Some consequences of ignoring relocations in the cost-benefit analysis of transportation infrastructure investments

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Abstract

Traditional cost-benefit models of investments in road infrastructure are often based on demand curves assuming a given spatial distribution of jobs and households. We first use numerical experiments based on a spatial general equilibrium model to illustrate how this potentially introduces a serious prediction bias in the willingness-to-pay for the investments. Our experiments illustrate that it is not in general possible to say whether ignoring relocation effects leads to over- or underprediction of commuting flows. We identify cases of both kinds, and also cases where substantial changes in the road transportation network affect total commuting flows only marginally.

1 Introduction

Cost-benefit appraisals of investments in transportation infrastructure are often based on estimates of traffic demand on the relevant road links. A correct ap-

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praisal of the investments requires that the estimation of the demand is made on a sound basis. In this chapter, commuting is the only trip purpose to be studied. Predictions of commuting flows are typically based on a demand curve estimated within a doubly-constrained modelling framework, which means that the spatial distribution of jobs and workers (households) is assumed to be given. This may be a reasonable assumption in some cases, for instance if the investments mainly affect the long distance traffic on a particular transport corridor. In many cases, however, changes in the transportation network will affect location decisions of local households and employers. In the long run, this may induce significant changes in the spatial distribution of jobs and people. In such cases, predictions based on a doubly-constrained modelling framework would be seriously biased. The main motivation of this chapter is to study the importance and the character of such a bias.

Relocation effects certainly represent a possible source of prediction errors in calculating induced traffic and welfare benefits in traditional cost-benefit appraisals of investments in road transportation infrastructure. In addition, the spatial distribution of jobs and households may itself be a target for regional policy. One important aspect to discuss is, for instance, whether improvements in the road network may contribute to preventing depopulation of peripheral areas. Predictions of such effects are therefore both interesting from a regional policy point of view, and as input to a cost-benefit analysis.

A first challenge is to specify an appropriate modelling framework. The approach to be followed in this chapter is to study potential relocation effects and the resulting prediction bias in a spatial general equilibrium modelling framework. The literature offers some very interesting operative spatial general equilibrium models. One successful set of models is the Spatial Computable General Equilibrium (SCGE) models, originating from the 'new economic geography', see for instance Fujita et al. (1999). This tradition of spatial general equilibrium models normally adopts a macroscopic perspective of the geography. The models are designed for a multiregional setting, with relatively large regions, ignoring spatial interaction of commuting and shopping, and intraregional disparities of for example labour and housing market characteristics.

Another tradition of spatial equilibrium modelling are large-scale models for urban planning. Such models are designed for metropolitan areas, and offer a very detailed description of spatial interaction and location characteristics of the local geography. This involves for instance traffic assignment problems, mode choice in transport, and several aspects of urban land use. Many specifications and applications can be found in the literature, after this kind of modelling had its renaissance at the end of the 1980s (Boyce, 1988). One well-known example of a large-scale model is the UrbanSim model, see Waddell et al. (2003).

Studying regional policy issues in for example a typical west Norwegian region calls for specifying a spatial dimension in between the large-scale models for metropolitan areas and the multiregional spatial general equilibrium models of the 'new economic geography'. Congestion, mode choice, and urban environmental and land use problems are not very relevant, but flows of commuting and shopping should be accounted for in explaining and predicting changes in the location pattern.

A non-technical description of the modelling framework is provided in Section 2. Section 3 introduces a simple 5-node imaginary geography, that is used in the numerical experiments to follow. Relocation effects of varying the distance from a peripheral zone to the central business district are studied in Section 3.1, while Section 3.2 focuses on prediction errors of ignoring relocation effects in cases where the travel distance is reduced by $\frac{1}{3}$. Section 3.3 demonstrates that the prediction errors are sensitive to the parameter representing the distance deterrence in intraregional moving decisions. The discussion is taken into a standard microeconomic cost-benefit analysis in Section 4, while Section 5 addresses environmental issues, represented by the possibility of negative externalities related to induced traffic from improvements in the road network. Finally, some concluding remarks are offered in Section 6.

2 A non-technical description of the modelling framework

This chapter utilises the spatial equilibrium model presented and developed in McArthur et al. (2014). The core of the model centres on the definition of equilibrium, involving intra-regional migration and commuting flows corresponding to a specific spatial distribution of jobs and workers between the zones of a region. To reach an operational model specification we introduce a set of reasonable hypotheses on the spatial behaviour of firms and households. Hence, we concentrate on the spatial dimension of the supply and demand for labour, and ignore many other aspects, for instance related to heterogeneity of jobs and workers.

Consider first the demand for labour at specific locations. Like most spatial general equilibrium models, the model to be presented incorporates the core elements of economic base modelling. This means that the model distinguishes between two types of firms. The activity of local sector firms is determined by demand arising from within the region, while production in basic sector firms is determined by factors unrelated to intraregional demand.

Basic sector firms, local innovativeness and competitiveness

As indicated in the left upper part of Figure 1, the number of basic sector jobs at a specific location depends on local innovativeness and competitiveness. This may reflect agglomeration economies or agglomeration diseconomies, the wage level, entrepreneurial spirit, transport costs, the availability of qualified workers etc. No attempt is made to explicitly account for local variations of innovativeness and competitiveness in the current version of the model to be presented, the spatial distribution of basic sector jobs is treated exogenously in the model.

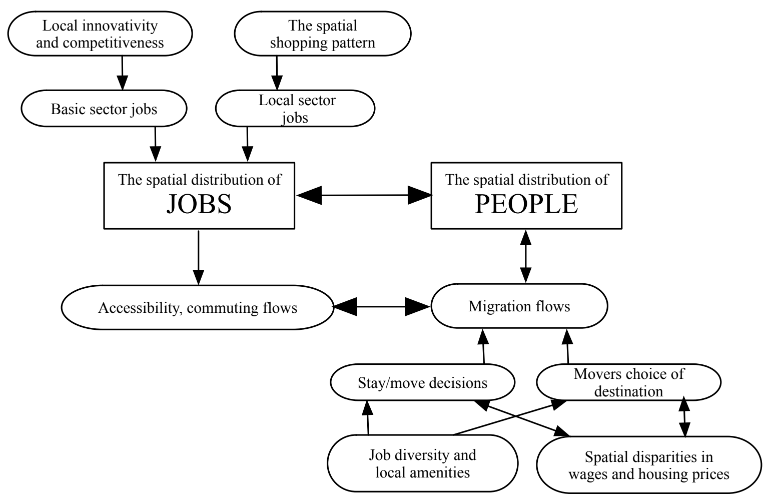


Figure 1: Basic mechanisms in the modelling framework.

Local sector firms: the spatial shopping pattern

The spatial distribution of local sector jobs reflects the residential location pattern and the spatial shopping behaviour of the households/customers. Retailing is the dominating local sector activity. As in most other forms of spatial interaction there is a distance deterrence effect in shopping travel patterns. In economic base theory, this can be used to support an assumption of proportionality between local sector employment and the population of a specific geographic area. It can be argued, however, that such an assumption of proportionality is unreasonable at the level of spatial aggregation considered in this chapter.

Hence, an alternative, more appropriate, approach is used. The basic idea is that consumer shopping behaviour results from a trade-off between price savings and transport costs. Gjestland et al. (2006) derived some results regarding this trade-off. The more realism added to assumptions on the distribution of price savings, product range, shopping frequency, and the valuation of time, the closer Gjestland et al. (2006) come to a smooth, concave function between the frequency of shopping locally and the distance from the shopping centre offering favourable prices.

A next step in deriving a spatial pattern of local sector activities is by recognising that economies of scale, transportation costs, and agglomeration benefits allow firms in a central location to offer goods and services at a lower price than firms located in more peripheral locations. Agglomeration benefits explain why some types of local sector activities will largely be concentrated in a centre. Administrative services often locate in the centre, giving rise to agglomeration benefits which in turn attract more activity. At the same time businesses in many cases choose to locate in the same area because consumers often perceive it to be beneficial if they can satisfy their demand for several goods and services with one shopping trip.

In other words, the potential for price savings pulls shopping towards urban centres, while transport costs contribute to explain why customers do some of their shopping close to where they live. For an illustration of the outcome of the relevant trade-off, assume that the region has just one centre. This assumption can be easily relaxed, into cases with many centres of various size. Consider next the number of shop-employees per resident, measuring the local-sector density (LSD). The trade-off is then represented by a pattern corresponding to the graph in Figure 2. Low prices explain a very high local-sector density in the centre of the region. A significant proportion of the shopping trips emanating from a suburb will, as a rule, be directed towards the regional centre, since customers here can benefit from low prices in the centre at relatively low transport costs. For zones which lie at a long distance from the centre, virtually all shopping will take place within the zone. As illustrated in Figure 2 the local sector density will be high in the regional centre, low in suburbs, and it will be approaching the regional average as the distance from the centre increases. Gjestland et al. (2006) find empirical support for such an intuitively appealing pattern from observations of Norwegian regions.

The level of local-sector density at a centre reflects the central place system of the region, and the importance and dominance of a centre can be argued to be a decreasing function of the average distance to potential customers outside the centre. The Appendix explains how this reasonable hypothesis and the relationship illustrated in Figure 2 are made operational in the spatial general equilibrium model.

The discussion so far means that the intraregional distribution of (local-sector) jobs reflects the residential location pattern. At the same time it makes sense to assume that residential location decisions are influenced by the job opportunities within a reasonable commuting distance. As indicated in Figure 1 this means that the spatial distribution of jobs and people are interdependent. This is the fundamental mechanism in economic base modelling, which will be addressed later in this section.

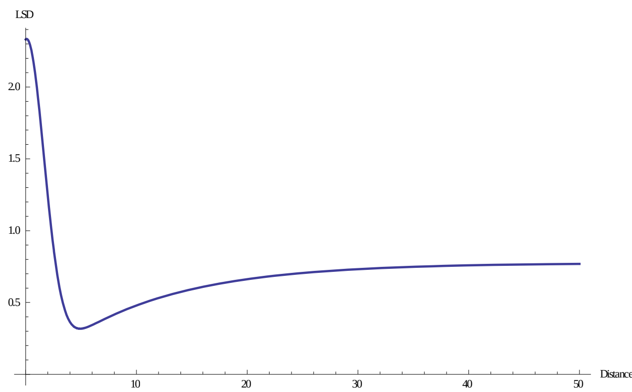


Figure 2: The spatial distribution of local sector jobs in a monocentric geography.

The decision to stay or move from a residential site

The residential location choice can be considered to result from a two-step decision process. First, a household decides whether to stay or move from the current residential site. Second, households moving have to choose between alternative locations. Consider first the diagonal elements of a matrix of transition, migration, probabilities.

One hypothesis incorporated into our model is that the probability of remaining in a zone is positively related to the labour market accessibility of the zone. This is consistent with the findings from Swedish microdata (Lundholm, 2010; Eliasson et al., 2003), while Van Ham and Hooimeijer (2009) find a similar result for the Netherlands. The explanation is that labour market accessibility allows greater flexibility, and can generally be seen as a favourable attribute for a residential location.

It is easy to find examples of sparsely-populated rural areas where unemployment is close to zero and out-migration of the working population is high (McArthur et al., 2012). An important reason for this is that the probability of finding an appropriate job in a peripheral area is low, and known, causing workers to migrate out of the area or drop out of the labour force. The point is that when labour market accessibility is below some critical level, it is the local balance between the demand and supply of labour which determines the probabilities of staying in a zone. This effect is represented by a relationship between the tendency to move and labour market accessibility in the model.

In this chapter, accessibility is represented by a measure for generalised distance to all other zones of the geography. Each zone is weighted by the number of jobs, adjusted for the competition for jobs, measured by the number of jobs as a proportion of the local number of job seekers. In addition, the weights involve a distance deterrence function that places a relatively high weight on destinations which lie within a short distance from the residential location.

Finally, the measure of generalized distance is combined with information on the local labour-market situation in the function that determines the probability that workers move from a specific zone. Assume that a zone has high unemployment. If this zone is centrally located in the region, with a low value of generalised distance, many workers will choose to commute rather than move from their current residential location. If, however, the generalised distance is long, then migration will be a more frequent spatial interaction response to high unemployment, defining a process towards a situation with a balance in the local labour market.

Spatial equilibrium and migration flows between different zones

The impact of job opportunities and the labour market situation is accounted for through the diagonal elements in the matrix of migration probabilities. The migration between different zones is modelled through the introduction of a search strategy where a worker evaluates destinations successively outwards over the network. The worker will move to the first place where the conditions are 'satisfactory'. Options further out in the network will then not be evaluated. Hence, an absorption effect is introduced, analogously to the basic idea in the theory of intervening opportunities (Miller, 1972). This further means that the probability of moving decreases as the worker evaluates alternatives which lie progressively further out in the network.

Another central hypothesis within the regional science literature is that distance limits spatial interaction. Accounting for the absorption effect and the distance deterrence effect forms a symmetric matrix, that is next normalised into a migration probability matrix. This matrix is then used to find the equilibrium solution for the system. An equilibrium spatial population pattern is reached if implementing the migration probabilities leaves the distribution of population between zones unchanged (Nævdal et al., 1996).

Job diversity, local amenities, spatial wage disparities and house prices

We do not incorporate job diversity, local amenities, spatial wage disparities and house prices into this version of this model. We include them in Figure 1 to illustrate where they would fit into the model.

The relationship between the spatial distribution of jobs and people, an economic base multiplier process

The spatial distribution of jobs are linked to the spatial distribution of people through labour market accessibility, and the simultaneity between commuting flows and migration flows. The economic base mechanism represents the more direct link between the location of jobs and people in Figure 1. As mentioned above, location decisions of local sector firms reflect the shopping behaviour and the location pattern of the households demanding the goods and services being offered. At the same time, workers employed in local sector firms tend to prefer a residential location close to the firm. Assume increased basic sector activity in a zone. This causes a rise in labour demand, attracts labour to the zone, and increases the demand for goods and services produced in the local-sector. This creates further demand for labour and initiates a positive growth cycle, known in the literature as an economic base multiplier process.

The equilibrium modelling approach in this research accounts for different kinds of interdependencies in a simultaneous treatment of location decisions made by firms and households. This can be argued to be a preferred approach to introducing a specific causality on the employment-population interaction. According to Hoogstra et al. (2011) the nature of this causality differs across space and time. They carried out a statistically supported literature review ("meta-analysis"), and found that the empirical evidence is highly inconclusive on the jobs-people direction of causality, although most result point towards "jobs follow people".

3 Prediction errors in a simple 5-node imaginary geography

Consider the very simple, 5-node, network illustrated in Figure 3. In this imaginary geography, the central business district (CBD) is assumed to be located in zone B. The distances from the CBD to the other zones are indicated in the figure. The suburban zone D is located 5 km from zone B, while the zones C and E are located within a reasonable commuting distance from the CBD; 30 and 20 km, respectively. In Figure 3 zone A appears to be a peripheral rural location, 80 km from the CBD. The distance between the zones A and B, d_{AB}, will be systematically varied to study the impact of this distance on the equilibrium employment and population in zone A. Reductions in distances may be due to investments in road infrastructure, for instance by removing the effect of topographical barriers through the construction of tunnels and/or bridges. Alternatively, d_{ij} can be interpreted as travelling times, and reduced travelling times can result from improved road standards, higher speed limits, and more efficient traffic management.

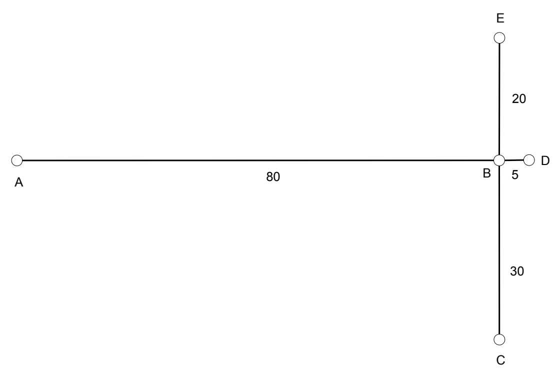


Figure 3: A 5-node network of zones

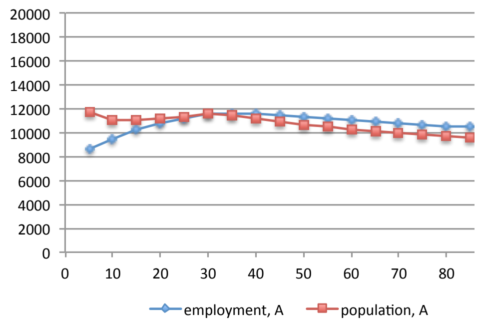
Finding an equilibrium spatial distribution of population and workers of course calls for a parametrisation of the model. The parameters are defined in the Appendix, which provides a technical model presentation. The parameter values chosen for the standard case of the numerical experiments are presented in A.7.

3.1 Relocation effects of variations in the distance from the central business district

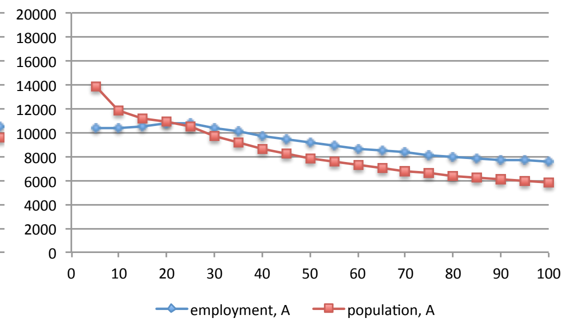
Assume that the central business district has a concentration of basic sector jobs, while non-CBD basic-sector jobs are evenly spread between the zones A, C, D, and E; $E^b_B = 10000, E^b_A = E^b_C = E^b_D = E^b_E = 3000$. The equilibrium solution following from the model depends on characteristics of the network. In this section we focus on the distance from zone A to the CBD, d_{AB}. Figure 4 offers an illustration of how the equilibrium employment and population in zone A changes when d_{AB} is systematically varied from 5 km to 100 km.

Consider first part a) of Figure 4, corresponding to a value of 0.25 of the parameter β, representing the elasticity of migration flows with respect to distance. For very low values of d_{AB} zone A appears as a suburban zone, with a high population and a relatively low number of local-sector jobs. The zone is attractive for commuters. It has a relatively low number of local-sector jobs, since households living here tend to do their shopping in the CBD rather than locally. Notice from the figure that increasing d_{AB} has no unambiguous effect on population and employment in zone A. There are two forces, pulling the equilibrium in different directions. First, increasing d_{AB} makes zone A less attractive as an origin of commuting. On the other hand people do more of their shopping locally when the distance to the CBD increases, making the zone more attractive for local-sector activities. In Figure 4a the effect through labour market accessibility on population dominates for variation of distance in the intervals $d_{AB} < 20$ and $d_{AB} > 30$, while the effect of increased local sector employment tends to dominate for $15 < d_{AB} < 30$. Compared to the other cases in the figure, however, population and employment are not substantially affected by variations in distance.

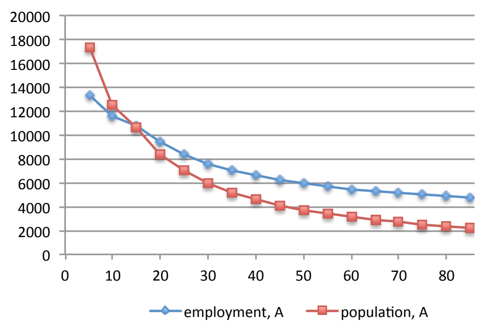
The other cases in Figure 4 correspond to higher negative values of the distance deterrence in migration (β) i.e. where migration is more deterred by distance. In the literature, estimates of this elasticity typically range between $-1,0$ and $-3,0$, see for example Schwartz (1973). It can be argued, however, that distance deterrence in migration depends on the geographical scale that is considered. The value of $\beta = -0,25$ corresponds to a hypothesis that internal



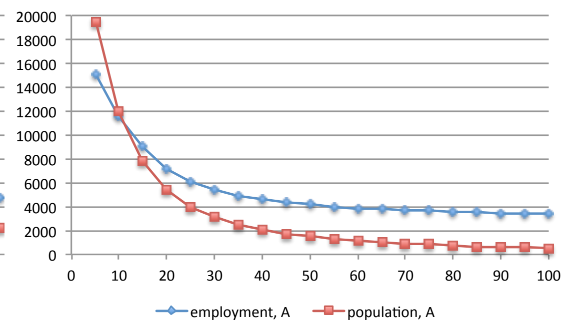
a) $\beta = -0,25$



b) $\beta = -0,5$



c) $\beta = -1,0$



d) $\beta = -1,5$

Figure 4: Equilibrium employment and population in zone A, corresponding to variations in d_{AB}, and to different values of the distance deterrence in migration (β).

moves within a region are not very sensitive to distance. Figure 4 demonstrates that the impact of variations in distance depends heavily on the value of this parameter. Keep in mind that the employment curves in the four parts of Figure 4 represents the local-sector employment plus the number of basic-sector jobs.

According to the four parts of Figure 4, equilibrium population and employment of zone A is a lot more sensitive to variations in distance in cases with strong residential site preferences, that is high negative values of β. If zone A is located close to the CBD and the rest of the system, workers living here can take advantage of a high labour market accessibility, without moving a long distance from their preferred residential location. Hence, this makes zone A popular as a residential location, especially in cases with a strong distance deterrence effect in local migration.

In a case where the negative value of β is high, the inhabitants have strong location preferences for their current residential area, and this is detrimental if the zone is peripherally located in the region. This contributes to explaining rural depopulation, even in cases where there are good prospects of receiving job offers in the zone. For high values of d_{AB}, zone A offers an unfortunate combination of low labour market accessibility and a location in a long distance from the preferred residential location for a large majority of the population in the region.

Consider next transportation infrastructure investments, reducing the travel distance from zone A to the CBD by one third. In one experiment, the distance is reduced from 60 km to 40 km, while the distance is reduced from 30 km to 20 km in another experiment. The model is used to predict relocation effects, and the results of the numerical experiments are presented in Table 1.

Assume first that relocation effects are measured by absolute changes, that

Table 1: Relocation effects of reduced distance from zone A to the CBD.

	$\beta=-0,25$		$\beta=-0,5$		$\beta=-1,0$		$\beta=-1,5$	
	E_A	L_A	E_A	L_A	E_A	L_A	E_A	L_A
$d_{AB}=60$	10997	10280	8677	7281	5445	3135	3884	1133
$d_{AB}=40$	11522	11153	9716	8670	6575	4584	4601	2052
$d_{AB}=30$	11576	11602	10400	9743	7626	5941	5412	3093
$d_{AB}=20$	10725	11152	10819	10944	9428	8413	7195	5403
$\Delta E(60\to40)$	525		1039		1130		717	
$\%\Delta E(60\to40)$	$4,8$		$12,0$		$20,8$		$18,5$	
$\Delta L(60\to40)$	873		1389		1449		919	
$\%\Delta L(60\to40)$	$8,5$		$19,1$		$46,2$		$81,1$	
$\Delta E(30\to20)$	-851		419		1802		1783	
$\%\Delta E(30\to20)$	$-7,4$		$4,0$		$23,6$		$32,9$	
$\Delta L(30\to20)$	-450		1201		2472		2310	
$\%\Delta L(30\to20)$	$-3,9$		$12,3$		$41,6$		$74,7$	

is the changes in the total number of jobs and people in zone A. According to Table 1, the absolute changes resulting from transport innovations tend to be most dramatic in the case where zone A is initially located relatively close to the central area of the region. In this case, zone A is predicted to experience a reduced population and employment if $\beta=-0,25$, while the zone is predicted to experience substantial increases in population and employment if intraregional moves are severely deterred by distance.

If workers are not very concerned with distance in making their intraregional moving decisions, an equilibrium solution results where the population is relatively evenly distributed between the zones A, C, D and E. In such a case, the character of the equilibrium solution is less sensitive to variations in distance than in cases where workers are more reluctant to move a long distance from their current residence. This is the reason why the model predicts more substantial relocation effects in the cases with high negative values of the relevant distance deterrence parameter, as reported in Table 1. The table also reveals a tendency that relative relocation effects are more dependent on the value of β than on the initial location of zone A.

Measured in percentage changes, the relocation effects are not very sensitive to the initial location of zone A. Relative changes are also, however, strongly dependent on the value of the distance deterrence in migration; relocation effects are considerably stronger for high negative values of β. Notice also from Table 1 that the balance between people/workers and jobs is more disturbed if the road transport innovation is introduced in a case where zone A is located close to the CBD. The problem to be addressed in the sections to follow is how such relocation effects affect the predicted increase in commuting flows resulting from improvements in the road network. What is the impact of ignoring relocation effects in traditional cost-benefit analyses of investments in transport infrastructure?

3.2 Relocation effects, prediction errors, and the initial position of zone A.

As stated in the introduction, ignoring relocation effects potentially introduces errors in the prediction of commuting flows. In this section, the focus is on how the prediction bias is depending on the initial location of the zone that benefits from improvements in the road transportation network. Commuting flows in the system are predicted by a doubly-constrained gravity model, see Section A.5. Consider once again variations in the distance between zone A and the CBD. Results of numerical experiments are presented in Table 2.

Table 2 reports induced commuting in two cases. One case is starting from a situation where $d_{AB} = 60$, the other is taking $d_{AB} = 30$ as a starting point. The model is next used to predict induced commuting flows corresponding to a reduction in travel distance of $\frac{1}{3}$. This corresponds to a reduction of distance of 40 and 20 km in the two cases, respectively. The upper part of the table refers to experiments where the spatial distribution of jobs and people are assumed to be given, unaffected by changes in the location of zone A relative to the CBD. The lower part of the table refers to experiments that account for the predicted changes in the row and column sums of the commuting flow matrix, that is for the changes in the spatial distribution of jobs and people that was predicted by the spatial equilibrium model, and discussed in the preceding section. The location pattern corresponding to $d_{AB} = 60$ and $d_{AB} = 30$ is of course the same in the two parts of the table.

The results in Table 2 are based on a value of the distance deterrence parameter in migration of $\beta = 1,0$. It follows from part c) of Figure 4 that zone A has a very low population if $d_{AB} = 60$ in such a case, and that the number of (basic sector) jobs are considerable higher. This high local net supply of jobs is reflected in the predicted commuting flows; according to Table 2, a lot more workers are commuting into zone A than from zone A in the case where $d_{AB} = 60$. Notice that the induced commuting flows to and from zone A are equal in the upper part of the table, ignoring rounding errors. This follows as a consequence of keeping constant the row and column sums of the commuting flow matrix.

The two cases in Table 2 refer to equal percentage changes in travel distance, but the reduction in physical distance is two times larger in the case where $d_{AB} = 60$ initially. This does not necessarily mean that the costs involved in this case is two times higher than the costs of reducing the travel distance from 30 km to 20 km. There may be higher costs involved in road infrastructure investments closer to the centre of the geography.

Notice first that the induced commuting in absolute terms are a lot higher in the case where zone A is initially located close to the CBD. With one exception this also applies in relative terms. The exception is commuting from zone A, which is very low prior to the reduction in travel distance. Hence, even

Table 2: Responses in commuting flows to changes in the travel distance (d_{AB}) in a case with $\beta = 1.0$.

	$\sum_j T_{Aj}$	$\sum_i T_{iA}$	$\sum_j T_{Aj} + \sum_i T_{iA}$
Ignoring relocation effects			
$d_{AB} = 60$	25	2335	2360
$d_{AB} = 40$	322	2633	2955
$d_{AB} = 30$	1583	3268	4851
$d_{AB} = 20$	2989	4674	7663
Induced commuting (60 $\rightarrow$ 40)	297	298	595
Induced commuting (30 $\rightarrow$ 20)	1406	1406	2812
% Induced commuting (60 $\rightarrow$ 40)	1188,0	12,8	25,2
% Induced commuting (30 $\rightarrow$ 20)	88,8	54,1	58,0
Accounting for relocation effects			
$d_{AB} = 60$	25	2335	2360
$d_{AB} = 40$	492	2483	2975
$d_{AB} = 30$	1583	3268	4851
$d_{AB} = 20$	4022	5036	9058
Induced commuting (60 $\rightarrow$ 40)	467	148	615
Induced commuting (30 $\rightarrow$ 20)	2439	1768	4207
% Induced commuting (60 $\rightarrow$ 40)	1868,0	6,3	26,1
% Induced commuting (30 $\rightarrow$ 20)	154,1	54,1	86,7

Note: T_{ij} = the number of commuters from zone i to zone j;
$\sum_j T_{Aj}$ is commuting from zone A, while $\sum_i T_{iA}$ is commuting into zone A.

a moderate increase in the number of commuters appears as a huge relative increase.

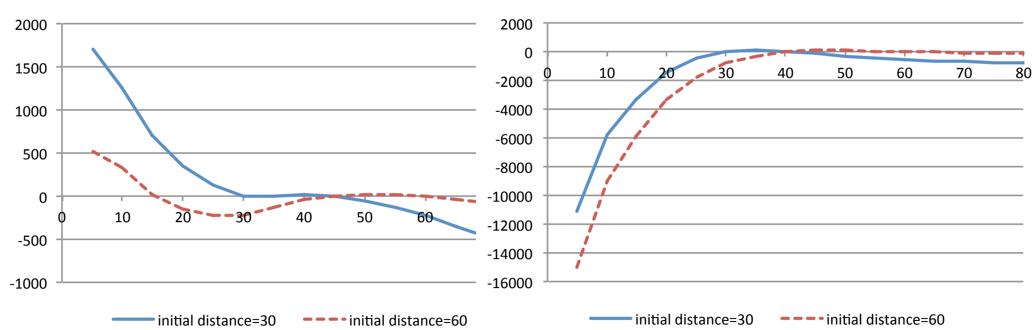
It can be argued that ignoring relocation effects leads to an underprediction of the induced commuting flows resulting from improvements in the road infrastructure. Transport innovations are offering new options that workers will take advantage of by choosing more preferred combinations of job and residence location. Intuitively, this leads to more commuting. To some degree this represents a hypothesis that is supported by the results of the numerical experiments reported in Table 2.

Consider first the reduction of travel distance from 60 km to 40 km. It follows from Table 1 that this induces a marked increase in the number of workers that are living in zone A. This explains why ignoring relocation effects leads to an underprediction in the number of commuters from zone A, as reported in Table 2. At the same time, however, more jobs in zone A are now occupied by local workers, explaining why the relocation effects actually contribute to reduce the induced commuting to zone A. In total, ignoring relocation effects in the case where $d_{AB} = 60$ initially, leads to a very marginal underprediction of commuting flows involving zone A; according to Table 2 the induced commuting is 26.1% in the case where relocation effects are accounted for, and 25.2% in the case where they are ignored.

According to the results reported in Table 2, the prediction errors from ignoring relocation effects is substantially higher, both in absolute and relative terms, in the case where zone A is located closer to the CBD.

3.3 Prediction errors and the distance deterrence in moving

It was demonstrated in Section 3.1 that relocation effects of changes in the transportation infrastructure are sensitive to the distance deterrence in intraregional moving decisions. Hence, prediction errors of ignoring relocation effects should also be expected to be sensitive to the value of β. This is confirmed by the simulation results illustrated in Figure 5. The curves in the figure refer to errors of ignoring relocation effects in predicting total commuting flows to and from zone A. Adjusted for the fact that the scaling on the vertical axis differs in the two parts of the figure, it is very apparent that prediction errors are a lot larger in part b) of the figure, corresponding to the case where the negative value of β is highest. This is consistent with the finding in Section 3.1 that the equilibrium spatial distribution of jobs and residences is not very sensitive to variations in distance for low negative values of β.



a) $\beta = -0.25$ b) $\beta = -1.0$

Figure 5: Prediction errors of ignoring relocation effects in predicting total commuting flows to and from zone A.

Figure 5 also illustrates the finding from Section 3.2 that the prediction bias from ignoring relocation effects is most severe in the case where the initial location of zone A is close to the centre of the geography. If zone A is initially located in a distance of 60 from the CBD, huge improvements in the transportation infrastructure is required to generate significant relocation effects, causing prediction errors. In the case with $\beta = 1.0$ and $d_{AB} = 30$ initially, commuting flows might be substantially underpredicted even for moderate reductions in the travelling time from zone A to the CBD.

One striking difference between the two parts of Figure 5 is that ignoring relocation effects might actually lead to an overprediction of induced commuting flows in the case with a low negative value of β. This might at a first glance seem to be a counter-intuitive result. As mentioned above, the reduced travel distance makes zone A more attractive as an origin for commuting flows, and workers can take advantage of new options by choosing more preferred combinations of job and residence location. Remember, however, from part a) of Figure 4, that a reduced d_{AB} might lead to reduced employment in zone A, since the households make more of their shopping in the CBD. This is reflected in Figure 6, where the prediction errors are split into flows to and from zone A. The figure clearly demonstrates that incoming commuting flows are overpredicted when the relocation of local sector jobs are ignored. It is important to consider predictions of total commuting flows as a net outcome of in- and out-commuting. As expected, ignoring relocation effects lead to an underprediction of commuting flows from zone A, also in the case with a low negative value of β. In Figure 6, however, the effects originating from shopping decisions are dominating.

4 Welfare calculations

When deciding whether to undertake a transportation investment, it is important to understand the costs and benefits. In this section, focus will be placed on the estimation of the direct benefits flowing to users. A standard microeconomic framework can be used to asses the change in welfare resulting from a

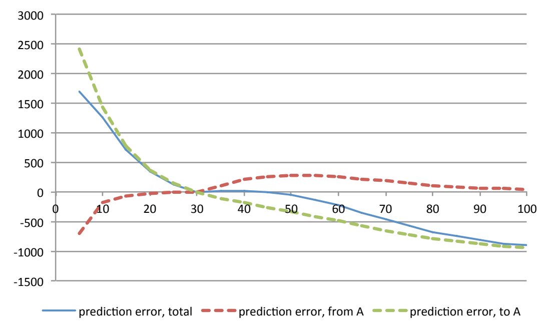


Figure 6: Prediction errors of commuting flows to and from zone A.

change in the transportation network. In order to proceed, an estimate of the demand function is required. An example demand curve for trips between two locations is shown in Figure 7.

Figure 7 depicts a situation where the generalised cost of travel across a link is given by P_0. Looking at the demand curve labelled 'Ex', the demand for trips is T_0. The consumer surplus for these road users is given by the area ABP_0. Assume now that an investment is made which reduces the generalised cost of travel to P_1. From a welfare perspective, two effects which must be considered. Firstly, the users who made the T_0 trips can now do so at a lower cost. This increases their consumer surplus by the amount P_0BDP_1. The additional effect is the *induced demand*, i.e. the increase in demand from T_0 to T_1. These users were not willing to travel at the previous price, but are willing to do so at the new price. The consumer surplus for these users is lower than that for the previous users. The consumer surplus from the new users is given by the area BCD. The total change in consumer surplus caused by the change is therefore given by P_0BCP_1.

An important assumption invoked in the construction of the demand curve 'Ex' illustrated in Figure 7 is that all other factors remain equal. One of these

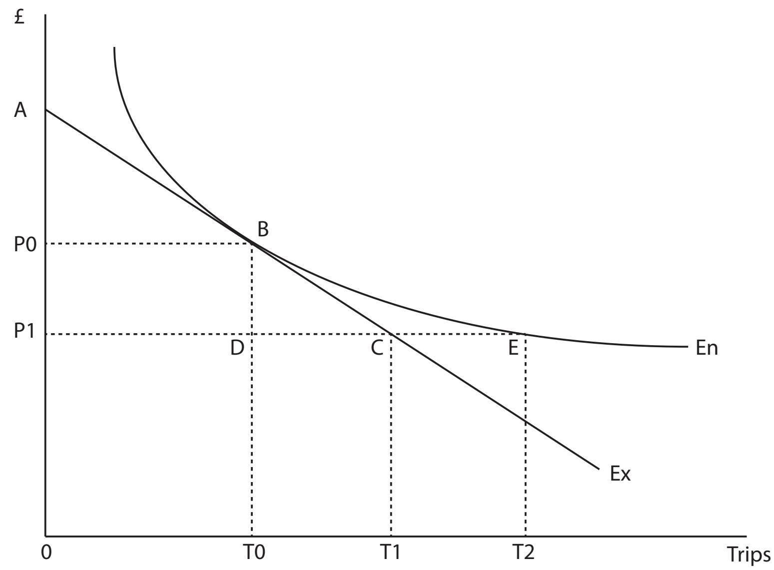


Figure 7: Demand for trips across a link as a function of the generalised cost of travel.

factors assumed to remain fixed is the location of workers and firms. However firms and workers will often relocate in response to a change in the transportation network, as has been demonstrated. In such a case, changes in the generalised cost of travel will result in a shift in demand rather than a movement along the same demand curve. Whether the shift will be outward or inward will depend on the preferences of the agents populating the geography as well as the geography itself.

Consider again a price of P_0, where the demand for trips is T_0. If the generalised cost is lowered to P_1, we would expect the demand for trips to rise to T_1 if the locations of firms and workers are fixed. If, however, the locations are allowed to vary, movement along the demand curve labelled 'En' is observed. Demand would therefore increase from T_0 to T_2 in response to the reduction of the generalised cost of travel. Failure to account for relocation effects, will result in an underestimation of the change in welfare by the area BCE. The total welfare change when accounting for relocation effects is therefore BDE.

This effect can be explored in our model. Two different demand curves for the demand for trips between zones A and B will be constructed. The distance will be systematically varied from 1 km to 80km to construct these curves. The change in welfare resulting from a reduction in the distance between A and B from 40 to 20 km will be estimated. In order to calculate welfare, this distance will be converted to a generalised cost of travel. To do this, the UK's Automobile Association's (The AA) estimate of the variable cost of motoring [1]. The variable costs amount to 13.92 pence per km. An estimate of the value of time is required. Firstly, we assume travel at a speed of 60 km/h, so that 1 km is the equivalent of 1 minute. We use the value of time spent commuting from the UK's Department of Transport's (DfT) Transport Appraisal Guidance (TAG)[2] inflated to 2012 GBP. This gives the cost of one minute of 11.73 pence. The total cost of commuting one km is therefore £0.26.

One theoretical point which should be noted is that we work with the Marshallian demand curve which accounts only for substitution effects and not income effects. This means that consumer surplus is measured rather than the more theoretically appealing measures of compensating variation (CV) or equivalent variation (EV) which can be derived from the Hicksian demand curve. In practice, consumer surplus is by far the most used measure. Partly this is because the CV and EV measures are more difficult to calculate. The CS will usually lie somewhere between the CV and EV measures. When income effects are small, as is usually the case with transport projects, the measures will provide similar results De Jong et al. (2007).

[1]See `www.theaa.com/resources/Documents/pdf/motoring-advice/running-costs/petrol2012.pdf` [Retrieved 11/09/2012] will be used. We assume a petrol engine and that the car's original purchase price was £14 000 to £17 000. Parking and toll charges are excluded from the cost.

[2]`www.dft.gov.uk/webtag/documents/expert/pdf/u3_5_6-vot-op-cost-120723.pdf` [Retrieved 11/09/2012]

Demand curves under the assumptions of fixed and variable locations for firms and workers and firms are presented in Figure 8. We begin at a situation where the distance between A and B is 40 km, corresponding to a cost of £10.26, and a total demand of 2 975 one-way trips per day. This corresponds to 1.19 million trips per year if workers work a 200 day year and make a return trip on each of these days. We now consider the impact of a reduction in distance to 20km, or a generalised cost of £5.13.

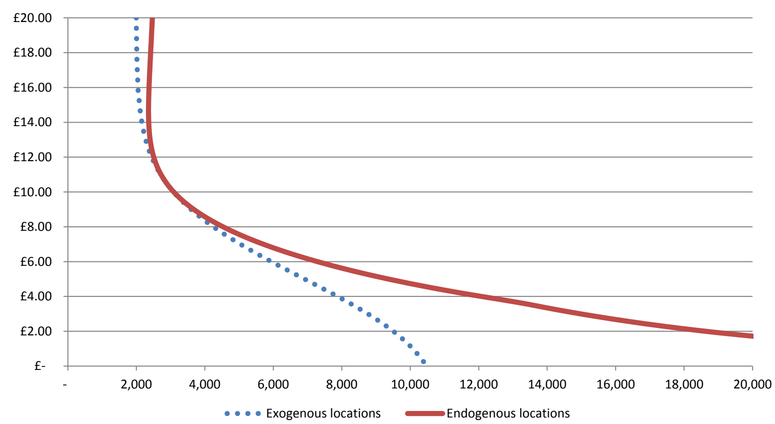


Figure 8: Demand for trips between zones A and B as a function of the generalised cost under the assumptions of a fixed and a variable locations of firms and workers.

If fixed locations are assumed, then a rise in demand to 6 783 one-way trips per day is predicted, a change of 3 808. If however firms and workers are allowed to move in response to the change, a rise in demand to 9 058 is predicted, a rise of 6 083. This means an assumption of fixed locations underestimates demand by 76%.

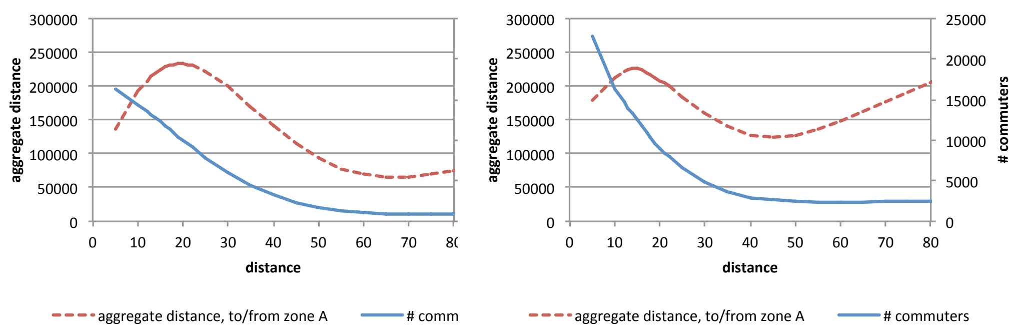
The estimated change in the consumer surplus can be obtained by integrating the demand function over the interval of the price change i.e. 10.26 to 5.13. We use Simpson's rule to numerically integrate the demand function. Assuming workers and firms have fixed locations, the change in consumer surplus is estimated to be £23 681 per half-day for all road users. If workers and firms are allowed to relocate, then the consumer surplus is estimated to be £26 873. This is a difference of £3 192 or 13.5%. On an annual basis, this amounts to an underestimation of £1 276 808.

In the example presented here, ignoring relocation effects resulted in an underestimation of consumer surplus of 13.5%. However, under different conditions, an under- or over-prediction may be observed. One important parameter is the sensitivity of workers to distance in making migration decisions. The example shown in Figure 8 assumed a distance deterrence parameter of $\beta = 1$. If we follow the same procedure as above but change β to a value of 0.2, we get an overestimation of 0.2% by assuming fixed locations of firms and workers.

It is unsurprising that making workers less sensitive to distance when considering where to live has this effect. When workers don't care about distances, shortening distances has little effect on their decisions. A range of under- and over-predictions are therefore possible. Careful modelling which takes into account location decisions is therefore important in evaluating the effect of changes in infrastructure.

5 Road improvements and aggregate commuting

The welfare calculations that were made in the previous section did not account for the possibility of negative externalities related to induced traffic resulting from improvements in the road network. From an environmental point of view it is often claimed that investments in road infrastructure in general generate more traffic and, consequently, more emissions and pollution. This is obviously an interesting perspective in a welfare evaluation of such investments. Figure 9 illustrates how the total number of commuters to and from zone A and the aggregate commuting distance to and from zone A depends on the distance between the zone and the regional centre, d_{AB}. No attempt has been made to account for the possibility that the average speed and emissions per vehicle might depend on the number of road users, due to congestion problems. The parameter representing the distance deterrence in intraregional moving decisions has a value of -0.25 in the left part of the figure, and -1.0 in part b) of the figure.



a) $\beta = -0.25$ b) $\beta = -1.0$

Figure 9: The impact of d_{AB} on the number of commuters and the aggregate commuting distance to and from zone A, for two values of the parameter representing distance deterrence in intraregional moving decisions.

Notice first that the number of commuters to and from zone A increases to a high level if the distance to the regional centre, d_{AB}, is short. This increase is more modest, however, in the case where the moving decisions of workers are not very sensitive to distance. Once again, this reflects the finding in Section 3.1 that the equilibrium spatial distribution of jobs and residences is less sensitive to variations in distance for low negative values of β. Notice also, from the right part of Figure 9, that the number of commuters is very insensitive to variations in distances over 45 in the case with $\beta = 1.0$. It also follows from the figure that reductions in distance, for $d_{AB} > 45$, induce reduced aggregate commuting distance. The dominating effect is that the average commuter to and from zone A travels a shorter distance as a consequence of road improvements.

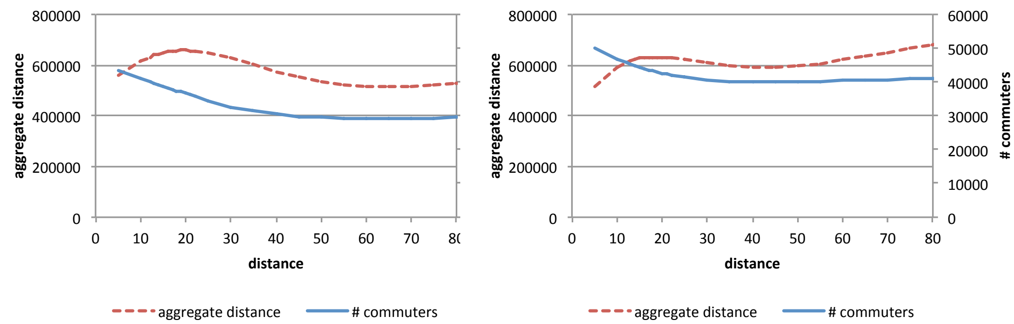
Assume next that the distance d_{AB} is initially shorter than approximately 15-20 km, prior to investments in the road network. It follows from Figure 9 that reductions in distance then lead to a reduced aggregate distance of commuting to and from zone A. The explanation is that shorter average commuting distance, combined with the effect of relocation effects, more than outweighs the effect of an increased number of commuters. The reduction in aggregate commuting distance is especially distinct in the case with a low negative value of β, reflecting for instance that the increased number of commuters is more modest in this case.

In principle, this reduction in aggregate commuting on a specific link does not necessarily provide an environmental argument in favour of road investments. The reduction may have its counterpart in increased traffic on other links in the system. Figure 10 illustrates how the total number of commuters and the aggregate system-wide commuting distance depend on the distance between zone A and the regional centre, d_{AB}. According to the figure, improvements in the road network may actually cause reductions in the aggregate commuting distance, despite the fact that the number of commuters increase.

6 Conclusions

It has been the aim of this chapter to draw attention to a potentially important source of error in estimating the benefits arising from changes in transportation infrastructure. This error occurs when it is assumed that firms and workers will not relocate in response to a change in infrastructure. In this chapter, a model is constructed for analysing this problem on an intraregional scale.

It was shown, using our model, that assuming fixed locations could result in either an under- or over-estimation of the traffic on the road link under analysis.



a) $\beta = -0.25$ b) $\beta = -1.0$

Figure 10: The impact of d_{AB} on the number of commuters and the aggregate commuting distance in the geography, for two values of the parameter representing distance deterrence in intraregional moving decisions.

The direction and magnitude of the error will depend on the preferences of agents in the geography, and the spatial structure of the region. One of the key factors is the sensitivity of people's migration decisions to distance. When workers are insensitive to distance, there is very little relocation in response to a change in the infrastructure. The reasoning is that distance receives a low weight in people's decision about where to live. When people are sensitive to distance, the opposite was true.

The spatial structure of the region also turned out to be important. Adjusting distances for settlements closer to the CBD had a much larger impact than making the same changes at a larger distance from the CBD. This is logical, given that thresholds generally exist for how far people are willing to commute, or how far they are willing to travel to go shopping. The configuration of settlements within a region will therefore also affect any relocation response to the change in the infrastructure.

We can therefore say, based on our numerical experiments, that there are a two factors which ought to raise particular concern about using a naive model assuming fixed locations. Firstly, when workers are sensitive to distance regarding their location decisions we would expect larger errors when erroneously assuming fixed locations. The second factor we can identify is when the change in infrastructure is taking place close to the CBD. As the distance to the CBD declines, and as workers become more sensitive to distance, the prediction errors can be expected to rise.

In terms of the cost benefit analysis of an infrastructure project, a number of important effects have been identified. A failure to adequately deal with location modelling may deny us, *ex ante*, information about outcomes which are potentially important in the decision making process. For instance, if we are concerned about equity between urban and rural areas, we may favour policies which encourage people to live in more peripheral areas. Here, the location effects are important as an end, rather than simply a means.

Perhaps the most important aspect of neglecting relocation effects is the effect on the estimated demand for a new or improved road. Relocation may result in higher or lower demand than would be expected if locations were assumed to be fixed. We have shown an example where the benefit was underestiamted by 13.5% due to an underestimation of demand. Such an error may make the difference between the project going ahead or not.

Incorrect predictions of demand will also prove problematic when estimating the expected environmental costs of a change in infrastructure. As has been shown, the environmental effects can be complex. A shorter journey time may increase demand, but reduce the overall distance driven by all drivers. Understanding how location decisions will respond to a change in infrastructure is important in understanding the environmental impact. A project which may appears to have a negative impact when using a naive model, may in fact have a positive impact when taking relocation effects into account.

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A A technical presentation of the model

This appendix provides a technical presentation of the mechanisms represented in Figure 1. The spatial distribution of basic sector firms is considered to be exogenously given, which means that aspects of local innovativity and competitiveness are not explicitly accounted for. In this version of the model we further ignore the possibility that migration decisions are affected by job diversity and local amenities, while housing prices and wages are assumed to be exogenously given.

A.1 Basic and local sector firms; the economic base multiplier

Total employment in zone i (E_i) is defined to be the sum of basic sector employment (E_i^b) and local sector employment (E_i^l) in the zone:

$$E_i \equiv E_i^b + E_i^l \tag{1}$$

Let $\boldsymbol{L}$ be a vector representing a given residential location pattern of workers, while T_{ij} is the probability that a worker lives in zone i and works in zone j. Hence, $\boldsymbol{T} = [T_{ij}]$ represents the commuting matrix in the geography, and by definition:

$$\boldsymbol{TE} = \boldsymbol{L} \tag{2}$$

The spatial distribution of local sector activities reflects both the spatial residential pattern and the spatial shopping behaviour. Assume that the number of workers living in a zone is proportional to the number of residents/consumers in the zone, and let C_{ij} be the number of local sector jobs in zone i which are supported by shopping from worker living in zone j. Hence, $\boldsymbol{C} = [C_{ij}]$ is a shopping matrix, and the spatial distribution of employment in local sector activities is given by:

$$\boldsymbol{E^l} = \boldsymbol{CL} \tag{3}$$

Given that the inverse of the matrix $\boldsymbol{(I-TC)}$ exists, it follows from Equations (1), (2) and (3) that:

$$\begin{aligned} \boldsymbol{L} &= (\boldsymbol{I}-\boldsymbol{TC})^{-1}\boldsymbol{TE^b} && (4) \\ \boldsymbol{E^l} &= \boldsymbol{C}(\boldsymbol{I}-\boldsymbol{TC})^{-1}\boldsymbol{TE^b} && (5) \end{aligned}$$

These solutions capture the economic base multiplier process: people attract local sector activities, while local sector employment opportunities attract workers (see Section 2). As mentioned above the spatial distribution of basic sector activities ($\boldsymbol{E^b}$) will be considered exogenous in the model, while the other variables ($\boldsymbol{C}, \boldsymbol{E^l}, \boldsymbol{T}, \boldsymbol{L}$) are represented by a set of equations representing shopping, commuting, location, and migration decisions of households and firms. In the next two subsections of this appendix we consider how residential location and migration decisions reflect spatial disparities in the labour market situation as well as characteristics of the spatial structure and the road transportation network.

A.2 Interzonal migration flows and spatial equilibrium

In modeling migration probabilities Nævdal et al. (1996) introduced a nice trick to facilitate construction of Markov chains. The construction uses a symmetric matrix $\boldsymbol{Q} = \{Q\}_{i,j=1}^{N}$, where all the elements ($Q_{ij} \geq 0, i, j = 1, 2, ..., n$) are dependent on the characteristics of the geography. The transition matrix $\boldsymbol{M} = \{P_{ij}\}_{i,j=1}^{N}$, is given by:

$$P_{ij} = \frac{Q_{ij}}{\sum_{k,k\neq j} Q_{kj}} \qquad i, j = 1, 2, ..., N \tag{6}$$

Nævdal et al. (1996) showed that any assumption about the coefficients Q_{ij} can be interpreted as an assumption about migration flows in the equilibrium state. As a next step Nævdal et al. (1996) introduced some network characteristics which are symmetric between zones, and which are relevant in explaining the relevant kind of spatial interaction. For a connected network with fixed Q_{ij}-s, the construction produces regular Markov chains. Nævdal et al. (1996) showed that the equilibrium condition is given by the eigenvector:

$$\boldsymbol{L} = \begin{bmatrix} \frac{\sum_{i,i\neq 1} Q_{i1}}{1-P_{11}} \\ . \\ . \\ . \\ \frac{\sum_{i,i\neq 1} Q_{iN}}{1-P_{NN}} \end{bmatrix} \tag{7}$$

Let $\alpha_i = 1 - P_{ii} \neq 0, i = 1, 2, ..., N$ be the probability that a person will not stay in zone i within the given time-frame. In this subsection we focus on internal migration flows, and the diagonal elements α_i of the migration probability matrix are assumed to be given. Assume next a strategy where a migrant evaluates destinations successively outwards over the network, and moves to the first zone where the conditions are 'satisfactory'. In addition, we introduce a simplifying assumption of constant absorption, defined by the absorption parameter s:

$$s = \frac{\text{Probability of moving to } (m+1)\text{-th neighbours}}{\text{Probability of moving to } m\text{-th neighbours}}, \qquad \text{constant in } m$$

As an operational assumption accounting for the impact of both distance and absorption the migration flows between zone i and its m-th neighbour will be proportional to $\frac{s^m}{d_{ij}^{\beta}}$, where β is a distance deterrence parameter. The step parameter n defines the maximum transition length, i.e., the transition probability is zero between neighbours of order greater than n. The symmetric $\boldsymbol{Q}$-matrix derived from this procedure defines the transition matrix $\boldsymbol{M}$ by (6). As an illustration, the transition matrix for a simple linear three-node system is given by:

$$\begin{bmatrix} 1-\alpha_1 & \frac{s\alpha_2}{d_{21}^\beta}\left(\frac{s}{d_{12}^\beta}+\frac{s}{d_{32}^\beta}\right) & \frac{s^2\alpha_3}{(d_{12}+d_{23})^\beta}\left(\frac{s}{d_{23}^\beta}+\frac{s^2}{(d_{12}+d_{23})^\beta}\right) \\ \frac{s\alpha_1}{d_{21}^\beta}\left(\frac{s}{d_{21}^\beta}+\frac{s^2}{(d_{21}+d_{32})^\beta}\right) & 1-\alpha_2 & \frac{s\alpha_3}{d_{23}}\left(\frac{s}{d_{23}^\beta}+\frac{s^2}{(d_{12}+d_{23})^\beta}\right) \\ \frac{s^2\alpha_1}{(d_{21}+d_{32})^\beta}\left(\frac{s}{d_{21}^\beta}+\frac{s^2}{(d_{21}+d_{32})^\beta}\right) & \frac{s\alpha_2}{\left(\frac{s}{d_{21}^\beta}+\frac{s}{d_{32}^\beta}\right)d_{32}^\beta} & 1-\alpha_3 \end{bmatrix}$$

In our chapter the coefficients will be state dependent, i.e., the Q_{ij}-s are functions of $\boldsymbol{E}$ and $\boldsymbol{L}$. In that case the equilibria are no longer unique, but the interpretation in terms of the strength of migration flows in the equilibrium state remains valid, see Nævdal et al. (1996). A standard application of Brouwer's fixpoint theorem gives that equilibria always exist in the state dependent case.

A.3 The decision to stay or move from a zone

It is a central hypothesis in the model that the decision to stay or move from a zone depends on the labour market accessibility of the zone. Labour market accessibility is introduced by a measure of generalized distance, rather than for example by a gravity-based Hansen accessibility measure (Hansen 1959). The generalized distance from zone i is given by:

$$d_i = \sum_{j\neq i} \frac{W_j}{\sum_{k\neq i} W_k} d_{ij} \tag{8}$$

Labour market accessibility is of course not just a matter of distances, the weights W_i represents the size of alternative job destinations. The size, and thickness, of a potential destination is assumed to be represented by the number of jobs; $W_j = E_j, j = 1, 2, ..., N$, defining d_i as the average Euclidean distance to potential employment opportunities in the geography. In a spatial labour market context, however, it can be argued that potential destinations within a reasonable commuting distance should be put more weight on than more distant destination alternatives. This is done through the introduction of a distance deterrence function $D(d_{ij})$, that places a relatively high weight on destinations which lie within a short distance from the residential location:

$$W_j = E_j(1 - D(d_{ij})) \tag{9}$$

The distance deterrence, and, hence, the weights, are parameterised by d_∞, d_0 and μ in the following logistic expression:

$$D(x) = \frac{1}{1 + e^{-k(x - x_0)}} \qquad x_0 = \frac{1}{2}(d_0 + d_\infty), k = \frac{2\log(\frac{1}{\mu} - 1)}{d_\infty - d_0} \tag{10}$$

d_∞ is the upper limit for how far workers, as a rule, are willing to commute on a daily basis, d_0 is the lower limit (internal distance) where people are insensitive to further decreases in distance, while μ captures friction effects in the system. The values of x_0 and k are given to satisfy the conditions $D(d_0) = \mu$ and $(1 - D(d_\infty)) = \mu$. If , e.g., $\mu = 0.05$, this means that the function will fall to 5% of its value outside the range where $d_0 \leq x \leq d_\infty$. Glenn et al. (2004) give a microeconomic and geometric justification for the use of such a function.

Finally, the definition of generalized distance also accounts for the competition for jobs at alternative locations (Liu and Zhu, 2004; Shen, 1998), represented in the model by the proportion of the total number of job seekers in each potential destination, $\frac{E_j}{L_j}$:

$$W_j = E_j(1 - D(d_{ij}))\frac{E_j}{L_j} \tag{11}$$

The definition of generalized distance is included in the diagonal elements of the migration matrix, reflecting workers spatial interaction response to an unfortunate local labour market situation ($L_i > E_i$). A high value of d_i (and $D(d_i)$) means that the migration decisions are very sensitive to the local labour market situation. On the other hand, a high local unemployment does not in itself bring about a significant out-migration from zones in highly accessible labour market location (low d_i), with an excellent commuting potential. This is captured by the following specification of α_i:

$$\alpha_i = \alpha_i(L_i) + D(d_i) \max\{\rho \left(\frac{L_i - E_i}{L_i} \right), 0\} \tag{12}$$

Here, the parameter ρ reflects the speed of adjustment to an unfortunate labour market situation, towards a situation with a balance in the local labour market, $L_i = E_i$.

A.4 The spatial distribution of local sector employment

It is reasonable to assume that local sector activities in a whole region (E_r^l) are proportional to population in the region (L_r):

$$E_r^l = \sum_i^n E_i^l = b \sum_i^n L_i = bL_r \qquad b > 0 \tag{13}$$

where b is the proportion parameter. Let the spatial distribution of local sector employment be represented by $\frac{E_i^l}{L_i}$, that is the number of shop-employees per resident at location i. Assume, as a simplification, a monocentric region, offering agglomeration benefits for local sector firms and price savings for households in shopping. Shopping decisions then results from a trade-off between price savings and transport costs.

Transportation costs provide an incentive for local sector firms to decentralize in order to cater for local demand. The trade-off between transport costs and potential price savings plays a central role in Gjestland et al. (2006), providing a theoretical base in favor of the hypothesis that the frequency of shopping locally is a smooth, concave, function of the Euclidean distance from the CBD. In our chapter we assume that there is only one CBD, and define the local sector density by:

$$\text{Local sector density} = \frac{E^l}{L}(\text{distance to CBD}) \tag{14}$$

$$= R_\infty(1 - \exp[-\beta_{\text{CBD}} \cdot \text{distance to CBD}]) \tag{15}$$

$$+ C \cdot \exp[-(\gamma \cdot \text{distance to CBD}/d_{\text{dispersion}})^2] \tag{16}$$

The only free parameter is β_{CBD} which controls the decay in the local sector density curve. The other parameters are defined as follows:

$$R_\infty = \frac{\sum_{i=1}^{N} E_i^l}{\sum_{i=1}^{N} L_i} \qquad \text{(average local sector density in the system as a whole)} \tag{17}$$

$d_{\text{dispersion}}$ is the spatial extension of the CBD, $\gamma = \sqrt{-\ln[\kappa]}$ forces the effect of the second term (16) down to κ% of its peak value at the boundary of the CBD. Given values for $\beta_{\text{CBD}}, R_\infty$ and $d_{\text{dispersion}}$, C is chosen such that the integral

$$\int_0^{d_{\text{dispersion}}} \text{Local sector density}(r) \cdot \frac{2r}{d_{\text{dispersion}}^2} \cdot L_{\text{CBD}} dr = E_{\text{CBD}}^l \tag{18}$$

The spatial distribution of local sector activities reflect the net effect of the price savings resulting from agglomeration forces and the transport costs of shopping in the CBD rather than locally.

A.5 Commuting flows

In the model to be used in this chapter, the location of workers and jobs are assumed to be fixed, calling for a doubly-constrained version of the gravity model. It is well known that a doubly-constrained gravity model is equivalent to the multinomial logit model, see Anas (1983) for details. This means that the model can be derived from random utility theory. The doubly-constrained gravity model incorporates set of balancing constraints, representing an assumption of a given spatial distribution of jobs and households. The following model specification ensures that the column sums of the predicted commuting flow matrix equal the total number of jobs at the corresponding destinations, and that each row sum equals the number of workers residing in the corresponding zone:

$$T_{ij} = A_i O_i B_j D_j e^{(-\beta_{\text{gravity}} d_{ij})} \tag{19}$$

$$A_i = \left[\sum_j B_j D_j e^{(-\beta_{\text{gravity}} d_{ij})} \right]^{-1} \tag{20}$$

$$B_j = \left[\sum_i A_i O_i e^{(-\beta_{\text{gravity}} d_{ij})} \right]^{-1} \tag{21}$$

Here:

T_{ij} is the number of commuters from origin i to destination j

O_i is the observed number of commuting trips originating from zone i

D_j is the observed number of commuting trips terminating in zone j

d_{ij} is the travel time from origin i to destination j

A_i and B_j are the balancing factors which ensure the fulfilment of the marginal total constraints; $\sum_j T_{ij} = O_i$ and $\sum_i T_{ij} = D_j$.

A.6 An iterative process towards spatial equilibrium

To initiate the iterative process, we begin with more or less random random initial values for employment and population ($\boldsymbol{E}_0 = \boldsymbol{E}_0^{\boldsymbol{l}} + \boldsymbol{E}_0^{\boldsymbol{b}}$ and $\boldsymbol{L}_0$). These values are fed into a state dependent migration matrix $\boldsymbol{M}$ and adjusted to fit a local sector density curve, which is then iterated until we find a fixed point $\boldsymbol{L}$, which represents the equilibrium solution for population (workers) i.e. that $\boldsymbol{ML} = \boldsymbol{L}$, and equilibrium values fitting the local sector (jobs) $\boldsymbol{E^l}$ to the local sector density curve.

A.7 Parameter values chosen for the numerical experiments

Absorption effects are ignored in the very simple transportation network (Figure 3), $s = 1$. The distance deterrence in internal migration flows is represented by an elasticity of $\beta = -1.0$, unless else is stated. The logistic distance deterrence function involved in determining the decisions to stay or move from a zone is specified by $d_\infty = 80, d_0 = 5$, and $\mu = 0.05$, while the speed of adjustment to an unfortunate labour market situation is given by $\rho = 1$. The form of the local sector density function is given by $\kappa = 0.05$ and a spatial extent of the CBD of $d_{\text{dispersion}} = 4$. Estimated commuting flows reflect a distance deterrence parameter of $\beta_{\text{gravity}} = 0.07$.