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An Integrated General Equilibrium Model for Evaluating Demographic, Social and Economic Impacts of Transport Policies

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Abstract

Under the legacy of dominant transport appraisal approach, which mainly relies on traditional cost-benefit assessment (CBA) analyses, candidate policies and associated projects are evaluated in a way to take primarily aggregate information into account. Although it is practical to use these methods, working with aggregate values leaves every kind of disparities aside and individual level information is lost in aggregation. This means that we need better economic models doing more than reducing outcomes of evaluated policies to numerical aggregates and averages. This study proposes a hybrid approach to grasp the heterogeneity among different agents and to endogenise interactions among different markets. A discrete choice theory-based household residential location and transport mode choice model and a traffic equilibrium model based on Wardrop's principles are embedded in a traditional computable general equilibrium (CGE) model representing a closed urban economy. This requires fully integrating three different models (economic model, household location and mode choice model, traffic equilibrium model) using a single mathematical framework. The proposed integrated model is tested using pseudo data of a city with four districts where connection between districts are provided through two-way roads passing through a central district. Households are categorised according to their residential location, working location, preferred commuting mode and social status. Different types of transport policies (i.e. capacity increase in private transport, public transport improvement) are evaluated and impacts of these policies on such parameters like household distribution, households' demands on consumption goods and housing, housing prices are analysed.

Keywords: Wider economy impacts, Transport Policy, Computable General Equilibrium, Discrete Choice Model

JEL Classification: C68, R21, R41

1. Introduction

Urban traffic congestion and its externalities have been one of the top priorities of major cities and, in order to reduce congestion, several projects have been performed or planned. Being apt to capacity increasing investments, as expected when political environments are taken into account, rather than measures on demand management, emerging cities have clung to expensive public projects aiming to increase either road capacity or public transport capacity, particularly underground systems and bus rapid transit (BRT) systems, to reduce traffic congestion. How successful these cities are in reducing traffic congestion (and/or increasing public transport ridership) is heavily under debate, as traffic is not getting better in these cities according to some indices for traffic conditions.

Increasing traffic congestion, despite many mega infrastructure projects, lays bare the need to plan urban transport better. It is obvious that better planning requires better tools, but we need better tools in what aspects? In our day, one can argue that assessment of transport policies and projects are too much focused on some specific questions: "What is the cost of implementing this transport policy?", "What amount of cost savings we can achieve after implementing this transport policy?" and "What other benefits rather than cost savings can this policy provide to the society?" Number and specificity of these questions can be increased or we can push the limits of innovation in order to find new types of benefits justifying ambitious policies and expensive infrastructure projects. How so ever many questions we may ask or new benefits we define, above mentioned assessment approach would probably lead us to work with aggregates (and averages) leaving every kind of disparities aside. To make it clear, how can we qualify a congestion pricing scheme or a traffic pollution charge scheme to be successful if they impede access to job market for low income people, in particular for women, living on outskirts of a city without an adequate public transport infrastructure? Approaching this from a different standpoint, are we sure about all the possible burdens candidate policies lay on different groups of people and individuals' responses in order to reduce effects of these burdens? Policy makers should question candidate policies asking "right questions" whether these policies would lead to undesired outcomes at household level: "Would the proposed policy cause change in health (or education) expenditures of low income people residing at a specific location?", "What would be the effect of this policy on working decisions of a specific group of people? Would they give up working after implementation of this policy?" or "What would be the impact of unskilled immigrants on road traffic? Which parts of the city would require investment in the future?" That's to say, we need more intelligent models with capability of assessing transport policies in a more comprehensive and equitable way.

As Graham (2007) discusses, standard cost and benefit appraisal methods do not address economic impacts of transport policies and investments completely. Microsimulation models are able to model households' and firms' behaviours using micro level data (Robilliard et al., 2001). However, these models are partial equilibrium models and they only consider household side of the economy (Peichl, 2008). On the other hand, general equilibrium models are generally able to provide insights about market mechanisms allocating resources on mutually interdependent markets. They use a few number of (or only one) representative agents (Peichl, 2008). Therefore, they are unable to grasp possible heterogeneity among agents and their behavioural responses to policy changes. In order to internalise transport externalities and distribution of impacts among different economic agents, integrating general models with microsimulation models is considered to be a promising method with substantial potential to close this gap.

This study follows the literature that utilizes a more hybrid approach to grasp the heterogeneity among different agents and also to endogenise interactions among different markets within a single framework. Such an integrated approach can handle impacts of transport policies comprehensively, while simultaneously capturing behavioural heterogeneity of different agents. This interaction is achieved by adding model components capturing key theoretical elements of discrete choice theory into a general equilibrium model.

One of the earlier examples of this integrated approach is Kim et al. (2004). The authors propose an integrated framework with a dynamic computable general equilibrium (CGE) model coupled with a transport model, which measures accessibility changes, in order to evaluate highway projects in terms of economic growth and regional disparity in South Korea. In this study, among the grid-type highway network with seven South-North highways and nine East-West highways, four highways are selected to be assessed in terms of economic measures (benefit-cost ratios and GDP, price and export multipliers) and distributional effects (wage and population) using the proposed integrated model.

Knaap and Oosterhaven (2011) use a CGE model (RAEM) of Knaap and Oosterhaven (2000) in order to evaluate impacts of six different rail connection alternatives for linking Groningen City and Schiphol Airport along with the reference scenario. They evaluate these infrastructure projects in terms of their regional employment effects and national output, price and welfare effects. Scenario analyses of this study show that all the projects would lead to varying levels of decrease in consumer price index, and eventually, increase in national output. The study shows that, among the alternatives, magnetic levitation track with stops at all five intermediate stations between Groningen City and Schiphol Airport (scenario MZM) would lead to a spatial shift of 8,100 jobs.

Anas and Hiramatsu (2012) use a spatial CGE model (RELU) detailed in Anas and Liu (2007) in order to understand impacts of increase in gasoline price on urban economy. This model in the study is calibrated for the Chicago MSA, which is divided into 5 rings covering 15 zones. They integrate this CGE model with a transport model (TRAN) modelling households' discrete choices on travel mode and route choice. Using this framework, they simulate the gasoline price increase in the Chicago MSA from a base value of 1.6 USD in 2000 to 2.45 USD in 2007 alongside with 2.7 percent decrease in technological fuel intensity (TFI) and changes in car acquisition costs. RELU-TRAN framework is used to evaluate impacts of cordon tolling to be implemented in the Chicago MSA in terms of travel, housing and labour markets, to compare Pigouvian tolling of traffic congestion and gasoline tax policies in terms of locations of jobs and residences and to evaluate the effects of planned public transport investments in Paris (Anas, 2013).

Hensher et al. (2012) integrate a transport and location choice modelling system (TRESIS) with a spatial CGE model (SGEM) in order to evaluate impacts of North-West Rail Link project in Sydney, Australia. TRESIS models decisions of households on residential location, housing type, working location, vehicle ownership and travel mode. Origin-Destination (OD) matrix of trips is also estimated using TRESIS model. Within SGEM, each zone in a city is treated as an economy and trade (employment and income flows) is allowed to take place among these zones. In this study, transport improvements of North-West Rail Link project are used by TRESIS in order to decide on household housing and working locations, and travel preferences. Output of the microsimulation model, which clearly identifies the potential employment redistribution within Sydney Metropolitan Area, is used in CGE model in order to model agglomeration and wider economic benefit of the project.

This study proposes a hybrid approach to grasp the heterogeneity among different agents and to endogenise interactions among different markets. A discrete choice theory based household residential location and transport mode choice model and a traffic equilibrium model based on Wardrop's principles are embedded in a general equilibrium model representing the characteristics of a closed urban economy. Such a task requires fully integrating three different models (economic model, household location and mode choice model, traffic equilibrium model) using a single mathematical framework.

Thanks to the integration procedure where models are running simultaneously, equilibrium values are calculated without any iteration looking for convergence. We test the proposed integrated model using a pseudo data set of a representative urban unit with four districts Households are differentiated according to their residential location, working location, preferred commuting mode and social status. In the scenario analysis, we evaluate a set of alternative transport policies (i.e. capacity increase in private transport, public transport improvement, cordon pricing) and analyse the impacts of such policies on a set of parameters including household locational distribution, households' demand on consumption goods and housing, and housing prices observed.

We study the model and the first set of scenario analyses in Section 2. In order to capture the relevance of representing the heterogeneity of households, we introduce the elements of heterogeneity (location categories, travel mode, socio/economic groups) in sequence and discuss the results under a specific scenario (a new private transport link between two districts of a city). Section 3 presents two other simulations under the full heterogeneity set, namely introduction of a (substitute) public transport system and introduction of cordon pricing policy. All scenarios are carried out utilizing a synthetic data for a city with four residential/working districts. Section 4 briefly concludes.

2. Model Specifications and Scenario Analysis

The study constructs an urban CGE model with heterogeneous households and firms. Households are assumed to be the owners of dwellings and capital stock, so households benefit from unearned income generated by renting these assets. Firms carry out production activities and distribute factor incomes. Government, landlords or any other decision makers are neglected within the model framework.

Transport sector and transport services enter into the model in two forms. On one hand, transport is included in households' utility problem due to disutility led by spent time on journeys. On the other hand, transport costs are considered within budget constraints of households. Travel activities, therefore, have negative impacts on household's utility level, particularly for people whose residential locations are far away from their working locations. Using this modelling approach, one would ensure the formation of a balance between housing and transport costs of each household. Otherwise, failing to represent one of the two cost items would lead the model to generate unexpected (and implausible) results. To give an example, without any transport cost, households would choose inexpensive housing locations regardless of their working locations or households would want to reside as close as possible to their working locations in order to minimise transport effects on their utilities in case of incurring no housing cost.

A travel model, which provides travel times between the specified nodes in the city, is embedded within the general equilibrium model. By this approach, extra traffic created by relocation of people can be loaded to congested network, and vice versa.

Turning to discrete choices of decision makers, households are assumed not to decide on their working locations but their housing locations and associated travelling modes. Producers are assumed to be fixed at their operational locations as well. This makes our model a residential location choice model within a general equilibrium framework.

2.1. Model Specifications

Households maximise their utilities in accordance with the following utility function and household budget constraint:

$$U_{iwmg}\left(d,c\right)=\left(\alpha_{iwmg}c_{iwmg}^{\rho}+\alpha_{iwmg}^{h}d_{iwmg}^{\rho}\right)^{1/\rho}-\gamma_{iwmg}\tau_{iwm} \quad (1)$$

$$-M_{iwmg}+r_{i}d_{iwmg}+pc_{iwmg}+\kappa_{iwm}\leq 0 \quad (2)$$

Here, d is the consumption on housing (floor space), c is quantity of consumed goods, $\rho=\left(\sigma-1\right)/\sigma$ and σ is the elasticity of substitution between the housing and the consumption good, α stands for CES coefficients of household utilities, γ is the coefficient for travelling disutility varying by household type and τ is travel time. Consuming one type of consumption good and housing units would increase household utility while travelling causes disutility.

The one-sector of the model representing aggregate economic activity is assumed to exhibit a constant-elasticity-of-substitution (CES) form using one type of labour and capital. Producers solve the following cost minimisation problem for a level of production output:

$$
\begin{aligned}
&\text{Min } \delta K + wL \\
&\quad s.t. \\
&y = \phi\left(\beta K^{\rho} + (1-\beta) L^{\rho}\right)^{1/\rho}
\end{aligned}
\tag{3}
$$

where δ is the rental rate of the capital used for the production and w is the wage rate paid to the employees. Therefore, factor demand functions can be interpreted in terms of production output as in the following equations:

$$L = \frac{y}{\phi}\left[\beta^{\sigma}\delta^{1-\sigma} + (1-\beta)^{\sigma} w^{1-\sigma}\right]^{\frac{\sigma}{1-\sigma}} (1-\beta)^{\sigma} w^{-\sigma} \tag{4}$$

$$K = \frac{y}{\phi}\left[\beta^{\sigma}\delta^{1-\sigma} + (1-\beta)^{\sigma} w^{1-\sigma}\right]^{\frac{\sigma}{1-\sigma}} \beta^{\sigma}\delta^{-\sigma} \tag{5}$$

Using factor demand functions, cost function of producers in terms of factor prices can be written as in the following form:

$$C(\delta, w) = \delta K + wL = \left[\beta^{\sigma}\delta^{1-\sigma} + (1-\beta)^{\sigma} w^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \frac{y}{\phi} \tag{6}$$

Thus, using the “zero profit” condition for producers, output price in terms of factor prices becomes:

$$p(\delta, w) = \frac{\left[\beta^{\sigma}\delta^{1-\sigma} + (1-\beta)^{\sigma} w^{1-\sigma}\right]^{\frac{1}{1-\sigma}}}{\phi} \tag{7}$$

Transport costs (κ_{iwm}) are added to total GDP of this one-sector economy. Therefore, market clearing conditions for production and housing imply that:

$$y = \sum_i \sum_w \sum_m \sum_g N_{i,m}(w, g)\left(c_{iwmg} + \kappa_{iwm}\right) \tag{8}$$

$$K = \sum_i \sum_w \sum_m \sum_g N_{i,m}(w, g) \cdot e_{iwmg}^{K} \tag{9}$$

$$L = \sum_i \sum_w \sum_m \sum_g N_{i,m}(w, g) \cdot e_{iwmg}^{L} \tag{10}$$

$$\sum_w \sum_m \sum_g N_{i',m}(w, g) \cdot d_{i'wmg} = \sum_i \sum_w \sum_m \sum_g e_{iwmg}^{H}(i') \qquad \forall i' \tag{11}$$

where N is the number of household with relevant attributes and e stands for household endowments for business capital, labour and housing in floor space.

Travel model calculates private transport travel times between nodes using travel time function of LeBlanc et al. (1975) where total travel time along an arc is a function of free flow travel time and additional time required due to increasing traffic density.

$$t(a) = \mathrm{A}(a) + \mathrm{B}(a)\left[\frac{q(a)}{Q(a)}\right]^4 \qquad \forall a \in A \tag{12}$$

where, $t(a)$, $\mathrm{A}(a)$, $\mathrm{B}(a)$, $q(a)$ and $Q(a)$ represent, respectively, time required to traverse arc *a*, free flow time required to traverse arc *a*, congestion coefficient for arc *a*, traffic flow on arc *a and* capacity of arc *a*.

Using above travel cost (time) equation, following equalities (and inequalities) are solved in order to calculate travel times between predetermined nodes.

(1) For balancing trips:

$$\sum_{a(i,j)} \upsilon(a,w) = \sum_{a(j,i)} \upsilon(a,w) + trip(i,w) \qquad i \neq w \tag{13}$$

(2) Individual rationality of drivers:

$$t(a) + \tau(j,w) \geq \tau(i,w) \qquad i \neq w \tag{14}$$

(3) Aggregate flow on any arc:

$$q(a) = \sum_{w} \upsilon(a,w) \tag{15}$$

where, $\upsilon(a,w)$ is the flow to node *w* along arc *a*, $trip(i,w)$ represents OD trips from node *i* to node *w* and equals to $\sum_{g} N_{i,m='car'}(w,g)$ and $\tau(i,w)$ is the time to get from node *i* to node *w*.

2.2. Scenario Analysis – I-1: Capacity Increase in Private Transportation (Model with location categories only)

We design a synthetic city for the prototype model described briefly above. This city has four different districts. One of these districts (District 4) is located among the others, which makes it a kind of central business district (CBD) of the city. All the districts are connected to each other via two-way roads passing through the 4th district (Figure 1).

The proposed model, in this Section is studied using the above synthetic city set-up and under the homogenous scenario of increased capacity of a (private) transport between districts 1 and 3. Here, we introduce the elements of heterogeneity (attributes) of the households sequentially. First, households are differentiated only in accordance with their residential locations (*i*) and working locations (*w*). In the next step, preferred commuting mode (*m*) is added to these categories. Commuting mode options represented in this study are public transport and private transport. In the third step, another category for households (*g*) is introduced where households are categorised according to factor types they own. First group of households owns the capital (business + housing) and second group owns the labour. This makes the first group "capital owners" and second group "workers". It should be noted that there is only one type of labour (single wage level) in the economy.

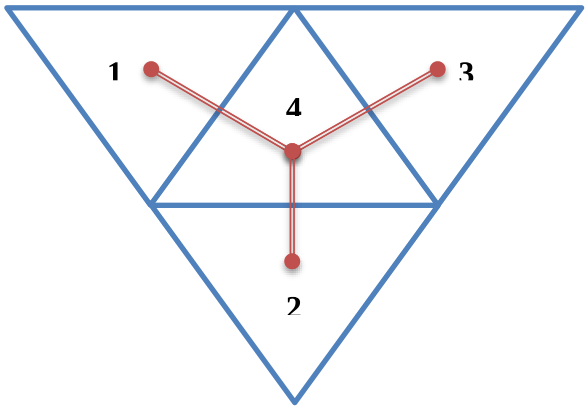

Figure 1: Locations of districts within the city

Under all these cases, we assume that the households maximise their utilities consuming housing units (floor space) and one type of consumption good. This leads us to have a one-sector economy within this city. Housing stock is assumed to be fixed. Housing rents are shared equally among households for the first two scenarios, while these rents are collected by capital owners in the third scenario. All transport costs the households bear are added to GDP, travels are not considered in household utility function as a utility increasing component like housing and consumption goods, though. However, the effects of transport costs are two-fold. On one hand, it has a flat-rate shrinking effect on household budget in accordance with the pair of housing location and working location. On the other hand, disutility of travel, which is associated with spent time for a travel, is taken into account within location choice decisions of households.

As already mentioned above, in this scenario, households are categorised according to their residential locations (1,2,3,4) and working locations (1,2,3,4). Rents for capitals (business + housing) are shared among households equally. The matrix showing the number of households for each locational pair constitutes OD matrix of the city (Table 1). It is assumed that there are 20,000 households in total and most households are prone to do within-district journeys.

Table 1: Number of households travelling between districts

		TO			
		1	2	3	4
FROM	1	2,500	500	500	1,500
	2	500	2,500	500	1,500
	3	500	500	2,500	1,500
	4	500	500	500	3,500

Turning to journeys to be done by these households and related travel costs, travel time required for within-district journeys are assumed to be fixed and travel time required for other journeys are calculated using above OD matrix and certain transport parameters[1] associated with the travel model. Travel costs are assumed to be equal to travel times.

[1] *A*=8, *B*=0.15 and *Q*=1000

Table 2: Travel times for journeys between districts

		TO			
		1	2	3	4
FROM	1	2	24.62	24.62	15.86
	2	24.62	2	24.62	15.86
	3	24.62	24.62	2	15.86
	4	10.76	10.76	10.76	2

For calibration purposes, all households are assumed to consume equal amount of consumption goods. The quantity of consumption good for each household is 50. Housing consumptions (rents paid to owners) in floor space are varying with respect to household categories and calculated in a way to satisfy the following set of equations:

$$\begin{aligned} &d(i,w)+c(i,w)+tc(i,w)=k+l+h \\ &h=\sum_i\sum_w n(i,w)\cdot d(i,w) \Big/ \sum_i\sum_w n(i,w) \end{aligned} \quad (16)$$

where households use their budgets (*k*: capital rent, *l*: wage and *h*: housing rent) for their consumption needs (*c*: consumption good, *d*: housing and *tc*: transport cost) and $n(i,w)$ denotes the number of households with residential location *i* and working location *w*. Housing consumptions of households are displayed in Table 3.

Table 3: Housing consumptions of households

		TO			
		1	2	3	4
FROM	1	42.62	20	20	28.76
	2	20	42.62	20	28.76
	3	20	20	42.62	28.76
	4	33.86	33.86	33.86	42.62

Households maximise their utility in accordance with the following utility function:

$$U_{iw}(d,c)=\left(\alpha_{iw}c_{iw}^{\rho}+\alpha_{iw}^{h}d_{iw}^{\rho}\right)^{1/\rho}-\gamma_{iw}\tau_{iw} \quad (17)$$

Household budget constraint can be written as follows:

$$-M_{iw}+r_i d_{iw}+pc_{iw}+\kappa_{iw}\le 0 \quad (18)$$

where *M* is the total income of a household, *r* is the rental rate for housing, *p* is the price for consumption good and κ is travelling cost. As previously mentioned, earned incomes (wages) and unearned incomes (rents for capitals and dwellings) constitute the household budget. Therefore, household budget (*M*) can be written as in the following equation:

$$M_{iw}=l+\delta e_{iw}^{K}+\sum_{i'} r_{i'} e_{iw}^{H}\left(i'\right) \quad (19)$$

where e^K and e^H are the endowments of capital and dwelling of a household respectively. Using utility function and budget constraint for households, demand functions for consumption good and housing units in terms of prices can be written as follows:

$$c_{iw} = \left(\frac{\alpha_{iw}}{p}\right)^{\sigma} \frac{M_{iw} - \kappa_{iw}}{\left(\alpha_{iw}^{h}\right)^{\sigma} r_i^{1-\sigma} + \left(\alpha_{iw}\right)^{\sigma} p^{1-\sigma}} \tag{20}$$

$$d_{iw} = \left(\frac{\alpha_{iw}^{h}}{r_i}\right)^{\sigma} \frac{M_{iw} - \kappa_{iw}}{\left(\alpha_{iw}^{h}\right)^{\sigma} r_i^{1-\sigma} + \left(\alpha_{iw}\right)^{\sigma} p^{1-\sigma}} \tag{21}$$

Household utility function isn't only used for calculating demand functions of consumption units but also for regional distribution of households within the city. Using MNL household location choice probabilities and exogenously given number of households travelling to a district $N(w)$, number of households residing at a specific location is calculated by using the following equation.

$$N_i(w) = \frac{\exp\left[\left(\alpha_{iw} c_{iw}^{\rho} + \alpha_{iw}^{h} d_{iw}^{\rho}\right)^{1/\rho} - \gamma_{iw}\tau_{iw}\right]}{\sum_j \exp\left[\left(\alpha_{jw} c_{jw}^{\rho} + \alpha_{jw}^{h} d_{jw}^{\rho}\right)^{1/\rho} - \gamma_{jw}\tau_{jw}\right]} N(w) \tag{22}$$

Integrating the above setting with the travel model, a capacity increasing scenario is tested. In this scenario, a direct link between districts 1 and 3 is proposed. It is assumed that technical properties of the new link would be identical with technical properties (properties affecting travel time, i.e. capacity, length) of the existing ones.

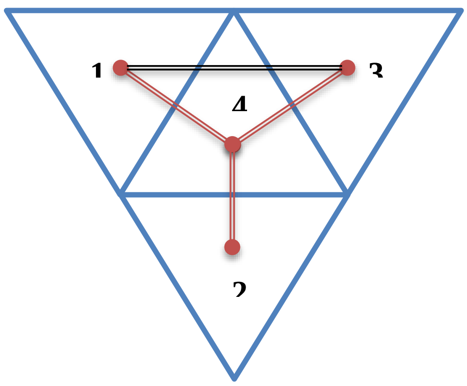

Figure 2: New link between district 1 and district 3

Results of the model indicate that interregional transport costs at equilibrium point would become fairly different than initial transport costs after implementation of the new link. As shown in Table 3, at some routes, about 8 percent deviation is observed. To give an example, at equilibrium point, travel time from District 2 to District 4 would be 7.97 percent lower than initial expectation while travel time from District 1 to District 4 would be 7.13 percent higher.

Table 4: Impact of new link on travel times

		Travel times (initial)				Travel times (equilibrium)			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	2	21.16	10.01	12.40	2	22.23	10.24	13.28
	2	24.01	2	24.01	15.86	22.69	2	22.69	14.60
	3	10.01	21.16	2	12.40	10.24	22.23	2	13.28
	4	10.15	10.76	10.15	2	10.09	10.95	10.09	2

This finding is important to understand the role of integrated models in evaluation of transport policies and investments, and also to have more accurate predictions. The main reason for having different travel time figures in two approaches is that people change their locations in response to changing accessibility of districts. Without taking into account of this phenomenon, it is very unlikely to predict impacts of this kind of projects accurately. Table 5 shows how household distribution would change substantially. As expected, improvement in accessibility between District 1 and District 3 increases the number of households travelling between these two districts significantly while number of households travelling within zones, which benefit from the lowest transport costs at initial setting, decreases.

Table 5: Impact of new link on household distribution

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	2500	500	500	1500	1991.81	550.69	1123.70	1612.78
	2	500	2500	500	1500	432.11	2414.62	432.11	1485.91
	3	500	500	2500	1500	1123.70	550.69	1991.81	1612.78
	4	500	500	500	3500	452.38	484.01	452.38	3288.52

This shift in people's preferences to reside in districts 1 and 3 should have impact in dwelling prices. Results of the model indicate that relative prices of these districts would become higher than the ones of the others. As shown in Table 6, the highest erosion in housing prices would exist in District 4, which is central district of the city. This distinction can be attributed to relative decrease in accessibility of District 4 due to improvements in districts 1 and 3.

Table 6: Impact of new link on housing prices

Initial				Equilibrium			
1	2	3	4	1	2	3	4
1.00	1.00	1.00	1.00	0.97	0.92	0.97	0.88

The model shows that price changes in housing would affect household decisions on consuming housing units in floor space. Table 7 indicates that households enjoy the relative price reduction in District 4, so the highest increase in demand is witnessed at this district and District 2 is the follower. For districts 1 and 3, where the accessibility is improved the most, slight changes in housing demand take place in general due to relatively high housing prices. However, for households travelling between these two districts, housing demand increases with a rate outpacing any other rate of increase. That decreasing transport cost gives way to use extra budget for utility increasing consumptions can be deemed as the main reason behind this distinction. It should also be noted that households travelling within districts 1 and 3 are the only groups having reduced housing demand among all groups of people. Considering consumption good demands of people, which is analysed below, we can say that decrease in total output due to decrease in transport costs would cause some level of decrease in household income. For this reason, some groups of people, which are already enjoying low transport costs, would be affected in a negative way. This finding is important that not every group of people would be influenced in a positive way by implemented policies or investments. Although, as in this case, an investment improves accessibility in a city there may be some groups of people already enjoying poor accessibility. This should lead us to elaborate on impacts of interventions in order to understand how their impacts differ in accordance with different groups and what kind of additional instruments we should consider to remove negative consequences threatening individual rationality of different groups.

Table 7: Impact of new link on housing demand

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	42.62	20.00	20.00	28.76	42.34	20.35	23.84	29.36
	2	20.00	42.62	20.00	28.76	21.02	44.24	21.02	30.09
	3	20.00	20.00	42.62	28.76	23.84	20.35	42.34	29.36
	4	33.86	33.86	33.86	42.62	36.26	35.88	36.26	45.55

Turning to consuming preferences of households on consumption good, the model provides interesting results as in previous analysis on housing demand. As explained before, decrease in demand of households doing within-district journeys in districts 1 and 3 can be explained by reduction in total output of the economy. This time, besides these groups of people, people doing within district journeys in District 2 and people travelling from District 4 to District 2 suffer from this fact although to a lesser extent. However, as in demand change in housing, household groups doing journeys between districts 1 and 3 enjoy the improvement in accessibility the most as expected.

Table 8: Impact of new link on consumption good demand

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	50.00	50.00	50.00	50.00	49.04	50.23	58.83	50.40
	2	50.00	50.00	50.00	50.00	50.33	49.71	50.33	50.10
	3	50.00	50.00	50.00	50.00	58.83	50.23	49.04	50.40
	4	50.00	50.00	50.00	50.00	50.26	49.74	50.26	50.16

2.3. Scenario Analysis – I-2: Model with locational categories and travel modes:

In this step, households' preferences on their commuting modes are added to the model structure. Therefore, households are categorised according to their residential locations and working locations, and preferred commuting mode between these locations. As in the first case, rents for business capitals and dwelling units are shared among households equally. This time, 23,800 households (13,700 private transport users and 10,100 public transport users) are assumed to be resided in the city. Numbers of households travelling between regions with respect to commuting modes are listed in Table 9 and Table 10.

Table 9: Number of households travelling between districts (private transport)

		TO			
		1	2	3	4
FROM	1	1,000	600	500	1,000
	2	500	600	500	1,500
	3	600	700	1,000	1,000
	4	900	800	1,000	1,500

Table 10: Number of households travelling between districts (public transport)

		TO			
		1	2	3	4
FROM	1	1,000	300	400	1,500
	2	600	1,000	700	1,000
	3	300	400	500	1,000
	4	400	300	200	500

This time, we have more complex travel time and cost structures when compared to the first case. For private transport mode, travel times and travel costs are assumed to be equal as in the first scenario, though. Travel time required for private within-district journeys are assumed to be fixed with the value of 5. For this mode, travel time required for other journeys are calculated as in the first scenario. However, travel time for public transport journeys do not vary in accordance with congestion level but with route lengths. To be more explicit, travel time for within-district journeys is assumed to be 10 while it is assumed to be 15 for adjacent districts and 30 for the others. Public transport cost for within-district journeys is assumed to be 4 and 10 for all the other journeys regardless of route lengths. Travel times and travel costs for each mode are provided in Tables 11 and 12.

Table 11: Travel times for journeys between districts for private and public transport

		Private Transport				Public Transport			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	5	21.83	21.32	10.92	10	30	30	15
	2	24.26	5	24.26	13.86	30	10	30	15
	3	22.60	23.12	5	12.20	30	30	10	15
	4	10.40	10.92	10.40	5	15	15	15	10

Table 12: Travel costs for journeys between districts for private and public transport

		Private Transport				Public Transport			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	5	21.83	21.32	10.92	4	10	10	10
	2	24.26	5	24.26	13.86	10	4	10	10
	3	22.60	23.12	5	12.20	10	10	4	10
	4	10.40	10.92	10.40	5	10	10	10	4

As in the first scenario, all households are assumed to consume equal amount of consumption goods with the quantity of 50 units and housing consumptions in floor space are assumed to be varying with respect to household categories. Housing consumptions are calculated mathematically in a way to satisfy the following set of equations, which is a modified version of equation set (16) with an additional household category index *m* denoting commuting mode:

$$\begin{aligned} & d(i,w,m)+c(i,w,m)+tc(i,w,m)=k+l+h \\ & h=\sum_i\sum_w\sum_m n(i,w,m)\cdot d(i,w,m)\Big/\sum_i\sum_w\sum_m n(i,w,m) \end{aligned} \tag{23}$$

After solving above equation set, we would find households' housing consumptions in floor space as in the following table.

Table 13: Housing consumptions of households

		Private Transport				Public Transport			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	39.26	22.42	22.94	33.34	40.26	34.26	34.26	34.26
	2	20.00	39.26	20.00	30.40	34.26	40.26	34.26	34.26
	3	21.66	21.14	39.26	32.06	34.26	34.26	40.26	34.26
	4	33.86	33.34	33.86	39.26	34.26	34.26	34.26	40.26

Household utility function, household budget constraint and household budget equation are revised accordingly with household indices as in Equation (24), Equation (25) and Equation (26):

$$U_{iwm}\left(d,c\right)=\left(\alpha_{iwm}c_{iwm}^{\rho}+\alpha_{iwm}^{h}d_{iwm}^{\rho}\right)^{1/\rho}-\gamma_{iwm}\tau_{iwm} \tag{24}$$

$$-M_{iwm}+r_i d_{iwm}+pc_{iwm}+\kappa_{iwm}\leq 0 \tag{25}$$

$$M_{iwm}=l+\delta e_{iwm}^{K}+\sum_{i'}r_{i'}e_{iwm}^{H}\left(i'\right) \tag{26}$$

Defining the above set of equations as a household utility maximisation problem would lead to have following demand functions for consumption good and housing units in terms of prices:

$$c_{iwm}=\left(\frac{\alpha_{iwm}}{p}\right)^{\sigma}\frac{M_{iwm}-\kappa_{iwm}}{\left(\alpha_{iwm}^{h}\right)^{\sigma}r_i^{1-\sigma}+\left(\alpha_{iwm}\right)^{\sigma}p^{1-\sigma}} \tag{27}$$

$$d_{iwm}=\left(\frac{\alpha_{iwm}^{h}}{r_i}\right)^{\sigma}\frac{M_{iwm}-\kappa_{iwm}}{\left(\alpha_{iwm}^{h}\right)^{\sigma}r_i^{1-\sigma}+\left(\alpha_{iwm}\right)^{\sigma}p^{1-\sigma}} \tag{28}$$

Using MNL household location and travel mode choice probabilities and exogenously given number of households travelling to a specific region, $N\left(w\right)$, number of households residing at a specific location and using a specific travelling mode is calculated by using the following equation.

$$N_{i,m}\left(w\right)=\frac{\exp\left[\left(\alpha_{iwm}c_{iwm}^{\rho}+\alpha_{iwm}^{h}d_{iwm}^{\rho}\right)^{1/\rho}-\gamma_{iwm}\tau_{iwm}\right]}{\sum_{j}\sum_{m'}\exp\left[\left(\alpha_{jwm'}c_{jwm'}^{\rho}+\alpha_{jwm'}^{h}d_{jwm'}^{\rho}\right)^{1/\rho}-\gamma_{jwm'}\tau_{jwm'}\right]}N\left(w\right) \tag{29}$$

Equations for production side of the economy are not affected by the new setting of household categories. Therefore, producers solve the same cost minimisation problem for a level of production output defined within the first scenario.

In this scenario, a direct link between districts 1 and 3 is proposed as illustrated previously in Figure (2). It should be noted that this link is used by only private cars although its technical properties are the same with the existing links' properties.

Results of the model indicate that interregional transport costs for private transport mode at equilibrium point would become fairly different than initial transport costs after implementation of the new link. As displayed in Table 14, travel time difference between initial expectation level and equilibrium level becomes more than 4 percent for some routes. At equilibrium point, travel times from District 3 to District 4 and District 2 would be 4.14 percent and 3.34 percent higher than initial expectations respectively. There is a general travel time decrease for journeys from District 2 when we compare equilibrium levels with initial levels. To give an example, travel time from District 2 to District 4 would be 2.54 percent lower.

Table 14: Impact of new link on travel times (private transport)

		Travel times (initial)				Travel times (equilibrium)			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	5	19.90	8.01	8.98	5	20.33	8.05	9.18
	2	22.44	5	22.62	13.86	22.01	5	22.12	13.51
	3	8.02	20.17	5	9.25	8.08	20.78	5	9.64
	4	8.58	10.92	8.76	5	8.51	11.15	8.61	5

Tables 15 and 16 show initial and equilibrium levels of household distribution within the city for each travel mode. As expected, building a direct link between districts 1 and 3 improves accessibility levels of these districts. For private transport users, this improvement would lead to increase in the number of households travelling between these two districts significantly. To be more clear, number of households travelling from District 1 to District 3 increases about 54 percent and while this figure for journeys in reverse direction is about 44 percent.

Another expected impact is on private transport. Building a new link serving only to private transport increases the attractiveness of private transport when compared to public transport. As the most obvious consequence of this, number of private transport users increases from 13,700 to 14,084. This means that an obvious shift in transport alternatives would happen as a result of this capacity increase.

Table 15: Impact of new link on household distribution (private transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	1000	600	500	1000	933.67	621.40	774.09	1052.38
	2	500	600	500	1500	500.95	590.18	496.60	1468.87
	3	600	700	1000	1000	865.78	736.06	931.17	1079.85
	4	900	800	1000	1500	855.49	781.67	927.57	1468.72

As shown in Table 16, number of public transport users for each location pair decreases at varying levels. It should be noted that these decreases for journeys to districts 1 and 3 are obviously higher than the others.

Table 16: Impact of new link on household distribution (public transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	1000	300	400	1500	933.59	296.29	372.02	1475.48
	2	600	1000	700	1000	557.93	983.73	648.03	979.10
	3	300	400	500	1000	280.92	395.98	465.50	985.97
	4	400	300	200	500	371.68	294.70	185.01	489.63

It is obvious that shifts in people' preferences in residential location and travelling mode would have impact on economic parameters. Results of the model indicate that relative prices in districts 1 and 3 would become substantially higher than the ones at the other regions as expected. Price increase for district 3 would be 8 percent while price decrease for District 4, which is CBD, would be as high as 4 percent. (Table 17)

Table 17: Impact of new link on housing prices

Initial				Equilibrium			
1	2	3	4	1	2	3	4
1.00	1.00	1.00	1.00	1.04	0.97	1.08	0.96

Table 18 and Table 19 show how housing demand of households using private transport and public transport changes respectively. We notice a general demand increase for districts 2 and 4 where relative housing prices decrease. Considering together increases in price and number of resident households for districts 1 and 3 would easily explain slight decreases in housing demand for these regions. However, for private transport users, it should be noted that housing demand of households travelling between District 1 and District 3 significantly increases (Table18). Private transport accessibility increase for people travelling between these districts is the underlying reason for this. Since there is no improvement for public transport users travelling between districts 1 and 3, we can't mention about a distinctive increase in housing demand for this group of people, but slight demand increases for people in districts 2 and 4 and slight decreases for the rest.

Table 18: Impact of new link on housing demand (private transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	39.26	22.42	22.94	33.34	38.22	22.37	26.47	33.17
	2	20.00	39.26	20.00	30.40	21.15	40.27	21.12	31.30
	3	21.66	21.14	39.26	32.06	24.86	20.87	37.26	31.45
	4	33.86	33.34	33.86	39.26	35.80	34.38	35.75	40.61

Table 19: Impact of new link on housing demand (public transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	40.26	34.26	34.26	34.26	39.19	33.39	33.39	33.39
	2	34.26	40.26	34.26	34.26	35.13	41.29	35.13	35.13
	3	34.26	34.26	40.26	34.26	32.57	32.57	38.20	32.57
	4	34.26	34.26	34.26	40.26	35.43	35.43	35.43	41.65

The model shows that households' consuming preferences on consumption good would be affected as their preferences on housing. Since transport costs for households using public transport for their commuting journeys don't change due to the new link between districts 1 and 3, we can see the impact of housing price changes on consumption decisions of households. To make it more clear, consumption good demand of households residing in districts 1 and 3 slightly decreases while the one of them residing at other districts increases without any exception (Table 21). It should be noted that these changes are moving along a narrow interval and the maximum change becomes only 1.38 percent. On the other hand, for private transport users, only two groups of households (among 16) demand less consumption goods when compared to the setting before building the new link (Table 20). For these people, consumption good demand decreases by 0.48 percent and 1.26 percent. In addition to this, humble rates, as in public transport, give way to quite high ones. To give an example, after implementing the new link, households travelling between districts 1 and 3 using their own private cars demand more consumption goods more by the rates of 17.96 percent and 19.40 percent. This, obviously, can be linked to general improvement in transport costs for private transport, particularly for the journeys between districts 1 and 3.

Table 20: Impact of new link on consumption good demand (private transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	50.00	50.00	50.00	50.00	49.76	50.99	58.98	50.85
	2	50.00	50.00	50.00	50.00	52.13	50.56	52.05	50.76
	3	50.00	50.00	50.00	50.00	59.70	51.33	49.37	51.02
	4	50.00	50.00	50.00	50.00	51.81	50.53	51.74	50.69

Table 21: Impact of new link on consumption good demand (public transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	50.00	50.00	50.00	50.00	49.75	49.81	49.81	49.81
	2	50.00	50.00	50.00	50.00	50.55	50.56	50.55	50.55
	3	50.00	50.00	50.00	50.00	49.45	49.45	49.35	49.45
	4	50.00	50.00	50.00	50.00	50.67	50.67	50.67	50.69

Apart from the previous scenario, introducing a new group of people (public transport users) has enabled us to understand the impact of the new link on different groups and what type of equity problems to be faced. Without making any improvement in public transport, even not making public transport available on the new link, public transport users would become definite losers of the proposed infrastructural "improvement".

2.4. Scenario I-3: Model with locational categories, travel modes and economic groups:

Next, we introduce a new attribute of heterogeneity to categorise households with respect to their endowments. As briefly discussed before, first group of households (capital owners) owns the capital (business + housing) within the economy. Generated income for rented capitals is shared among this group equally. Second group of households (workers) owns the labour. There is only one type of labour that is employed within production activities. This leads to have a single wage level in the economy.

Now, households are categorised according to their residential locations and working locations, preferred commuting mode between these locations and abovementioned economic groups they are in. As in the second scenario, 23,800 households (13,090 private transport users + 10,710 public transport users) are residing in the city. About 16 percent of households (3,859 households) are assumed to be capital owners. It should be noted here that capital owners are assumed to be more apt to use their private vehicles for their commuting trips when compared to workers. About 84 percent of capital owners use private transport, while this figure is roughly half for workers. Numbers of households with different economic groups travelling between districts with respect to commuting modes are listed in Tables 22 and 23.

Table 22: Number of travelling households with different economic groups (private transport)

		Capital owners				Workers			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	324	141	139	328	880	212	270	935
	2	110	162	180	365	397	536	492	1,230
	3	87	129	203	221	404	355	255	805
	4	203	171	185	283	801	906	750	631

Table 23: Number of travelling households with different economic groups (public transport)

		Capital owners				Workers			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	76	30	32	72	720	517	459	1,165
	2	22	30	36	85	571	872	492	820
	3	21	14	22	39	388	602	1,020	935
	4	44	5	43	57	252	18	222	1,029

For this scenario, for private transport mode, travel times and travel costs are assumed to be equal as in other scenarios. Travel time required for private within-district journeys is fixed to 5 and travel time required for other journeys is calculated using the travel model. As in the second scenario, travel time required for public transport journeys do not change due to the congestion level but with route lengths. Travel time and cost structures for this mode are adopted from the previous scenario without any change.

It should also be noted that transport time and cost figures do not change with economic group of households. The categories effective in these figures are households' locations (both residential and working) and their preferences on commuting mode.

Since we have distinctive income levels for each economic group of households, we would introduce different consumption levels for these groups. Capital owners consume more consumption goods than workers do. Consumption level for capital owners is assumed to be 400 and it is assumed to be 40 for workers. As in previous scenarios, housing consumptions in floor space are assumed to be varying with respect to household categories. Housing consumption for each household category is calculated using the following set of equations with an additional household category index g (1=capital owners, 2=workers) denoting economic group of households:

$$
\begin{aligned}
& d\left(i,w,m,g=1\right)+c\left(i,w,m,g=1\right)+tc\left(i,w,m\right)=k+h \\
& d\left(i,w,m,g=2\right)+c\left(i,w,m,g=2\right)+tc\left(i,w,m\right)=l \\
& h=\sum_i\sum_w\sum_m\sum_g n\left(i,w,m,g\right)\cdot d\left(i,w,m,g\right)\Big/\sum_i\sum_w\sum_m n\left(i,w,m,g=1\right)
\end{aligned} \tag{30}
$$

Solving this equation set mathematically would lead to have households' housing consumptions in floor space as in the following tables. Please notice that capital owners' housing consumptions are fairly higher than workers' consumptions, much as the difference is not as much as in consumption goods.

Table 24: Housing consumptions of households (private transport)

		Capital owners				Workers			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	72.36	56.82	56.36	66.84	32.99	17.45	16.99	27.46
	2	50.07	72.36	50.00	60.48	10.69	32.99	10.63	21.10
	3	56.55	56.94	72.36	66.96	17.17	17.57	32.99	27.58
	4	66.95	67.35	66.88	72.36	27.58	27.97	27.51	32.99

Table 25: Housing consumptions of households (public transport)

		Capital owners				Workers			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	73.36	67.36	67.36	67.36	33.99	27.99	27.99	27.99
	2	67.36	73.36	67.36	67.36	27.99	33.99	27.99	27.99
	3	67.36	67.36	73.36	67.36	27.99	27.99	33.99	27.99
	4	67.36	67.36	67.36	73.36	27.99	27.99	27.99	33.99

Household utility function, household budget constraint and household budget equation are revised accordingly with household indices as follows:

$$U_{iwmg}\left(d,c\right)=\left(\alpha_{iwmg}c_{iwmg}^{\rho}+\alpha_{iwmg}^{h}d_{iwmg}^{\rho}\right)^{1/\rho}-\gamma_{iwmg}\tau_{iwm} \tag{31}$$

$$-M_{iwmg}+r_i d_{iwmg}+pc_{iwmg}+\kappa_{iwm}\le 0 \tag{32}$$

$$M_{iwmg}=\delta e_{iwmg}^{K}+\sum_{i'}r_{i'}e_{iwmg}^{H}\left(i'\right) \qquad \left(g=1\right) \tag{33}$$

$$M_{iwmg}=l \qquad \left(g=2\right) \tag{34}$$

Solving household utility maximisation problem using the above setting would lead us to have following demand functions for consumption good and housing units in terms of prices:

$$c_{iwmg} = \left(\frac{\alpha_{iwmg}}{p} \right)^{\sigma} \frac{M_{iwmg} - \kappa_{iwm}}{\left(\alpha_{iwmg}^{h}\right)^{\sigma} r_i^{1-\sigma} + \left(\alpha_{iwmg}\right)^{\sigma} p^{1-\sigma}} \tag{35}$$

$$d_{iwmg} = \left(\frac{\alpha_{iwmg}^{h}}{r_i} \right)^{\sigma} \frac{M_{iwmg} - \kappa_{iwm}}{\left(\alpha_{iwmg}^{h}\right)^{\sigma} r_i^{1-\sigma} + \left(\alpha_{iwmg}\right)^{\sigma} p^{1-\sigma}} \tag{36}$$

It is assumed that number of households belonging to an economic group and travelling to a specific working location is given and assumed to be fixed. Using these values, $N(w,g)$, and MNL household location and travel mode choice probabilities, for any group of households commuting to any destination, number of households residing at a specific location and using a specific travelling mode is calculated by using the following equation.

$$N_{i,m}(w,g) = \frac{\exp\left[\left(\alpha_{iwmg} c_{iwmg}^{\rho} + \alpha_{iwmg}^{h} d_{iwmg}^{\rho} \right)^{1/\rho} - \gamma_{iwmg} \tau_{iwm} \right]}{\sum_{j} \sum_{m'} \exp\left[\left(\alpha_{jwm'g} c_{jwm'g}^{\rho} + \alpha_{jwm'g}^{h} d_{jwm'g}^{\rho} \right)^{1/\rho} - \gamma_{jwm'g} \tau_{jwm'} \right]} N(w,g) \tag{37}$$

In this scenario, as in the first two scenarios, a direct link between districts 1 and 3 is proposed as illustrated previously in Figure (2). This link is used by only private cars and it is technically identical with the existing links.

When we compare the results of interregional transport times of private transport for initial setting just after implementing the new link and equilibrium level, we find that some results differ at fairly high rates. To give an example, at equilibrium level, travel time from District 2 to District 4 would be 15.45, while it is initially expected to be 16.88 (Table 26). As already explained previously, this explains why people’s movements around the city should be taken into account to have accurate predictions and implement proper policies and projects.

Table 26: Impact of new link on private transport mode travel times

		Travel times (initial)				Travel times (equilibrium)			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	5	19.04	8.00	9.02	5	19.32	8.07	9.14
	2	25.66	5	25.88	16.88	24.04	5	24.18	15.45
	3	8.01	18.79	5	8.78	8.10	19.18	5	9
	4	8.78	10.01	9	5	8.59	10.18	8.73	5

As for people’s movements within the city and their travel mode preferences, it can be concluded that building a direct link carrying private transport traffic between districts 1 and 3 increases demand for private transport. Number of households using private transport increases from 13,090 to 13,619 at a rate of about 4 percent. When we look at the details of this increase, as expected, increases in number of households (both capital owners and workers) travelling between districts 1 and 3 are the main factors. For capital owners, number of households travelling from District 1 to District 3 increases by 46.14 percent, while number of households travelling in opposite direction increases by 143.28 percent (Table 27). For workers, number of households travelling from District 1 to District 3 increases by 126.06 percent, while number of households travelling in opposite direction increases by 67.95 percent (Table 28).

Table 27: Impact of new link on household distribution (capital owners + private transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	324	141	139	328	260.87	143.97	203.14	326.25
	2	110	162	180	365	107.64	157.87	172.12	359.06
	3	87	129	203	221	211.65	137.93	183.17	237.75
	4	203	171	185	283	176.23	164.44	164.90	276.18

Table 28: Impact of new link on household distribution (workers + private transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	880	212	270	935	805.40	230.35	610.35	953.41
	2	397	536	492	1,230	418.94	528.47	494.69	1212.90
	3	404	355	255	805	678.53	381.41	225.78	843.47
	4	801	906	750	631	743.59	890.39	694.85	623.29

It is obvious that these changes due to improvement in private transport accessibility of districts 1 and 3 would lead to substantial changes in number of residents for each district. District 3 is the leading region attracting new households with an increase of 5.15 percent. As expected, number of households in District 1 increases by 2.46 percent while number of households in districts 2 and 4 decreases by 2.54 percent and 4.92 percent respectively.

Table 29: Impact of new link on household distribution (capital owners + public transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	76	30	32	72	61.18	29.58	28.31	71.73
	2	22	30	36	85	17.48	29.24	31.41	83.53
	3	21	14	22	39	17.35	14.16	19.83	39.84
	4	44	5	43	57	34.59	4.81	37.12	55.66

Table 30: Impact of new link on household distribution (workers + public transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	720	517	459	1,165	658.95	511.04	404.66	1,155.89
	2	571	872	492	820	520.91	859.85	432.28	810.84
	3	388	602	1,020	935	357.40	598.81	902.86	933.53
	4	252	18	222	1,029	229.29	17.69	194.54	1,016.66

Turning to economic impacts of shifts in people' preferences in residential location and travelling mode, results of the model show that relative prices in districts 1 and 3, particularly District 3, would become substantially higher than the ones at the other locations as expected. District 3 is the region where prices increases the most with a rate of about 9 percent while price increase in District 1 is about 1 percent. This result is matching with increases in housing demand for these regions as explained above. It should be noted that, within this scenario, price differences among districts becomes more obvious when compared to the previous one. Besides significant price increase in District 3, housing price for District 4 (CBD) decreases by 7 percent. Please notice that this figure was about 4 percent in the previous scenario (Table 31).

Table 31: Impact of new link on housing prices

Initial				Equilibrium			
1	2	3	4	1	2	3	4
1.00	1.00	1.00	1.00	1.01	0.96	1.09	0.93

Table 32, Table 33, Table 34 and Table 35 provide housing demand information for each type of household. Model results indicate that, in line with changes in number of households and housing prices, a general consumption (in floor space) increase is observed for districts 2 and 4, and needless to say, other regions have a reverse situation. However, when we look at the whole picture closer, for private transport users, housing consumption of this group increases in some cases. As a consequence of decreasing private transport cost (particularly between districts 1 and 3) some households increase their housing consumption. To give an example, workers travelling from District 1 to District 3 would increase their housing consumption by 22.12 percent, which is the highest increase rate in housing consumption. This rate is followed by the housing consumption increase rate of workers travelling in reverse direction with the value of 15.54 percent. This shows how improvements in accessibility and transport costs would affect final consumption, albeit an increase in housing prices. Another important result that should be mentioned here is that improvements in accessibility and transport costs do not affect housing consumptions of capital owners as much as workers' consumptions. This can be linked to that these households would rather consume consumption goods more when compare to housing.

Table 32: Impact of new link on housing demand (capital owners + private transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	72.36	56.82	56.36	66.84	71.90	56.62	57.60	66.61
	2	50.07	72.36	50.00	60.48	51.38	73.78	51.30	61.83
	3	56.55	56.94	72.36	66.96	55.24	54.26	68.69	63.77
	4	66.95	67.35	66.88	72.36	69.95	70.07	69.87	75.34

Table 33: Impact of new link on housing demand (workers + private transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	32.99	17.45	16.99	27.46	32.81	17.74	20.74	27.89
	2	10.69	32.99	10.63	21.10	11.64	33.90	11.55	22.15
	3	17.17	17.57	32.99	27.58	19.84	16.96	30.97	26.49
	4	27.58	27.97	27.51	32.99	29.83	29.39	29.72	34.80

Table 34: Impact of new link on housing demand (capital owners + public transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	73.36	67.36	67.36	67.36	72.90	66.94	66.94	66.94
	2	67.36	73.36	67.36	67.36	68.67	74.81	68.67	68.67
	3	67.36	67.36	73.36	67.36	63.96	63.96	69.63	63.96
	4	67.36	67.36	67.36	73.36	70.11	70.11	70.11	76.38

Table 35: Impact of new link on housing demand (workers + public transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	33.99	27.99	27.99	27.99	33.81	27.84	27.84	27.84
	2	27.99	33.99	27.99	27.99	28.74	34.93	28.74	28.74
	3	27.99	27.99	33.99	27.99	26.32	26.32	31.90	26.32
	4	27.99	27.99	27.99	33.99	29.48	29.48	29.48	35.86

The model shows that households' consuming preferences on consumption good would also be affected. As building a new link carrying only private transport traffic leads to improvement in private transport costs, major improvements in household consumptions are achieved for private transport users. To give an example, workers travelling from District 1 to District 3 using their own private vehicles would consume about 22.56 percent more after the new link. This figure is about 20.64 percent for this group of households travelling in reverse direction. It should also be noted that a few number of groups using private transport would consume less consumption goods. This means that, for this group of people, achieved improvements in transport costs supress well the increases in housing costs. (Table 36 and Table 37)

Table 36: Impact of new link on consumption good demand (capital owners + private transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	400	400	400	400	398.92	399.99	410.26	400.11
	2	400	400	400	400	402.82	400.28	402.75	401.33
	3	400	400	400	400	408.02	398.00	396.46	397.81
	4	400	400	400	400	402.78	401.08	402.72	401.36

Table 37: Impact of new link on consumption good demand (workers + private transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	40	40	40	40	39.94	40.80	49.02	40.76
	2	40	40	40	40	42.73	40.34	42.68	41.20
	3	40	40	40	40	48.26	40.32	39.22	40.11
	4	40	40	40	40	41.70	40.51	41.65	40.67

Turning to public transport users, model results indicate that, in line with changes in housing prices, a general consumption increase is observed for districts 2 and 4, and decrease for the others. Without any improvement in transport costs, changing housing costs would lead to these changes in households' consumption preferences. However, the most striking result that should be noted here is that workers doing within-district journey in District 3 using public transport would consume 1.99 percent less after the new link. This figure is the lowest among all types of households.

Table 38: Impact of new link on consumption good demand (capital owners + public transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	400	400	400	400	398.91	398.92	398.92	398.92
	2	400	400	400	400	400.20	400.29	400.20	400.20
	3	400	400	400	400	396.60	396.60	396.43	396.60
	4	400	400	400	400	401.22	401.22	401.22	401.39

Table 39: Impact of new link on consumption good demand (workers + public transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	40	40	40	40	39.93	39.94	39.94	39.94
	2	40	40	40	40	40.31	40.35	40.31	40.31
	3	40	40	40	40	39.29	39.29	39.21	39.29
	4	40	40	40	40	40.61	40.61	40.61	40.68

3. Scenario Analyses under Full Heterogeneity

In this Section we provide the analyses of two different scenarios using the setting defined in Section 2.2.3, under full heterogeneity of households. The first scenario we analyse in this Section is introducing a new link between districts 1 and 3 as in Section 2. But, this time, this new link is used by only public transport vehicles. As the result of this link, public transport travel time between these regions is assumed to decrease from 30 to 20 units, while there are no changes in public transport fees (Figure 3).

The next scenario is introducing a fee for private transport users travelling to District 4 (central district). This practice is often named as "cordon pricing" in the literature. Cordon pricing can be considered as a form of congestion charge (or congestion pricing) scheme, which comes to the fore in order to solve congestion problem although it was originally presented as an instrument financing improvements for transport systems.

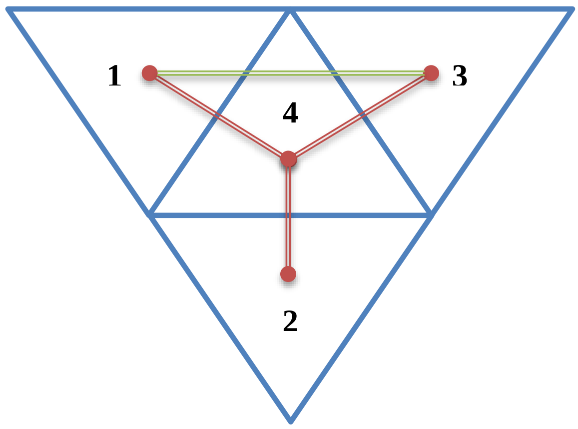

Figure 3: New public transport link between District 1 and District 3

The main rationale beneath congestion charge is that traffic congestion is a kind of market failure caused by “excessive demand” for a public good and implementing a “corrective charge” is needed to internalise traffic congestion externalities (Santos and Newbery, 2001). Although “French engineers” Jules Dupuit (1844) and Joseph Minard (1850) have provided visionary studies in this field, transport related congestion and its pricing mechanisms have not been examined thoroughly before Arthur C. Pigou (1920) where he prepares the ground for taxation according to “marginal social cost” in road transport. In very early versions of Pigou’s “The Economics of Welfare”, it is claimed that rightly chosen measures can be used in order to increase the efficiency of transport. Pigou provides an illustration with two alternative routes and states that shifting some carts from one route to another would be possible by imposing differential taxation against a route. He claims, by this way, that significant level of relief can be provided in the taxed route with a slight trouble in the other route. This illustration is considered to be the milestone debate on congestion charging, since Pigou proposes pricing not for financing infrastructure but for increasing the efficiency of “publicly owned roads” and the social welfare. Besides, Pigou criticizes the road transport taxation mechanism in a way that motorists do not pay for the damage they cause on the infrastructure.[2] However, within this scenario, we would not introduce a marginal social cost pricing scheme, but a fixed toll charged to drivers travelling to District 4.

3.1. Scenario II: Capacity and service improvement in public transport:

In this scenario, rather than building a link carrying private transport traffic, a new public transport route is introduced between districts 1 and 3. This leads to improvement in public transport service delivery and reduces travel time between these districts. As mentioned before, public transport fees do not change (Tables 40 and 41).

The model results show that the public transport improvement in question would lead to certain changes in private transport journeys. Namely, travel times (and travel costs) for private transport journeys would decrease on most of the routes. This improvement should be attributed to the shift in travel mode, which is discussed in detail later in this part. It should be noted that, on certain routes, improvements in private transport travel times would be more than 2 percent while there are slight increases in travel times on some routes.

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[2] That alternative routes have different physical features is not explicitly stated in the book, but it is required to provide such traffic changes in different routes.

Table 40: Travel times for journeys between districts for private and public transport

		Private Transport				Public Transport			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	5	20.54	21	10.52	10	30	**20**	15
	2	27.29	5	27.36	16.88	30	10	30	15
	3	20.81	20.42	5	10.40	**20**	30	10	15
	4	10.41	10.01	10.48	5	15	15	15	10

Table 41: Travel costs for journeys between districts for private and public transport

		Private Transport				Public Transport			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	5	20.54	21	10.52	4	10	10	10
	2	27.29	5	27.36	16.88	10	4	10	10
	3	20.81	20.42	5	10.40	10	10	4	10
	4	10.41	10.01	10.48	5	10	10	10	4

As we have mentioned above, the improvement in public transport would lead to a change in people's travel mode preferences favouring public transport. After the improvement, number of private transport users decrease from 13,090 to 12,926 at a rate of about 1.25 percent, which is fairly lower than the one of previous scenario where a new link carrying private transport traffic is built between the same regions. In order to understand how this is reflected on different groups of people, we can have a look at people's movements within the city. Below tables show generated distribution of different groups of people with respect to their commuting locations, travel mode preferences and economic groups they belong to.

Tables 42 and 43 indicate that, regardless of their economic group, drivers travelling to District 1 and District 3 drop their private vehicles the most when compared to others travelling to other districts. However, when we look at these figures closer we will see that number of drivers travelling from districts 1 and 3 to districts 2 and 4 increase. The main reason beneath this striking outcome should not be linked to travel times as the intervention in public transport leads to very little or no improvement in driving times on these routes, but to population increase in these regions. The number of public transport users, for both economic groups, travelling from districts 1 and 3 to districts 2 and 4 increase as well. As expected, number of public transport users travelling between districts 1 and 3 would increase at a substantial rate. To give an example, number of public transport users belonging to the capital owners group and travelling from District 3 to District 1 would increase by about 148 percent.

Table 42: Impact of new public transport route on household distribution (capital owners + private transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	324	141	139	328	310.85	142.01	136.17	329.80
	2	110	162	180	365	108.06	161.15	174.56	363.16
	3	87	129	203	221	85.80	130.47	196.28	222.87
	4	203	171	185	283	194.68	169.38	177.15	281.19

Table 43: Impact of new public transport route on household distribution (workers + private transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	880	212	270	935	853.16	212.86	265.32	936.42
	2	397	536	492	1,230	391.46	535.29	480.77	1,227.14
	3	404	355	255	805	397.82	356.91	244.83	806.67
	4	801	906	750	631	776.16	903.76	723.82	630.05

Turning to economic impacts of this intervention in public transport, results of the model show that relative housing prices in districts 1 and 3 would increase while prices in other regions would fall slightly. This result is in line with demand increase in housing in districts 1 and 3 due to public transport accessibility improvement. (Table 44) Recalling housing price changes in previous scenario, changes for this scenario appear to be modest. However, it should be noted that magnitude of intervention plays a critical role in magnitude of results. Within this scenario, public transport travel time is assumed to decrease from 30 to 20. It must be born in mind that setting a different level of improvement would have caused different equilibrium levels obviously. In line with changing housing prices and locations of households, housing demand for each household residing in districts 1 and 3 decreases and the one for other regions increases without any exceptions

Table 44: Impact of new public transport route on housing prices

Initial				Equilibrium			
1	2	3	4	1	2	3	4
1.00	1.00	1.00	1.00	1.02	0.99	1.03	0.98

The model shows that changes in housing prices would affect households' consuming preferences on consumption good. As relative housing prices in districts 1 and 3 increase, household demand on consumption goods would decrease in order to compensate this increase. Accompanying with the results on housing demand, this gives an important insight about people's mobility behaviours. The model results indicate that, after the improvement in public transport between districts 1 and 3, higher number of households would begin to live in these regions although they would consume less on both dwellings and consumption goods. The main factor beneath this motivation is the improvement in travel time, which is not represented in household utility function in monetary terms. However, any changes in travel time conditions, accompanied with or without changes in transport costs, would affect utility function that is used in location choices of households. This should lead us to use a benchmarking indicator taking into consideration travel time valuations of households besides their consumptions on housing and other goods in order to compare different policies.

3.2. Scenario III: Introducing cordon pricing for traffic inflow to central district:

In this scenario, rather than a capacity improving intervention, a toll for the entrances to the central district is introduced. After this intervention, drivers travelling to District 4 would have to pay 10 units toll besides their transport costs. This immediately leads private transport journeys to the central district more expensive. Journeys starting and ending in central district are not charged. Public transport fees and times remain unchanged (Tables 45 and 46).

Table 45: Travel times for journeys between regions for private and public transport

		Private Transport				Public Transport			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	5	20.54	21	10.52	10	30	30	15
	2	27.29	5	27.36	16.88	30	10	30	15
	3	20.81	20.42	5	10.40	30	30	10	15
	4	10.41	10.01	10.48	5	15	15	15	10

Table 46: Travel costs for journeys between regions for private and public transport

		Private Transport				Public Transport			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	5	20.54	21	**20.52**	4	10	10	10
	2	27.29	5	27.36	**26.88**	10	4	10	10
	3	20.81	20.42	5	**20.40**	10	10	4	10
	4	10.41	10.01	10.48	5	10	10	10	4

Results show that, for this setting, introducing a cordon pricing results in unexpected and backfiring outcomes. Congestion charge schemes are often used to restrict private vehicle usage, promote public transport and, eventually, relieve traffic congestion. However, in our case, travel times to central district are increased after introduction of cordon pricing (See figures in bold in Table 47). This increase can be explained by increase in private car usage towards central district.

Table 47: Impact of cordon pricing on private transport travel times

		Travel times (initial)				Travel times (equilibrium)			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	5	20.54	21	**10.52**	5	20.56	20.98	**10.55**
	2	27.29	5	27.36	**16.88**	27.30	5	27.35	**16.92**
	3	20.81	20.42	5	**10.40**	20.79	20.43	5	**10.42**
	4	10.41	10.01	10.48	5	10.37	10.01	10.43	5

Here, the number of households travelling to the central district increases, particularly for workers, although there is no substantial change in number of other households. To give an example, number of workers using private and travelling from District 2 to District 4 increases from 1,230 to about 1,263. This increase is even greater than total increase in private transport users, which is about 27.

Tables 48 and 49 show how number of public transport users evolves after implementation of cordon pricing scheme around central district. As already mentioned, an unexpected shift in travel mode favouring private transport takes place. Public transport loses about its 27 riders. It should be noted almost all these losses are coming from the group of workers and ones travelling to the central district play critical role in this.

Table 48: Impact of cordon pricing on household distribution (capital owners + public transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	76	30	32	72	75.89	29.96	31.98	71.33
	2	22	30	36	85	21.90	29.93	35.89	84
	3	21	14	22	39	20.96	13.99	22.01	38.65
	4	44	5	43	57	44.35	5.04	43.41	56.96

Table 49: Impact of cordon pricing on household distribution (workers + public transport)

		Initial				Equilibrium			
		TO				TO			
		1	2	3	4	1	2	3	4
FROM	1	720	517	459	1,165	722.43	517.09	460.48	1,152.34
	2	571	872	492	820	572.06	872.61	493.30	810.61
	3	388	602	1,020	935	388.99	602.16	1,024.31	924.93
	4	252	18	222	1,029	253.25	18.05	223.27	1,020.45

Looking all the household distribution tables above together, number of households living and working in the central district decreases from 2,000 to 1,986. Given working locations of households remain unchanged, after introduction of cordon pricing, these households would move to the other regions. Relative increase in housing prices in District 4 can explain this movement. Table 50 shows that housing prices in District 4 would be higher than the others. This is an expected consequence of cordon pricing as travelling to this region from other regions would be more expensive. It is obvious that this relative price increase in transport would increase demand in centrally located houses. This finding can be supported by other studies in literature. Sato and Hino (2006) show that housing prices increase in and near the charge area using a spatial CGE model for road pricing in Tokyo. In an ex-post evaluation study, Tang (2016) shows that, using households' land registry transactions and census data, Western Extension Zone (WEZ) of congestion charge scheme in London increases in-cordon housing prices at a rate of 3.68 percent when compared to houses within 1 km away from the boundary.

Table 50: Impact of cordon pricing on housing prices

Initial				Equilibrium			
1	2	3	4	1	2	3	4
1.00	1.00	1.00	1.00	0.96	0.96	0.97	1.00

Housing prices explain only a portion of households' movements. To explain remaining movements, we should look at households' behaviours closer. This requires investigating parameters explaining household preferences and heterogeneity among these households. Recalling household utility function in Equation (31),

$$U_{iwmg}\left(d,c\right)=\left(\alpha_{iwmg}c_{iwmg}^{\rho}+\alpha_{iwmg}^{h}d_{iwmg}^{\rho}\right)^{1/\rho}-\gamma_{iwmg}\tau_{iwm}$$

it should be reminded that travel time valuation differs in accordance with the household group. Initial household distribution, so the initial setting, is critical to determine the levels of travel disutility parameter γ. At this point, we would go into details of movements of workers preferring to use private transport for their journeys from District 2 to District 4. Model results show that number of this group of households increase unexpectedly although cost of private transport increases due to cordon pricing and public transport offers shorter travel times for their journeys. This "subtler" consequence can be explained by the difference between γ parameters for two travel modes. Travel disutility parameter for private transport is about 0.0032 while this figure is about 0.0234 for public transport. This leads households travelling on this route to shift from public transport to private transport.

Turning to other macroeconomic impacts of cordon pricing, housing demand of households travelling to the central district using their own private vehicles decrease as they would have increasing transport cost after cordon pricing. Almost all the other household groups consume more on housing due to reductions in relative housing prices. There are slight decreases for some groups of households residing in the central district due to relatively high housing costs for this region.

It is interesting that economic group of households plays a distinction role in households' consumption good demands. Apart from households suffering from cordon pricing, households belonging to capital owners group would consume less on consumption goods while the other group of households consume more. This can be attributed to decreasing housing prices as housing rents constitute capital owners' income budget besides rents obtained for business capitals. For private transport users travelling to the central district, due to increasing transport costs, consumption good demand decreases substantially

4. Concluding Remarks

This study proposed a hybrid approach to grasp the heterogeneity among different agents and to endogenise interactions among different markets. A discrete choice theory based household residential location and transport mode choice model and a traffic equilibrium model based on Wardrop's principles are embedded in a general equilibrium model representing the characteristics of a closed urban economy. Such a task requires fully integrating three different models (economic model, household location and mode choice model, traffic equilibrium model) using a single mathematical framework.

Thanks to the integration procedure where models are running simultaneously, equilibrium values are calculated without any iteration looking for convergence. We tested the proposed integrated model using a pseudo data set of a representative urban unit with four districts Households are differentiated according to their residential location, working location, preferred commuting mode and social status. In the scenario analysis, we evaluate a set of alternative transport policies (i.e. capacity increase in private transport, public transport improvement, cordon pricing) and analyse the impacts of such policies on a set of parameters including household locational distribution, households' demand on consumption goods and housing, and housing prices observed.

We studied the model under three distinct scenarios, namely the capacity increase of private transport, the capacity increase in public transport and cordon pricing. In order to capture the relevance of representing the heterogeneity of households, we introduced elements of heterogeneity (location categories, travel mode, socio/economic groups) in sequence and discussed the results under the first scenario (a new private transport link between two districts of a city). The two other simulations are studied under the full heterogeneity set, namely introduction of increased capacity for public transport system and introduction of cordon pricing policy. All scenarios are carried out utilizing a synthetic data for a city with four residential/working regions.

Our results show that heterogeneity among people in terms of their preferences and valuations is very critical in transport and land use policies. Without considering demographic structures of cities and producing accurate parameters for their preferences, toward policies would only lead to partial analyses.

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