented non-working single and couple households as well as homogeneous and heterogeneous two-worker households. The households differ not only in endowments and preferences, but also in size and the composition regarding their members. We found that first, changes in the household structure ceteris

ceteris paribus affect a city in various ways and second, the impacts of such changes are closely linked and interdependent.

Changing the urban household structure affects the labor force participation. Urban labor supply of lower-skilled workers increases while labor supply of higher-skilled workers decreases when the number of single-person households rises in the city, associated with a remarkable increase in the urban wage differential. Indeed, an increase in wage inequality has been a feature of the U.S. labor market for decades. As has been demonstrated, changes in the household structure can also contribute to wage inequality within an urban economy.

Furthermore, housing demand and rents in the city are key features of the effects of changes in the household structure. Housing demand increases with an increase in the number of single-person households implying rising city rents. The reason for this is that economies of scale in housing cannot be realized in smaller households. Hence, overall housing demand increases substantially when moving to a 'Singles City'. Rent changes are stronger in the suburbs (see Table 8), reflecting the fact that the centralizing effect of the city center becomes less important when more city residents live as single persons. Indeed, in the U.S., smaller household types traditionally associated with more central residential locations are becoming more increasingly common in suburbs (Center on Urban & Metropolitan Policy, 2002).

In addition, urban commuting and shopping patterns depend on household structure. Extreme cross commuting drops, while intrazonal commuting rises when more workers live alone. This ceteris paribus results in lower average commuting distances travelled. Moreover, in cities with a higher number of single-person households less trips are made to shopping locations farther away from home.

However, there is some evidence that average commuting time and distance have not decreased over the last decades, although average household size did decline. This suggests that, besides the household structure, there are further effects influencing average commuting time and distance. For instance, it would be interesting to see whether considering a variable city size would increase average commuting time and distance, although average

household size in the city decreases.

Implementing such a differentiated household structure allows studying a broad range of further urban economic issues. The model could be applied to various policies that arise in today's cities. However, some issues can only be examined in the case of appropriate model extensions. For instance, trip chaining is ignored in this model version, as in most urban models so far, except for Anas (2007). But, especially in the case of two-worker households, trip chaining can increase household utility. Assuming that both household members are employed at different locations. Then, they can satisfy their love for spatial product variety by shopping trips that directly originate at work location. Or, travel times can be modeled such that they depend on traffic volume (see Anas and Xu, 1999). The implementation of mode choice would allow considering mode availability within households. This can influence full economic commuting and shopping costs. As a result, for instance, location decisions, commuting and shopping patterns and labor supply decisions of household members can differ due to differences in full economic travel costs, even in homogeneous two-worker households.

In addition, the modeling of children offers the opportunity to examine various interesting issues. Children influence labor force participation of parents and, probably also the location decision of the household (see e.g. Sermons and Koppelman, 2001). For instance, the locations of private schools and child care facilities might influence the joint residential as well as the work location decision of household members in the urban area. Assuming children in the household, the low-skilled member of a heterogeneous two-worker household might even commute shorter distances on average due to household responsibilities.

Furthermore, due to the fact that income tax schemes treat different households differently, the effects of national or, if there is tax autonomy, of local fiscal policies on an urban economy can be examined by implementing taxation. Since wages are endogenously determined in the model, income tax rates can influence labor decisions and thus wages in the city. This in turn can affect location decisions. These and further aspects are left for future work.

Appendix-A: Sensitivity Analysis

Table 11: Some results of the 'Base City' simulation - Sensitivity Analysis A

| Parameters | | SNW | CNW | SW $\forall h$ | HoTW $\forall h$ | HeTW |
|--|--------------|---------|--------------------|----------------|------------------------------------|---------|
| η | | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| ω | | - | 0.2 | - | 0.2 | 0.2 |
| ρ | | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 |
| Λ | | 5 | 5 | 5 | 5 | 5 |
| | | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 |
| Rent [\$ / m ² / year] | | 59.20 | 107.43 | 176.78 | 107.43 | 59.20 |
| Wage | low-skilled | 10.15 | 9.85 | 9.80 | 9.85 | 10.15 |
| | high-skilled | 24.93 | 24.39 | 24.27 | 24.39 | 24.93 |
| Price [\$ / unit] | | 102.91 | 113.64 | 125.00 | 113.64 | 102.91 |
| Output/resident [units] | | 39.29 | 36.80 | 33.79 | 36.80 | 39.29 |
| Shopping/resident [units] | | 23.74 | 22.71 | 20.99 | 22.71 | 23.74 |
| Jobs | low-skilled | 149,647 | 154,187 | 155,332 | 154,187 | 149,647 |
| | high-skilled | 63,995 | 66,115 | 66,780 | 66,115 | 63,995 |
| Location decision [% HH of HH-Type y] | | | | | | |
| SNW | | 28.0 | 16.8 | 10.4 | 16.8 | 28.0 |
| CNW | | 26.6 | 17.5 | 11.8 | 17.5 | 26.6 |
| SW | low-skilled | 25.4 | 18.4 | 12.4 | 18.4 | 25.4 |
| | high-skilled | 25.7 | 18.2 | 12.2 | 18.2 | 25.7 |
| HoTW | low-skilled | 24.0 | 19.1 | 13.8 | 19.1 | 24.0 |
| | high-skilled | 24.4 | 18.8 | 13.6 | 18.8 | 24.4 |
| HeTW | | 24.6 | 18.7 | 13.4 | 18.7 | 24.6 |
| | | | Income [\$ / year] | | Housing [lot size m ²] | |
| SNW | | | 21,531 | | 38 - 114 | |
| CNW | | | 43,061 | | 68 - 205 | |
| SW | low-skilled | | 16,730 - 17,295 | | 34 - 96 | |
| | high-skilled | | 38,221 - 40,711 | | 87 - 248 | |
| HoTW | low-skilled | | 30,688 - 32,432 | | 57 - 155 | |
| | high-skilled | | 70,851 - 76,386 | | 148 - 413 | |
| HeTW | | | 50,626 - 54,484 | | 102 - 284 | |

Table 12: Some results of the 'Base City' simulation - Sensitivity Analysis B

| Parameters | | SNW | CNW | SW $\forall h$ | HoTW $\forall h$ | HeTW |
|--|--------------|-------------------|---------|----------------|------------------------------------|---------|
| η | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| ω | | - | 0.99 | - | 0.99 | 0.99 |
| ρ | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Λ | | 15 | 15 | 15 | 15 | 15 |
| | | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 |
| Rent [\$ /m ² /year] | | 81.21 | 111.87 | 145.26 | 111.87 | 81.21 |
| Wage | low-skilled | 12.51 | 12.21 | 12.03 | 12.21 | 12.51 |
| | high-skilled | 23.75 | 23.03 | 22.57 | 23.03 | 23.75 |
| Price [\$ /unit] | | 115.43 | 120.32 | 125.00 | 120.32 | 115.43 |
| Output/resident [units] | | 48.59 | 37.87 | 29.28 | 37.87 | 48.59 |
| Shopping/resident [units] | | 34.40 | 24.26 | 16.18 | 24.26 | 34.40 |
| Jobs | low-skilled | 168,046 | 148,365 | 130,178 | 148,365 | 168,046 |
| | high-skilled | 73,755 | 63,163 | 53,164 | 63,163 | 73,755 |
| Location decision [% HH of HH-Type y] | | | | | | |
| SNW | | 32.7 | 14.0 | 6.6 | 14.0 | 32.7 |
| CNW | | 32.8 | 15.2 | 8.0 | 15.2 | 32.8 |
| SW | low-skilled | 30.1 | 15.8 | 8.2 | 15.8 | 30.1 |
| | high-skilled | 30.5 | 15.6 | 7.8 | 15.6 | 30.5 |
| HoTW | low-skilled | 26.7 | 17.9 | 10.8 | 17.9 | 26.7 |
| | high-skilled | 27.6 | 17.4 | 10.0 | 17.4 | 27.6 |
| HeTW | | 28.5 | 16.8 | 9.4 | 16.8 | 28.5 |
| | | Income [\$ /year] | | | Housing [lot size m ²] | |
| SNW | | 24,934 | | | 54 - 96 | |
| CNW | | 49,867 | | | 96 - 171 | |
| SW | low-skilled | 21,698 - 21,973 | | | 53 - 96 | |
| | high-skilled | 40,017 - 40,420 | | | 102 - 183 | |
| HoTW | low-skilled | 39,355 - 40,330 | | | 88 - 152 | |
| | high-skilled | 73,148 - 74,854 | | | 170 - 295 | |
| HeTW | | 58,230 - 58,683 | | | 131 - 236 | |

Table 13: Changes in rents, wages, prices, output, shopping - Sensitivity analysis A

| | Zone 1 or 5 | Zone 2 or 4 | Zone 3 |
|---------------------------------------|-----------------|-----------------|-----------------|
| Rent [$\$/\text{m}^2/\text{year}$] | | | |
| 'Singles City' | 65.74 (+11.05%) | 116.07 (+8.04%) | 186.86 (+5.70%) |
| 'Couples City' | 56.44 (-4.66%) | 104.15 (-3.05%) | 173.35 (-1.94%) |
| Wage - low-skilled [$\$/\text{h}$] | | | |
| 'Singles City' | 8.52 (-16.06%) | 8.29 (-15.84%) | 8.26 (-15.71%) |
| 'Couples City' | 10.91 (+7.49%) | 10.58 (+7.41%) | 10.49 (+7.04%) |
| Wage - high-skilled [$\$/\text{h}$] | | | |
| 'Singles City' | 27.77 (+11.39%) | 27.16 (+11.36%) | 27.03 (+11.37%) |
| 'Couples City' | 23.83 (-4.41%) | 23.33 (-4.35%) | 23.21 (-4.37%) |
| Prices [$\$$] | | | |
| 'Singles City' | 103.80 (+0.86%) | 114.04 (+0.35%) | 125.00 |
| 'Couples City' | 102.47 (-0.43%) | 113.46 (-0.16%) | 125.00 |
| Output/resident [units/year] | | | |
| 'Singles City' | 39.99 (+1.77%) | 37.64 (+2.29%) | 34.69 (+2.66%) |
| 'Couples City' | 39.12 (-0.45%) | 36.54 (-0.69%) | 33.51 (-0.83%) |
| Shopping/resident [units/year] | | | |
| 'Singles City' | 23.51 (-1.00%) | 22.64 (-0.34%) | 21.01 (+0.08%) |
| 'Couples City' | 23.87 (+0.54%) | 22.78 (+0.27%) | 21.02 (+0.11%) |

Note: In parentheses: Changes in relation to 'Base City' of sensitivity analysis A

Table 14: Changes in rents, wages, prices, output, shopping - Sensitivity analysis B

| | Zone 1 or 5 | Zone 2 or 4 | Zone 3 |
|---------------------------------------|-----------------|-----------------|-----------------|
| Rent [$\$/\text{m}^2/\text{year}$] | | | |
| 'Singles City' | 87.68 (+7.97%) | 117.54 (+5.07%) | 150.14 (+3.36%) |
| 'Couples City' | 77.48 (-4.59%) | 108.89 (-2.66%) | 143.05 (-1.52%) |
| Wage - low-skilled [$\$/\text{h}$] | | | |
| 'Singles City' | 9.20 (-26.46%) | 9.06 (-25.80%) | 9.00 (-25.19%) |
| 'Couples City' | 14.07 (+12.47%) | 13.50 (+10.57%) | 13.14 (+9.23%) |
| Wage - high-skilled [$\$/\text{h}$] | | | |
| 'Singles City' | 29.18 (+22.86%) | 28.37 (+23.19%) | 27.87 (+23.48%) |
| 'Couples City' | 22.25 (-6.32%) | 21.62 (-6.12%) | 21.22 (-5.98%) |
| Prices [$\$$] | | | |
| 'Singles City' | 115.47 (+0.03%) | 120.23 (-0.07%) | 125.00 |
| 'Couples City' | 115.72 (-0.25%) | 120.51 (-0.16%) | 125.00 |
| Output/resident [units/year] | | | |
| 'Singles City' | 49.10 (+1.06%) | 37.90 (+0.07%) | 29.11 (-0.59%) |
| 'Couples City' | 47.83 (-1.56%) | 37.68 (-0.52%) | 29.37 (+0.31%) |
| Shopping/resident [units/year] | | | |
| 'Singles City' | 34.31 (-0.27%) | 23.69 (-2.36%) | 15.44 (-4.58%) |
| 'Couples City' | 34.00 (-1.16%) | 24.40 (+0.56%) | 16.58 (+2.42%) |

Note: In parentheses: Changes in relation to 'Base City' of sensitivity analysis B

Changes in commuting trips [%] in relation to 'Base City' of sensitivity analysis A

| | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 |
|--------|---------------|--------------|--------------|--------------|---------------|
| Zone 1 | +25.7 (-12.7) | +18.3 (-8.4) | +7.4 (-1.9) | -3.0 (+5.2) | -10.8 (+10.9) |
| Zone 2 | +13.6 (-5.0) | +20.1 (-8.2) | +12.5 (-4.0) | +1.0 (+2.7) | -7.8 (+8.6) |
| Zone 3 | -1.6 (+4.3) | +8.3 (-1.2) | +19.2 (-6.7) | +8.3 (-1.2) | -1.6 (+4.3) |
| Zone 4 | -7.8 (+8.6) | +1.0 (+2.7) | +12.5 (-4.0) | +20.1 (-8.2) | +13.6 (-5.0) |
| Zone 5 | -10.8 (+10.9) | -3.0 (+5.2) | +7.4 (-1.9) | +18.3 (-8.4) | +25.7 (-12.7) |

Note: In parentheses: 'Couples City' changes in relation to 'Base City' of sensitivity analysis A

Changes in commuting trips [%] in relation to 'Base City' of sensitivity analysis B

| | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 |
|--------|---------------|---------------|---------------|---------------|---------------|
| Zone 1 | +26.2 (-12.0) | +13.5 (-5.4) | -12.6 (+6.7) | -35.9 (+23.5) | -47.9 (+38.9) |
| Zone 2 | +5.1 (+1.0) | +32.1 (-11.4) | +13.1 (-2.7) | -21.0 (+12.4) | -41.5 (+27.3) |
| Zone 3 | -25.4 (+18.5) | +4.3 (+1.8) | +43.6 (-13.7) | +4.3 (+1.8) | -25.4 (+18.5) |
| Zone 4 | -41.5 (+27.3) | -21.0 (+12.4) | +13.1 (-2.7) | +32.1 (-11.4) | +5.1 (+1.0) |
| Zone 5 | -47.9 (+38.9) | -35.9 (+23.5) | -12.6 (+6.7) | +13.5 (-5.4) | +26.2 (-12.0) |

Note: In parentheses: 'Couples City' changes in relation to 'Base City' of sensitivity analysis B

Changes in shopping trips [%] in relation to 'Base City' of sensitivity analysis A

| | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 |
|--------|-------------|-------------|-------------|-------------|-------------|
| Zone 1 | +2.1 (-0.7) | +2.1 (-0.9) | +1.8 (-0.9) | +0.8 (-0.6) | -0.1 (-0.3) |
| Zone 2 | -1.9 (+1.2) | -0.7 (+0.7) | -0.9 (+0.7) | -2.0 (+1.0) | -3.1 (+1.4) |
| Zone 3 | -5.5 (+2.7) | -4.2 (+2.2) | -3.0 (+1.8) | -4.2 (+2.2) | -5.5 (+2.7) |
| Zone 4 | -3.1 (+1.4) | -2.0 (+1.0) | -0.9 (+0.7) | -0.7 (+0.7) | -1.9 (+1.2) |
| Zone 5 | -0.1 (-0.3) | +0.8 (-0.6) | +1.8 (-0.9) | +2.1 (-0.9) | +2.1 (-0.7) |

Note: In parentheses: 'Couples City' changes in relation to 'Base City' of sensitivity analysis A

Changes in shopping trips [%] in relation to 'Base City' of sensitivity analysis B

| | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 |
|--------|--------------|--------------|--------------|--------------|--------------|
| Zone 1 | +3.8 (-1.9) | -3.9 (+0.4) | -10.4 (+2.9) | -10.5 (+2.1) | -9.5 (+1.4) |
| Zone 2 | -7.9 (+0.3) | +4.9 (+0.0) | -6.7 (+2.5) | -12.4 (+1.5) | -13.3 (+0.5) |
| Zone 3 | -14.9 (+0.5) | -8.5 (+1.3) | +7.1 (+1.5) | -8.5 (+1.3) | -14.9 (+0.5) |
| Zone 4 | -13.3 (+0.5) | -12.4 (+1.5) | -6.7 (+2.5) | +4.9 (+0.0) | -7.9 (+0.3) |
| Zone 5 | -9.5 (+1.4) | -10.5 (+2.1) | -10.4 (+2.9) | -3.9 (+0.4) | +3.8 (-1.9) |

Note: In parentheses: 'Couples City' changes in relation to 'Base City' of sensitivity analysis B

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