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# Reducing Traffic Congestion in Beirut

## An Empirical Analysis of Selected Policy Options

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## Abstract

Beirut, the capital city of Lebanon, faces huge traffic congestion, the cost of which is estimated to be more than 2 percent of the city's gross regional product. Effective policies are needed, based on weighing their overall economic cost and benefit to society. This study developed an empirical model based on microeconomic theory, accounting for production and consumption behavior related to transportation in the Greater Beirut Area, to simulate various policy combinations. A key finding of the study is that individual supply-side policies, such as the expansion of roads or introduction of a bus rapid transit system, are quite effective at reducing traffic congestion while increasing economic output and welfare. They also account for most of the benefits from implementing policy packages with supply- and demand-side measures. The introduction of bus rapid transit with expansion of the road system to feed the bus rapid transit system reduces congestion by about 16 percent and congestion costs by more than 50 percent. This would increase Beirut's gross regional product by roughly 2 percent, and the average social welfare of the residents of Beirut by 4 percent. In contrast, demand-side instruments, implemented alone, lower gross regional product and welfare with limited effects on congestion.

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# Reducing Traffic Congestion in Beirut: An Empirical Analysis of Selected Policy Options[1]

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## 1. Introduction

Urban transportation in Beirut, the capital city of Lebanon, where more than 40% of the country's total population lives, is facing several challenges, including inadequate infrastructure, traffic congestion, local air pollution and road accidents. The fifteen-year civil war between 1975 and 1990 caused significant destruction of the transportation infrastructure and contributed to the deterioration of the public transport system (Diab and Obeid, 2012). Expansion of urban transport capacity is not meeting the speed of population growth and urbanization, the centralization of activity around the capital and more recently the huge refugee influx from the Syrian Arab Republic. Traffic congestion is considered one of Beirut's most serious urban development problems.

The urban transportation problem is such that up to 70% of travel time in the Greater Beirut Area (GBA) is lost in delays due to traffic congestion, and the average reported intermodal road speed is 11 kilometers per hour (calculated as the weighted average speed across all modes). Car speed is within 9.4-13.5 km/hour. Bus speed is 6.5-9.3 km/hour, minibus speed is 7.5-10.8 km/hour and taxi speed is in the range of 8.6-12.3 km/hour (all calculated from Abou Zeid and Hassan (2016)). The congestion problem is increasing due to rapid motorization along with increased household income and growth of middle income households. Almost half of the total vehicles in Lebanon circulate in the GBA and the traffic volume in the GBA reaches 7,000 vehicles per hour in the northern entrance of Beirut (World Bank, 2015).

Traditionally in developing as well as developed countries, supply-side measures are offered to address traffic congestion problems. These include expansion of road networks and improvement of public transportation systems through the introduction of new or the expansion of existing light rail transit, bus rapid transit and metro systems (see, for example Chalak et al. (2016)). In addition to these supply side responses, there is growing interest in using demand side measures, particularly fiscal or pricing reforms to address the broader societal costs (or negative externalities) of transportation systems.[3] A more novel approach is congestion tolls, which economists have long advocated as an effective way of allocating scarce roadway capacity to the highest valued users.

[3] See Timilsina and Dulal (2008) for an in-depth discussion of fiscal policy instruments to reduce congestion and environmental pollution from urban transportation.

Several studies have evaluated demand side instruments for other cities in the developing world.[4] However, there exist very few studies of cities in the Mediterranean/North Africa (MENA) region. Parry and Timilsina (2012) evaluated demand side instruments to reduce urban transport externalities in the Greater Cairo Metropolitan Region (GCMR). However, demand side instruments alone may not provide the best solutions to reduce negative externalities from urban transportation if supply-side measures that complement the demand side instruments are limited. For example, increased taxation of private vehicles either through fuel, mileage driven or upfront capital costs would not cause sufficient substitution of private vehicles with mass transportation if adequate infrastructure for mass transportation does not exist. It is therefore important to examine the trade-offs between demand and supply-side instruments. The existing literature has not analyzed the demand and supply instruments together, focusing instead on demand side instruments only (see. e.g., Parry and Timilsina, 2012; Parry and Timilsina, 2015; Anas and Timilsina, 2015). This study compares both supply and demand side instruments.

The extent to which the supply side and demand side instruments would be effective in the GBA is an empirical question considering several characteristics specific to the GBA. For example, the GBA offers only a limited number of alternatives to private vehicles. Motorization has rapidly increased despite the fact that import duties on vehicles account for more than 50% of a vehicle's total value, the gasoline tax is one of the highest in the region and parking space is severely limited. The situation is worsened by the high cost of housing which causes people to reside away from the city center whereas most jobs are concentrated there. The city also lacks a reliable public transportation system. The GBA's transportation system is additionally strained due to the influx of Syrian refugees over the last few years. Affluent Syrian families, concentrated in the GBA, have brought their cars into Lebanon and intra-city trips in the GBA have significantly increased. It is estimated that the influx of Syrian refugees has resulted in sudden traffic increases in the GBA in the range of 15-25% (World Bank, 2015).

We develop an empirical model that can simulate both supply and demand side policy instruments to reduce the negative externalities from urban transportation in the GBA. On the supply side, the model considers expansion of urban roads, a bus rapid transit running on special

[4] See, for example, Anas and Timilsina (2009b), Anas, Timilsina and Zheng (2009), and Parry and Timilsina (2009) for applications to São Paulo, Beijing, and Mexico City, respectively.

lanes and an increased number of regular buses. On the demand side, policy instruments included are higher fuel and parking pricing. The model represents the behavior of all relevant agents including households, producers (commercial enterprises) and the government. Travel cost includes various monetary costs to households including transit fares, expenditures on automobile fuel, possible congestion tolls levied on auto travel, and the costs of vehicle ownership as well as value of their time (e.g., wage rate). Households have a choice to live nearby their workplaces paying higher rents but avoiding costs of commuting, or they can live away from city centers with lower rental costs and real estate values but pay higher cost for commuting (including the value of time). Through a budget constraint, more spending on travel implies a trade-off as households have less money for other goods. Travel by each mode also involves a time cost, which again involves a trade-off as this reduces the amount of time people have available for other activities at home. Travel time per mile differs across modes, and reflects the inverse of the average travel speed for a transportation vehicle. The model is calibrated with data from Beirut and the economic implications of several urban transportation policies are simulated.

We study several policy packages. Policy package 1 introduces 120 Bus Rapid Transit (BRT) buses which will run on dedicated bus lanes in addition to 250 regular buses. It also includes a 25% increase in the parking tax. Policy package 2 is the same BRT but the parking tax increase is replaced by additional road lanes in suburban Greater Beirut. Policy package 3 includes building an international class ring road in suburban Greater Beirut accompanied by a doubling of the existing excise tax on gasoline. Policy simulation results show an improvement in traffic congestion and decreases in VMT and gasoline consumption across all three policy scenarios. Policy packages 1 and 2 show big gains in social welfare due to a significant increase in traffic speed under BRT. The cost-benefit ratio for each policy can be measured as a gain in social welfare in Lebanese pounds (LBP) per LBP of expenditure. While the cost-benefit ratio is 9.6 and 5.01 for Policy packages 1 and 2 respectively, the cost of implementing Policy package 3 outweighs its benefit.

There are a few existing studies for Beirut analyzing various transportation improvement scenarios such as the re-organization of the bus system and the implementation of bus rapid transit (e.g. DMJM & Harris and INI Group, 2003; IBI Group and TEAM, 2009). The existing studies are, however, limited to economics specific to the project activities, whereas the current study assesses the impacts to the entire city considering many factors, normally not included in a project economic analysis, such as potential changes in the wage rate and real estate prices using a city level general equilibrium framework.

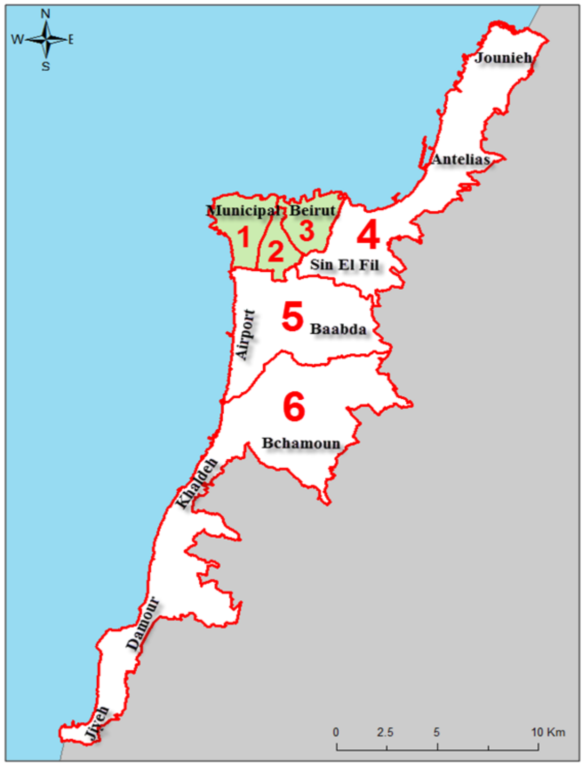
The paper is organized as follows. Section 2 describes the model equations and the equilibrium structure of the model. Section 3 describes how the model was calibrated from the data, followed by a description of the policy instruments and the scenarios simulated in the study. Section 4 presents and discusses the various policy instruments, and Section 5 presents the effects of the three policy packages. Appendix A presents supplemental tables that include the detailed output of the simulations. Section 6 draws conclusions. Detailed descriptions of data are presented in Appendix B (a summary of the more extensive report by Abou Zeid and Hassan (2016)).

## 2. Model structure

The metropolitan area is divided into two zones as shown in Figure 1. The central area is zone 1 (Municipal Beirut or MB) and the outer area is zone 2 (Greater Beirut or GB). We will use the subscripts $i, j, z = 1,2$ to denote these zones where $i$ will be used for the zone as a place of residence, $j$ as a place of work (job location) and the destination of a commute, and $z$ as the destination of a non-work or shopping trip from *i*. Modes of travel are $m = 1,...,4$, where $m = 1$ is private car, $m = 2$ public bus, $m = 3$ is minibus and $m = 4$ is taxi. Bus rapid transit is introduced as a fifth mode as needed. All four modes share the roads.

The model consists of consumers, firms, real estate developers and the public sector and follows the economic methodology of Anas and Liu (2007). In the labor markets, consumers who are workers and firms that offer jobs are matched up and equilibrium wages are determined in each zone $j = 1,2$. In production, output produced in each zone satisfies the demand for export and for consumption from local consumers coming to shop in that zone. In the residential $(k = 1)$ and commercial $(k = 2)$ building markets, consumers and firms are matched up to the stock of housing, and rents are determined for each type of building floor space in each zone $i = 1,2$. The stock of buildings is adjusted by real estate developers who construct and demolish residential and commercial buildings. Demolishing buildings creates land that is added to the available developable land, and constructing buildings reduces the available developable land. The transport sector is controlled by the government that sets gasoline taxes, parking fees and can increase the capacity of roads and buses. Such actions are compared by calculating the value of social welfare, which will be explained later.

**Figure 1:** Study Area




## 2.1 Consumers

Consumers who work choose the triplet $(i, j, m)$ that is a place of residence (housing), a place of work and a mode $m$ for commutes and non-work trips. Thus, there are $2 \times 2 \times 4 = 16$ discrete alternatives. In an inner stage of the choice process, the consumer chooses for each $(i, j, m)$, continuous variables: the quantity of floor space $h$ at zone $i$, and the quantity of goods $Z_z$ the consumer would buy at $z = 1, 2$. Thus, in the inner stage the consumer maximizes the following direct utility function:

$$\max_{Z_z, h} U_{ijm} = (1 - \beta_i) \ln[\sum_z (Z_{z|ijm})^\eta]^{1/\eta} + \beta_i \ln h_{ijm} + \gamma \ln(2G_{ijm}) + E_{ijm} + e_{ijm}, \quad (1)$$

with respect to the budget constraint:

$$\sum_{z'} p_{z|ijm} Z_{z'|ijm} + R_{Hi} h_{ijm} = w_j Hd + M_i - g_{ijm} d - \Delta_m g^p_{jm} d \ . \quad (2)$$

The parameters are as follows. $\beta_i$ is the share of disposable income spent on housing and $1-\beta_i$ is the share spent on goods purchased from $z=1,2$. $\frac{1}{1-\eta}$ is the elasticity of substitution between goods from $z=1$ and $z=2$; $\gamma<0$ controls the disutility of the commuting time, $G_{ijm}$, so that the marginal disutility is $-\gamma\frac{1}{2G_{ijm}}$. $E_{ijm}$ are fixed amenity effects of the choice $(i,j,m)$, and $e_{ijm}$ are random utilities that for each $(i,j,m)$ vary among the consumers. On the right side of the budget constraint we have the annual earned income $w_j Hd$ where $H$ is work hours per day and $d$ is the number of work days per year and $w_j$ is the hourly wage rate at workplace $j$. $M_i$ is unearned income. $g_{ijm}$ is the daily two-way monetary cost of commuting from residence zone $i$ to workplace zone *j* using mode *m*. $g^{p}_{jm}$ is the daily parking cost at *j*. Only private cars incur parking cost, and this is captured by $\Delta_1=1$ and $\Delta_m=0$ for $m>1$. Hence, the right side of the budget constraint is the worker's disposable income after commuting-related monetary costs are subtracted from annual earned plus unearned income. On the left side is the expenditure of the worker, consisting of housing floor area rented in zone $i$ at the unit housing rent $R_{Hi}$, and expenditure on goods purchased in zones z=1 and z=2 at the travel-cost-inclusive unit prices $p_{z|ijm}=p_z+\left(g_{izm}+\Delta_m g^{p}_{zm}\right)q_{izm}$ where $p_z$ is the unit mill price at the zone of sale $z$, in the parenthesis is the two-way monetary cost of the trip and the parking and $q_{izm}$ is the number of trips needed to purchase a unit quantity.

Nonworking consumers solve the same problem, except that there is no workplace or commuting cost, hence unearned income is the only part of their disposable income. Dropping the workplace subscript *j*:

$$\max_{Z_z,h} U_{im}=\left(1-\beta_i\right)\ln[\sum_z(Z_{z|im})^{\eta}]^{1/\eta}+\beta_i\ln h_i+E_{im}+e_{im}, \tag{3}$$

subject to the budget constraint:

$$\sum_z p_{z|im}Z_{z|im}+R_i h_{im}=M_i. \tag{4}$$

Solving these inner stage maximization problems yields the following Marshallian demands for goods and for housing floor space. For workers:

$$Z_{z|ijm} = \frac{p_{z|ijm}^{\frac{1}{\eta-1}}}{\sum_{z'} p_{z'|ijm}^{\frac{\eta}{\eta-1}}} (1-\beta_i)\left(w_j Hd + M_i - g_{ijm}d - \Delta_m g_{jm}^{p} d\right), \tag{5}$$

$$h_{ijm}\left(R_{Hi}, w_j\right) = \beta_i \frac{\left(w_j Hd + M_i - g_{ijm}d - \Delta_m g_{jm}^{p} d\right)}{R_{Hi}}. \tag{6}$$

For non-workers:

$$Z_{z|im} = \frac{p_{z|im}^{\frac{1}{\eta-1}}}{\sum_{z'} p_{z'|im}^{\frac{\eta}{\eta-1}}} (1-\beta_i) M_i, \tag{7}$$

$$h_i\left(R_{Hi}\right) = \beta_i \frac{M_i}{R_{Hi}} \;. \tag{8}$$

Substituting the Marshallian demands into direct utility, we get the indirect utility functions for workers and non-workers:

$$\begin{aligned}\tilde{U}_{ijm} &= (1-\beta_i) ln(1-\beta_i) + \beta_i \ln \beta_i + ln\left(Hw_j d + M_i - g_{ijm}d - \Delta_m g_{jm}^{p} d\right) \\ &-\beta_i lnR_{Hi} + (1-\beta_i)\frac{1-\eta}{\eta}\ln(\sum_z p_{z|ijm}^{\eta/(\eta-1)}) + \gamma \ln\left(2 * G_{ijm}\right) + E_{ijm},\end{aligned} \tag{9}$$

$$\tilde{U}_{im} = (1-\beta_i) ln(1-\beta_i) + \beta_i \ln \beta_i + lnM_i - \beta_i lnR_{Hi} + (1-\beta_i)\frac{1-\eta}{\eta}\ln(\sum_z p_{z\backslash im}^{\eta\backslash(\eta-1)}) + E_{im}^{ue} \tag{10}$$

In the outer stage, the discrete choice utility maximization problem results in multinomial logit models by assuming that the random utilities are distributed accordingly among the consumers. So we have the following choice probabilities for workers and non-workers:

$$P_{ijm}\left(\boldsymbol{R_{Hi}}, \boldsymbol{w}, \boldsymbol{p}\right) = \frac{e^{\lambda \tilde{U}_{ijm}}}{\sum_{i'j'm'} e^{\lambda \tilde{U}_{i'j'm'}}}, \tag{11a}$$

$$P_{im}\left(\boldsymbol{R_{Hi}}, \boldsymbol{p}\right) = \frac{e^{\lambda \tilde{U}_{im}}}{\sum_{i'm'} e^{\lambda \tilde{U}_{i'm'}}}. \tag{11b}$$

### 2.2 Firms

Firms in a zone $j$ produce output $X_j$ with a constant returns to scale Cobb-Douglas production function combining as inputs, annual hours of labor, $L_j$, at the unit wage rate $w_j$; and commercial building floor space, $S_{Bi}$, at the unit business rent, $R_{Bj}$: $X_j = A_j L_j^{\delta} S_{Bj}^{1-\delta}$, where $\delta$ is the cost-share of labor and $A_j$, a constant reflecting exogenous zonal productivity effects. Firms are assumed to be competitive, hence making zero profits. This implies that the output price equals the marginal and average cost. Hence:

$$p_j = \frac{w_j^{\delta} R_{Bj}^{1-\delta}}{A_j \delta^{\delta} \left(1-\delta\right)^{1-\delta}}, \quad j = 1, 2. \tag{12}$$

The labor demand, *LD,* and the demand for commercial floor, *SD*, space in zones *j* =1, 2 are:

$$LD_j = \delta \frac{p_j X_j}{w_j}, \tag{13}$$

$$SD_{Bj} = \left(1-\delta\right) \frac{p_j X_j}{R_{Bj}}. \tag{14}$$

### 2.3 Transportation

As mentioned earlier, in the transportation sector there are trips by the four modes (private car, bus, minibus and taxi), and two trip purposes: commutes from residence to workplace location and non-work trips to buy goods. These trips are loaded to the road network to generate monetary costs of travel, $g_{ijm}$, per person-trip under conditions of congestion. In addition, parking costs for private cars, $g_{jm}^{p}$, are also part of the transportation sector. The congested travel times, $G_{ijm}$, consist of three additive components: waiting time, in-vehicle time and access/egress time:

$$G_{ijm} = G_{ijm,\ wait} + G_{ijm,\ invehicle} + G_{ijm,\ access/egress}$$

(15)

The monetary cost ex-parking, of a consumer's person-trip by mode *m*, from residence zone *i* to workplace zone or non-work trip destination *j* is given by:

$$g_{ijm} = \Delta_m \phi_{ijm} \left(1 + \Delta_m \tau_{VAT}\right) P_{Fg} 2 D_{ij} F_{ijm} \left(s_{ijm}, \mathrm{e}_m\right) + \left(1 - \Delta_m\right) f_m. \tag{16}$$

Recalling that $\Delta_1 = 1$ for the private car mode, while $\Delta_m = 0$ for $m = 2,3,4,$ the two additive terms measure gasoline expenditure and fares. $D_{ij}$ is the one-way trip distance per kilometer and

$F_{ijm}\left(\breve{s}_{ijm}, \mathrm{e}_m\right)$ is liters per vehicle-kilometer for mode $m$ as a function of vehicle traffic speed $\breve{s}_{ijm}$ (to be determined below from the congestion technology) and mode fuel efficiency $\mathrm{e}_m$. $P_{Fg}$ is the price of gasoline per liter including any excise tax and $\tau_{VAT}$ the ad-valorem tax rate on gasoline at the pump. $\phi_{ijm}$ is the inverse vehicle occupancy of the mode, and $f_m$ is the two-way fare that applies for $m > 1$. The liters per vehicle kilometer function is:

$$F_{ijm}\left(\breve{s}_{ijm}, \mathrm{e}_m\right) = \mathrm{e}_m[\left(3.78541178 \backslash 1.6093\right) \times (0.122619 - 0.0117211 \times \left(\breve{s}_{ijm}\right) + 0.0006413 \times (\breve{s}_{ijm})^2$$
$$-0.000018732 \times (\breve{s}_{ijm})^3 + 0.0000003 \times (\breve{s}_{ijm})^4 - 0.0000000024718 \times (\breve{s}_{ijm})^5 + 0.000000000008233 \times (\breve{s}_{ijm})^6, \tag{17}$$

$$\breve{s}_{ijm} = s_{ijm} / 1.6093, \quad s_{ijm} = \frac{D_{ij}}{G_{ijm,\ invehicle} / 60}. \tag{18}$$

Parking cost is positive only for the private car mode. It is assumed that commuters park off-street and non-work trips can park either off-street or on-street. The average parking cost per commuter per day (W) is:

$$g_{j1}^{p} = fee_j^{W,off} \times share_j^{W,off} \tag{19}$$

And the average parking cost per non-commuter per day (NW) is:

$$g_{z1}^{p} = fee_z^{NW,off} \times share_z^{NW,off} + fee_z^{NW,on} \times share_z^{NW,on} \tag{20}$$ [5]

To determine congested travel times, we need to add up trips by $(i, j, m)$ and then calculate the private-car-equivalent traffic loads across the different modes. So the sum of work and non-work trips by the mode $m$ per day are:

$$T_{ijm} = T_{ijm}^{W} + \frac{1}{365} T_{ijm}^{NW}, \tag{21a}$$

where the number of consumer-workers is $N^W$, and the work trips are obtained by:

$$T_{ijm}^{W} = N^W P_{ijm}, \tag{21b}$$

[5] The percentage of private car commuters that pays for parking is 46% (in $j = 1$) and 20% (in $j = 2$). In the case of non-work trips, 25% pays for off-street parking in $j = 1$ but no one pays for off-street parking in $j = 2$; whereas the shares of on-street parking for non-work trips in $j = 1$ and $j = 2$ are 25% and 20% respectively.

and the number of non-workers is $N^{NW}$ and the number of non-work trips is obtained by multiplying the number of workers and non-workers with their respective choice probabilities:

$$T_{izm}^{NW} = \sum_{j=1,2} N^{W} P_{ijm} Z_{z|ijm} q_{izm} + N^{NW} P_{im} Z_{z|im} q_{izm} \tag{21c}$$

To combine the trips by mode in order to derive a combined traffic load, we need $\ell_m$ to convert vehicles of mode $m$ into car-equivalent units. Then, a car-equivalent traffic load is:

$$LOAD_{ij} = \sum_{m} \phi_{ijm} (T_{ijm}^{W} + \frac{1}{365} T_{ijm}^{NW}) \ell_m . \tag{22}$$

We also calculate vehicle miles traveled (VMT) and total gasoline consumption (TGC):

$$VMT_{ijm} = 2 D_{ij} \phi_{ijm} \left( T_{ijm}^{W} + \frac{1}{365} T_{ijm}^{NW} \right) \tag{23}$$

$$TGC_{ijm} = 2 D_{ij} \phi_{ijm} \left( T_{ijm}^{W} + \frac{1}{365} T_{ijm}^{NW} \right) F_{ijm} \left( \breve{s}_{ijm}, \mathrm{e}_m \right). \tag{24}$$

For congestion, we use the BPR-type flow congestion function with parameters $c_0, c_1, c_2$ to get the in-vehicle travel times. The resulting travel times for the four $(i, j)$ zone pairs, adjusted for mode slowness by the parameters $\Psi_m$ are:

$$G_{11m,\ invehicle} = c_0 \left[ 1 + c_1 \left( \frac{LOAD_{11} + 0.5 \times LOAD_{21} + 0.5 \times LOAD_{12}}{\xi_1 CAP_1} \right)^{c_2} \right] D_{11} \Psi_m \tag{25a}$$

$$G_{12m,\ invehicle} = c_0 \left[ 1 + c_1 \left( \frac{LOAD_{12}}{\theta_1 (\xi_2 CAP_1) + \theta_2 (\xi_3 CAP_2)} \right)^{c_2} \right] D_{12} \Psi_m \tag{25b}$$

$$G_{21m,\ invehicle} = c_0 \left[ 1 + c_1 \left( \frac{LOAD_{21}}{\theta_1 (\xi_4 CAP_1) + \theta_2 (\xi_5 CAP_2)} \right)^{c_2} \right] D_{21} \Psi_m \tag{25c}$$

$$G_{22m,inv} = c_0 \left[ 1 + c_1 \left( \frac{LOAD_{22} + 0.5 \times LOAD_{21} + 0.5 \times LOAD_{12}}{\xi_6 CAP_2} \right)^{c_2} \right] D_{22} \Psi_m \tag{25d}$$

$CAP_1,\ CAP_2$ are road capacities associated with the two zones. These are blended by using the coefficients $\theta_1, \theta_2$ to obtain the capacities of the road relevant to the inter-zonal trips. $\xi_1, \xi_2$ are coefficients we calibrate.

Finally, a refinement of the model is to take into account what happens when more buses or round-trips of existing buses are added to the public transportation system. Adding buses will increase congestion if the buses run empty or not very full. The inverse vehicle occupancy ratio for buses should increase, keeping total bus riders constant, but it can decrease as more people switch to bus, as the added buses reduce waiting times. To capture these two relationships, we use the functions:

$$\phi_{ij2} = \frac{round-trips_{ij2} \times Bus_{ij}}{\varsigma_{ij0}(T_{ij2})^{\varsigma_{ij}}}, \tag{26}$$

and

$$G_{ij2,wait} = a_{ij2} * Bus_{ij}^{-\beta_b}, \tag{27}$$

where $Bus_{ij}$ is the number of buses (fleet size) used in the system.

## 2.4 Labor market

The labor market equilibrium in each zone is calculated by solving for the wages so that the supply of labor equals the demand for labor:

$$\sum_{im} N^e P^e_{i1m}\left(\boldsymbol{R_{Hi}}, \boldsymbol{w}, \boldsymbol{p}\right) Hd = \delta \frac{p_1 X_1}{w_1}, \tag{28a}$$

$$\sum_{im} N^e P^e_{i2m}\left(\boldsymbol{R_{Hi}}, \boldsymbol{w}, \boldsymbol{p}\right) Hd = \delta \frac{p_2 X_2}{w_2} \tag{28b}$$

## 2.5 Output market

The output produced in each zone satisfies the demand from the local population and the demand for export:

$$X_1 = \sum_{ijm} N^e P^e_{ijm}\left(\boldsymbol{R_{Hi}}, \boldsymbol{w}, \boldsymbol{p}\right) Z^e_{1|ijm}\left(\boldsymbol{p}, w_j\right) + \sum_{im} N^{ue} P^{ue}_{im}\left(\boldsymbol{R_{Hi}}, \boldsymbol{p}\right) Z^{ue}_{1|im}\left(\boldsymbol{p}\right) + \Xi_1 \tag{29a}$$

$$X_2 = \sum_{ijm} N^e P^e_{ijm}\left(\boldsymbol{R_{Hi}}, \boldsymbol{w}, \boldsymbol{p}\right) Z^e_{2|ijm}\left(\boldsymbol{p}, w_j\right) + \sum_{im} N^{ue} P^{ue}_{im}\left(\boldsymbol{R_{Hi}}, \boldsymbol{p}\right) Z^{ue}_{2|im}\left(\boldsymbol{p}\right) + \Xi_2 \tag{29b}$$

## 2.6 Real estate market

In the residential real estate rental market, the floor space demanded by consumers (workers and non-workers) equals the available residential floor space stock, while in the commercial real estate market the demand for floor space by firms equals the stock of commercial floor space:

$$\sum_{jm} N^e P^e_{ijm}\left(\boldsymbol{R_{Hi}}, \boldsymbol{w}, \boldsymbol{p}\right) h^e_{ijm}\left(R_{Hi}, w_j\right) + \sum_{m} N^{ue} P^{ue}_{im}\left(\boldsymbol{R_{Hi}}, \boldsymbol{p}\right) h^{ue}_{im}\left(R_{Hi}\right) = S_{Hi},\ i = 1,2. \tag{30}$$

$$\left(1-\delta\right)\frac{p_i X_i}{R_{Bi}} = S_{Bi},\ i = 1,2. \tag{31}$$

The values of floor space ($V_{Hi}, V_{Bi}$) and of developable land ($V_{0i}$) are determined by the following three equations. These are derived by assuming the following competitive bidding process in stationary state by risk neutral and forward-looking investors, a framework adapted from Anas and Arnott (1991). Suppose that an investor buys land at the beginning of a time period. The bid per unit of such land reflects the rent on vacant land that is collected during the period and the expected value of the capital gains that can be realized by exercising the option to construct either residential or commercial floor space, or by keeping the land undeveloped. It is assumed that the investor would choose the most profitable of the three possible actions, but – in the beginning of the period – does not yet fully know the costs associated with each option.

$$V_{0i} = R_{0i} + \frac{1}{\Phi_{0i}} \ln\{e^{\Phi_{0i}\left(\frac{V_{0i}}{1+r} - K_{0i}\right)} + e^{\Phi_{0i}\left(\frac{(V_{Hi}-C_{Hi})m_{Hi}}{1+r} - K_{Hi}\right)} + e^{\Phi_{0i}\left(\frac{(V_{Bi}-C_{Bi})m_{Bi}}{1+r} - K_{Bi}\right)}\} \tag{32a}$$

In the above and the following equations, $m_{ki}$ is the structural density (floor space to land area ratio) of type *k* building in zone *i*. $C_{ki}$ is the cost of constructing a type *k* building in zone *i,* and $K_{ki}$ the non-financial cost. $\Phi_{0i}$ is the dispersion parameter of the unobserved nonfinancial costs for land investors. *r* is the interest rate.

An investor owning an existing residential or commercial building acts similarly with the land investor (and with similar parameters) but has two options: to either demolish the building or keep it as is. Hence, in the beginning of the period the building investor would bid the rent from the period plus the expected capital gains from the options to demolish or not:

$$V_{Hi} = R_{Hi} + \frac{1}{\Phi_{Hi}} \ln\{e^{\Phi_{Hi}\left(\frac{V_{Hi}}{1+r} - k_{HHi}\right)} + e^{\Phi_{Hi}\left(\frac{1}{1+r}\left(\frac{V_{0i}}{m_{Hi}} - D_{Hi}\right) - k_{H0i}\right)}\} \tag{32b}$$

$$V_{Bi} = R_{Bi} + \frac{1}{\Phi_{Bi}} \ln\{e^{\Phi_{Bi}\left(\frac{V_{Bi}}{1+r} - k_{BBi}\right)} + e^{\Phi_{Bi}\left(\frac{1}{1+r}\left(\frac{V_{0i}}{m_{Bi}} - D_{Bi}\right) - k_{B0i}\right)}\} \tag{32c}$$

The construction probabilities are:

$$Q_{0Hi} = \frac{e^{\Phi_{0i}\left(\frac{(V_{Hi}-C_{Hi})m_{Hi}}{1+r} - K_{Hi}\right)}}{e^{\Phi_{0i}\left(\frac{V_{0i}}{1+r} - K_{0i}\right)} + e^{\Phi_{0i}\left(\frac{(V_{Hi}-C_{Hi})m_{Hi}}{1+r} - K_{Hi}\right)} + e^{\Phi_{0i}\left(\frac{(V_{Bi}-C_{Bi})m_{Bi}}{1+r} - K_{Bi}\right)}} \quad (33a)$$

$$Q_{0Bi} = \frac{e^{\Phi_{0i}\left(\frac{(V_{Bi}-C_{Bi})m_{Bi}}{1+r} - K_{Bi}\right)}}{e^{\Phi_{0i}\left(\frac{V_{0i}}{1+r} - K_{0i}\right)} + e^{\Phi_{0i}\left(\frac{(V_{Hi}-C_{Hi})m_{Hi}}{1+r} - K_{Hi}\right)} + e^{\Phi_{0i}\left(\frac{(V_{Bi}-C_{Bi})m_{Bi}}{1+r} - K_{Bi}\right)}}$$

(33b)

$$Q_{00i} = 1 - Q_{0Bi} - Q_{0Hi} \quad (33c)$$

And the demolition probabilities are:

$$Q_{H0i} = \frac{e^{\Phi_{Hi}\left(\frac{1}{1+r}\left(\frac{V_{0i}}{m_{Hi}} - D_{Hi}\right) - k_{H0i}\right)}}{e^{\Phi_{Hi}\left(\frac{1}{1+r}\left(\frac{V_{0i}}{m_{Hi}} - D_{Hi}\right) - k_{H0i}\right)} + e^{\Phi_{Hi}\left(\frac{V_{Hi}}{1+r} - k_{HHi}\right)}} \quad (33d)$$

$$Q_{HHi} = 1 - Q_{H0i} \quad (33e)$$

$$Q_{B0i} = \frac{e^{\Phi_{Bi}\left(\frac{1}{1+r}\left(\frac{V_{0i}}{m_{Bi}} - D_{Bi}\right) - k_{B0i}\right)}}{e^{\Phi_{Bi}\left(\frac{1}{1+r}\left(\frac{V_{0i}}{m_{Bi}} - D_{Bi}\right) - k_{B0i}\right)} + e^{\Phi_{Bi}\left(\frac{V_{Bi}}{1+r} - k_{BBi}\right)}} \quad (33f)$$

$$Q_{BBi} = 1 - Q_{B0i} \quad (33g)$$

We assume that at equilibrium, the flow of demolished floor space equals 40% of the flow of constructed floor space, an arbitrary assumption the plausibility of which was confirmed by simulations, and that the total amount of land in each zone remains unchanged:

$$0.4 S_{0i} Q_{0Hi} - \frac{1}{m_{Hi}} S_{Hi} Q_{H0i} = 0 \quad (34a)$$

$$0.40 S_{0i} Q_{0Bi} - \frac{1}{m_{Bi}} S_{Bi} Q_{B0i} = 0 \quad (34b)$$

$$S_{0i} + \frac{1}{m_{Hi}} S_{Hi} + \frac{1}{m_{Bi}} S_{Bi} = LAND_i \quad (34c)$$

Given rents, the equilibrium values are calculated from (32a)-(32c), and given the values, the equilibrium stocks of available land and aggregate floor spaces ( $S_{0i}, S_{Hi}, S_{Bi}$ ) are found by solving (34a)-(34c).

**2.7 The public sector**

A policy will cause the economy to move from the base equilibrium pre-policy to the new equilibrium post-policy. The change in welfare is the compensating variation of the consumer plus the annualized change in real estate values, plus the changes in the revenue of operating the public transportation system, plus the changes in the revenues from parking and gasoline taxes less the costs of bus and road additions:

$$\Delta W = CV + \frac{r}{(N^e+N^{ue})}\left(\sum_{i,k=o,H,B} S_{ik}^{POLICY}V_{ik}^{POLICY} - S_{ik}^{BASE}V_{ik}^{BASE}\right)$$

$$+ \frac{1}{(N^e+N^{ue})}(\Delta PT\ Revenue + \Delta GasolineTax\ Revenue + \Delta ParkingTax$$

$$Revenue - Total\ Cost\ of\ New\ Bus - New\ Road\ Construction\ Cost) \quad (35)$$

The welfare levels of a worker and a non-worker in units of utility are:

$$W_e^{BASE} = \frac{1}{\lambda}\ln(\sum_{ijm}\exp(\lambda U_{ijm}^{e,BASE})) \quad (36a)$$

$$W_{ue}^{BASE} = \frac{1}{\lambda}\ln(\sum_{im}\exp(\lambda U_{im}^{ue,BASE})) \quad (36b)$$

The compensating variation is the maximum dollar amount a worker or non-worker would pay to enjoy the benefits of the policy. The following steps show how the CV is calculated:

$$U_{ijm}^{e,POLICY} = u_{ijm}^{e,POLICY} + \ln(y_{ijm}^{e,POLICY}) \quad (37a)$$

$$U_{im}^{ue,POLICY} = u_{im}^{ue,POLICY} + \ln(y_i^{ue,POLICY}) \quad (37b)$$

CV for worker and non-worker can be solved as:

$$W_e^{BASE} = \frac{1}{\lambda}\ln(\sum_{ijm}\exp\lambda[u_{ijm}^{e,POLICY} + \ln\left(y_{ijm}^{e,POLICY} - CV^e\right)]) \quad (38a)$$

$$W_{ue}^{BASE} = \frac{1}{\lambda}\ln(\sum_{im}\exp\lambda[u_{im}^{ue,POLICY} + \ln\left(y_i^{ue,POLICY} - CV^{ue}\right)]) \quad (38b)$$

$$CV = \frac{N^e}{(N^e+N^{ue})}CV^e + \frac{N^{ue}}{(N^e+N^{ue})}CV^{ue}\ . \quad (39)$$

The other components of welfare are calculated as follows:

$$PT\ Revenue = \sum_{ijm=2,3} T_{ijm} * f_m \quad (40a)$$

$$ParkingTax\ Revenue = \sum_j g_{j1}^p[\sum_i \emptyset_{ij1}T_{ij1}^W] + \sum_z g_{z1}^p[\sum_i \emptyset_{ij1}T_{iz1}^{NW}] \quad (40b)$$

$$GasolineTax\ Revenue = \sum_{ijm\neq 2} \tau_{VAT}P_{Fg}TGC_{ijm} \quad (40c)$$

## 3. Calibration

The elasticity of location choice with respect to housing rent used in the model is -0.35. Anas and Chu (1984) reported a range for housing cost elasticity between -0.26 to -0.86 from previous studies and estimated it to be -0.36 for the Chicago MSA. Indra (2014) in a study of 275 metropolitan areas, found the residential choice elasticity with respect to housing cost in US to be -0.28. We believe any value around -0.36 is very reasonable. Based on this rent elasticity, we calibrated the dispersion parameter, $\lambda$, in the consumer's choice probability.

The elasticity of location choice with respect to commute time weighted across all modes is -1.0735. The data for this mode choice elasticity is taken from the study for Beirut by Danaf et al. (2014). Since no mode choice elasticity was present for minibus, we considered the mode choice elasticity for bus and minibus to be the same. Based on their weighted value of elasticity with respect to commute time, we calibrated the travel time disutility parameter, $\gamma$, in the consumer's choice probability.

There is no value in the literature related to housing construction from vacant land for Beirut. We assumed that the probability of housing construction from vacant land is 0.0035 in both MB and GB. These probabilities are derived from the supply of newly constructed housing floor space aggregated across MB and GB.[6] Assuming that the probability of construction is the same for MB and GB, the probability of vacant land constructed into housing is derived. As there are no data on the construction probability of commercial floor space from vacant land, we assumed that the share is based on the existing commercial floor space relative to residential floor space, adjusting the residential construction probability with this ratio.

Based on the above, the elasticity of housing/commercial construction with respect to the value of housing/commercial floor space was set at 0.5 (MB) and 2.1 (GB). The elasticity of housing/commercial demolition with respect to the value of vacant land was set at 0.05 (MB) and 0.21 (GB), that is at one-tenth the corresponding construction elasticity. Based on these construction and demolition elasticity values, the constants in the probabilities of construction and demolition are calibrated. We also confirmed that the assumed ratio of demolished to constructed floor space of 40% seems to yield plausible comparative statics results.

[6] The source of these data is from the Order of Engineers.

The waiting time function for buses was derived from the relationship between average waiting time and number of buses as provided in Meignan et al. (2007). In the base case, the parameter constant, $a_{ij2}$, is calibrated to match the base data on waiting time for bus by origin and destination, $(i, j)$. Think of a scenario where there is an increase in bus supply. On the one hand, this will potentially encourage people to switch to bus from all other modes as the waiting time for bus improves. This will reduce aggregate traffic for all other modes and hence it will reduce congestion. On the other hand, additional buses running on roads will take more space and frequent stops will disrupt the traffic flow, which will increase congestion on the roads. The net effect depends on how many buses are running on roads, relative to the switch in ridership to bus from the other modes. Equation (26) implies that an additional bus can potentially create congestion on the road for the other modes. Equation in (25) is the most commonly used congestion function. The value of the exponent, $c_2$, can typically range from 1.2 to 4. We are using the value of 3.5 suggested in Arnott (2013). Detailed discussions on the data and key assumptions are presented in Appendix A. The calibration results are summarized in Tables 1-4.

**TABLE 1:** Base data except transportation

| | **Municipal Beirut** | **Greater Beirut** |
|---|---|---|
| *Residents* | 445,184 | 997,422 |
| *%Workers* | 41.18 | 44.01 |
| *Jobs* | 198,839 | 423,489 |
| **Production** | | |
| $A_i$ | 19,877.33 | 11,925.34 |
| $w_i$ | 4363.2 | 3452.035 |
| $\delta$ | 0.30 | 0.30 |
| $\Xi_i / X_i$ | 0.55 | 0.73 |
| **Consumers** | | |
| $\beta_i$ | 0.29 | 0.27 |
| $M_i$ (LBP) | 3,636,000 | 2,876,696 |
| $\frac{1}{1-\eta}$ | 2 | 2 |
| $\gamma$ | 0.7539 | 0.7539 |
| **Real estate** | | |
| $R_{oi}$ (LBP/Sq. Meter) | 503,640 | 73,350 |
| $R_{Bi}$ (LBP) | 426,750 | 227,400 |
| $R_{Hi}$ (LBP) | 175,800 | 83,550 |

| | | |
|---|---|---|
| $V_{Hi}$ (LBP) | 5,860,000 | 2,785,000 |
| $V_{Bi}$ (LBP) | 8,535,000 | 4,548,000 |
| $V_{0i}$ (LBP) | 16,788,000 | 2,445,000 |
| $S_{Bi}$ (Sq. Meters) | 11,859,051 | 37,501,072 |
| $S_{Hi}$ (Sq. Meters) | 5,259,996 | 21,342,698 |
| $S_{0i}$ (Sq. Meters) | 4,650,000 | 52,610,000 |

**TABLE 2:** Base data on transportation

| Origin, Destination | 1,1 | 1,2 | 2,1 | 2,2 |
|---|---|---|---|---|
| Mode splits (person trips) | | | | |
| Car | 48388 | 99398 | 111876 | 241934 |
| Bus | 1051 | 2158 | 2429 | 5253 |
| Minibus | 6544 | 13442 | 15130 | 32718 |
| Taxi | 4052 | 8324 | 9369 | 20261 |
| Distances (one-way) in kilometers | | | | |
| Any mode | 6.6 | 11.9 | 12.3 | 9.4 |
| Travel times (one-way) in minutes | | | | |
| Car | 42.1 | 53 | 57 | 46.4 |
| Bus | 77.6 | 98.3 | 104.2 | 88.8 |
| Minibus | 63.1 | 81.7 | 86.8 | 73.5 |
| Taxi | 58.33 | 72.33 | 76.73 | 65.13 |
| $\theta_1, \theta_2$ | 0.18 | | 0.82 | |
| $CAP_1$, $CAP_2$ (square meters) | 3,675,177 | | 17,295,559 | |
| | Car | Bus | Mini-bus | Taxi |
| $\phi_m$ | 0.5882 | 0.0893 | 0.1686 | 0.8475 |
| $\ell_m$ | 1 | 2 | 1.6 | 1.4 |
| $\Psi_{ijm}$ | 1 | 1.45 | 1.25 | 1.10 |
| Wait time (in minutes) | 0 | 6.5 | 0.5 | 6 |
| Access/egress (in minutes) | | | | |
| Car | 0 | 0 | 0 | 0 |
| Bus | 10 | 15 | 15 | 15 |
| Minibus | 10 | 15 | 15 | 15 |
| Taxi | 6.03 | 8.03 | 8.03 | 8.03 |
| Fare (one-way) in LBP | | | | |
| Car | 0 | 0 | 0 | 0 |
| Bus | 1000 | 1000 | 1000 | 1000 |
| Minibus | 1000 | 1000 | 1000 | 1000 |
| Taxi | 2000 | 4000 | 4000 | 4000 |
| $\zeta_0, \zeta_1$ (in Bus) | (1,1) | (1,2) | (2,1) | (2,2) |
| | 17.0865, 0.8 | 11.0164, 0.8 | 7.3064, 0.8 | 7.7022, 0.8 |

| | | | | |
|---|---|---|---|---|
| $a, \beta$ (in Bus) | 42.6668, -0.335 | 41.0472,-0.335 | 41.0472,-0.335 | 41.0472,-0.335 |

**TABLE 3:** Target values used in calibration

| Name | Value |
|---|---|
| Elasticity of location choice w.r.t housing rent | -0.35 |
| Elasticity of location choice w.r.t commute time across all mode | -1.0735 |
| Elasticity of housing/business construction w.r.t value of housing/business stock by MB and GB respectively | 0.5,2.1 |
| Elasticity of housing/ business demolition w.r.t value of land by MB and GB respectively | 0.05,0.21 |
| Demolition to construction ratio | 0.40 |
| New annual housing construction in housing units | 12678 |
| Labor share in production function | 0.3 |
| Free-flow speed (km/hour) | 100 |
| Congestion parameter constants ($c_1, c_2$) | 0.2, 3.5 |
| Adjustment parameter in phiijm of bus ($\varsigma_{ij}$) | 0.8 |
| Delivered price to mill price | 0.1 |

**TABLE 4:** Calibrated values

| Variable Name | Symbol | Value |
|---|---|---|
| Dispersion parameter in utility function | $\lambda$ | 1.8353 |
| Disutility parameter for commute | $\gamma$ | 0.7317 |
| Probability of housing construction from vacant land | $Q_{0Hi}$ | 0.0035; 0.0035 |
| Probability of housing demolition into vacant land | $Q_{H0i}$ | 0.0011;0.0041 |
| Probability of commercial building construction from vacant land | $Q_{0Bi}$ | 0.0066;0.0066 |
| Probability of commercial building demolition from vacant land | $Q_{B0i}$ | 0.0038;0.0141 |

## 4. Defining Policy Instruments and Simulation Scenarios

The study considers both demand side and supply side scenarios. Demand side instruments aim to reduce the excessive part of the demand for transportation services that relies on private vehicles. Supply side instruments aim to adjust the infrastructure capacity to provide transportation services (buses or roads and parking spaces). While there could be a large number of policy instruments and scenarios, considering all of them is beyond the scope of the study. We considered the most plausible instruments based on discussions with various stakeholders in Beirut.

### 4.1. Demand Side Policy Instruments

Demand side instruments increase the prices of transportation services provided by automobiles. Such instruments are the fuel tax, the parking fee, congestion charges, the tax on vehicles, etc. Since motorization has increased despite a very high vehicle tax (import duty), increasing that tax further may not be very effective. Congestion charges, which have been used in some cities in developed countries (Singapore, London, Stockholm, Milan), may be difficult to implement in Beirut. So we considered two pricing instruments: the fuel tax and the parking fee. An increase in transportation cost through an increase in the fuel tax or parking fee would work in two ways. First, it would reduce transportation service demand from private vehicles by cutting their unnecessary or wasteful use and second, it would encourage the substitution of private transportation with public transportation.

***Increased fuel taxation:*** As in many cities around the world, gasoline and diesel are the main fuels used for transportation in Beirut. Since the excise tax on gasoline in Lebanon was halved from 33 US¢/liter (LBP 9,900/20 liters) to 16.5 US¢/liter (LBP 4,950/20 liters) in March 2011, one scenario could be to reinstate the previous tax level, doubling the current excise tax rate from that level. Since diesel is used mainly for public transportation and one strategy to reduce congestion is to encourage switching from the private transportation mode to the public transportation mode, we did not apply any tax on diesel.

***Increased parking fees:*** The objective of this policy instrument is to make parking in GB more expensive so that it discourages the use of private vehicles. An increase in parking fee whether it is off-street parking or on-street parking is expected to contribute to this objective. At present, paid street parking allows a maximum of two hours of parking on the street. Most commuters use off-street parking lots or garages. Recent statistics show that 46% of commuters pay for parking in Municipal Beirut and 20% of commuters pay for parking in Greater Beirut. In 2013, the average daily off-street parking rate is estimated to be 3,187 LBP/day in Municipal Beirut and 2,500 LBP/day in GB. Considering all commuters (those who pay and those who do not pay for off-street parking), the average off-street parking cost across commuters is 1,466.1 LBP/day in MB and 500 LBP/day in GB.

On-street parking is usually used by non-commuters. Paid (or metered) street parking is installed only in Municipal Beirut (but not everywhere) and not in Greater Beirut. The current on-street parking rate is 1,000 LBP/hour. We assumed that 50% of all non-commuting trips park for free, 25% use paid street parking, and 25% use paid off-street parking. For street parking, the average duration of parking is assumed to be around 45 minutes (TEAM International, 2009), resulting in an average street parking cost of 750 LBP. Since the off-street parking rate for commuters is 3,187 LBP/day, the average parking cost paid by non-commuters in Municipal Beirut is estimated to be LBP 984.25.[7] For GBA, the average parking cost paid by non-commuters is LBP 500.[8]

**4.2. Supply Side Measures**

The objective of the supply side measures is to expand infrastructure capacity including construction of new roads, particularly in the periphery of Municipal Beirut where land is available for the expansion of road networks, construction of underground metro or over-ground light railway transit (LRT), bus rapid transit systems, etc. Considering the huge costs of building transportation infrastructure and the considerable time needed to complete the mega projects, we treat two relatively cheaper options: construction of a new ring road in the periphery of Municipal Beirut (i.e., in GB) and addition of lanes to existing roads.

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[7] *Off-street parking rate * percent of non-commuters that pay off-street parking + on-street parking rate * percent of non-commuters that pay on-street parking + 0 * percent of non-commuters that do not pay parking = 3187 * 0.25 + 750 * 0.25 = 984.25.*

[8] *Off-street parking rate * percent of non-commuters that pay off-street parking + 0 * percent of non-commuters that do not pay parking = 2500 * 0.2 = 500.*

**Road expansion in GB**: We considered a *peripherique* (ring road) along the periphery of Municipal Beirut in GB. This 20-km road is estimated to cost US$2 billion including the cost of expropriation. It will have two levels with a total (over both levels) of 5 lanes per direction. Assuming a 3.6-m lane width, the total width is 36 m. The increase in road capacity in Greater Beirut (GB) due to the Peripherique is then 20,000 m × 36 m = 720,000 $m^2$.

**Lane Addition**: We considered adding one lane in each direction to the coastal highway along a 10-km section in GB (in the part that falls north of MB). The expected cost is in the range of US$150 million to US$200 million. Assuming a 3.6-m lane width, the increase in road capacity in Greater Beirut (GB) due to the lane addition project is 2 × 3.6 × 10,000 = 72,000 $m^2$.

**Network extension of buses**: Since the government has a plan to purchase 250 new buses to be deployed in Greater and Municipal Beirut, we considered a scenario of adding these buses which will be owned by the city. Increasing the number of buses, would reduce bus waiting times due to increased frequency of service, but the additional buses would also add to road congestion, if they did not draw enough riders from the other modes.

**Introducing Bus Rapid Transit (BRT):** BRT will primarily cover 22 km between Beirut-Tabarja and 20 km within Beirut. As the BRT will run on dedicated lanes, there will be a reduction in road capacity because one lane will be taken from the road in each direction. This will happen over a distance of 15 km. So we need to remove from GB a road capacity[9] of 108,000 $m^2$. Road capacity will not decrease in MB as dedicated lanes will be taken from the parking lanes in MB. The targeted speed that BRT will try to achieve is 30-35 km/hr in GB and 20-25 km/hr in MB. The expected speed in MB is lower because of traffic lights. The one-way fare of BRT bus is assumed as 60% higher than regular bus fare.

## 5. Results of the Policy Simulations

We first present results from simulations in which we change the values of individual policy instruments or public investment activities. This is followed by results of three policy packages where these policy instruments and public investment activities described above, are combined at different levels. The policy simulation results discussed and presented in this section are driven by several important margins of adjustment in the model, such as:

[9] For BRT scenario in GB, 2 lanes * 15 km (length) * 3.6 of width/lane = 108,000 $m^2$.

1) Consumers' choice of place of residence and place of workplace.
2) Switching of consumers from one mode to another for work and non-work trips.
3) Consumers substituting between composite good consumption and housing floor space consumption and between consumption acquired by making non-work trips to MB or GB.
4) Firms substituting between labor and building inputs in production.
5) Conversion of vacant land to residential /commercial floor space construction or demolition of residential /commercial floor space to vacant land.

**5.1. Results from simulation of individual policy instruments or investment activities**

There are four simulations to measure the impacts of individual policy instruments or investment actions. These are: (i) Expanding road capacity; (ii) Adding bus capacity; (iii) Increasing the taxes on gasoline (increase in the excise tax); (iv) Parking cost increase (increasing the parking tax rate). Below we discuss the most important results from each of these simulations. Detailed results under each simulation are provided in the long tables of Appendix A.

**5.1.1 Expanding road capacity**

The road capacity increase for GB is 720,000 square meters, i.e., an increase of 4.1% in total road area in GB. Detailed results of this simulation are shown in Table A1.

After increasing the road supply in GB, population and employment decentralizes to GB. As a result of that, wages in MB rise and fall in GB since the supply of labor to GB increases at the expense of the labor supply to MB. The fall in housing demand in MB leads to a fall in the residential rent in MB. Opposite results can be seen in GB where rent rises due to increase in housing demand. Price of output increases in MB and decreases in GB. Increase in nominal and real output increase the demand for commercial floor space resulting in an increase in the rent of commercial floor space.

With the increase in road supply, congestion decreases somewhat and because this favors private vehicles, people switch to private vehicle from the other modes. The aggregate mode share increases for private vehicles even when the private vehicle trips of MB-to-MB decrease as both population and employment shift to GB. Travel time decreases across all modes. The aggregate traffic load decreases for MB-MB and MB-GB but increased for GB-MB and GB-GB. Aggregate non-work trips along with VMT increase but gasoline consumption decreases due to the improved speed. The improved speed and the switch to private vehicles result in a decrease in revenues from the gas tax and public transit fares, but parking tax revenue increases.

The increase in the rent for commercial floor space stimulates construction and stock increases in both MB and GB. For residential floor space, stock decreases in MB but increases in GB. The fall in residential stock in MB frees up land which is in part utilized for the construction of new commercial floor space. As demand increases for both residential and commercial floor space in GB, vacant land decreases.

Workers in MB benefit from falling residential rents and the rising wages along with decrease in travel cost and travel time, but are adversely affected by the rising output price. Non-workers in MB benefit from falling residential rents and decrease in travel cost but are affected adversely by the higher goods prices, whereas workers and non-workers in GB benefit from lower output prices and lower travel costs but are adversely affected by the increase in residential rents and the decrease in wages. An average worker seems to be better off by this policy while an average non-worker is worse-off by this policy. The overall social welfare improves.

Note that with a congestion function exponent of $c_2 = 3.5$, the change in social welfare is bigger than with $c_2 = 2$. The reason is that the effect of an increase in road capacity begets more congestion relief when the exponent is higher.

The main results of this policy on key transportation and economic indicators are summarized in Figures 2a and 2b, respectively. As illustrated in these figures, the expansion of roads in the GB would substitute bus (mini and large bus) trips with auto (car and taxi) trips. It would reduce travel times for all vehicles and also the total travel costs. While revenues from fuel taxation and parking fees decrease, total rents, total values of properties including existing buildings, new buildings and vacant lands and gross regional products of the city will increase. Although percentage change in rental and property values look small, in absolute terms they are large. For example, the expansion of roads will increase rental values in Beirut (both MB & GB) by 38 billion LBP to 62 billion LBP depending upon the value for congestion coefficients. Similarly, the expansion of roads will increase values of properties (residential, commercial and vacant lands in Beirut) by 575 billion LBP to 801 billion LBP. The gross regional product of Beirut would increase by 42 billion LBP to 67 billion LBP.

**Figure 2a.** Impacts of road expansion policy on transportation activity
(% change from the base case)

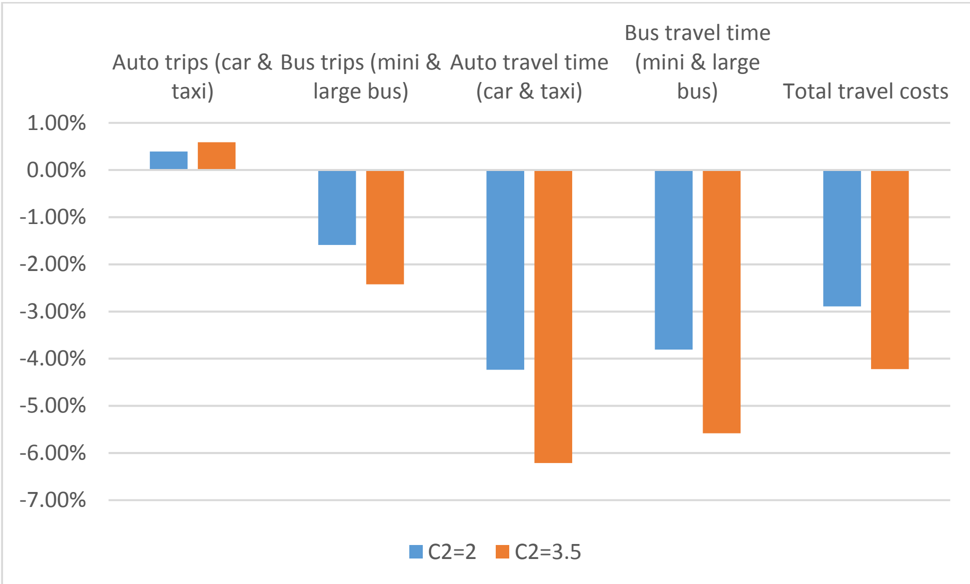
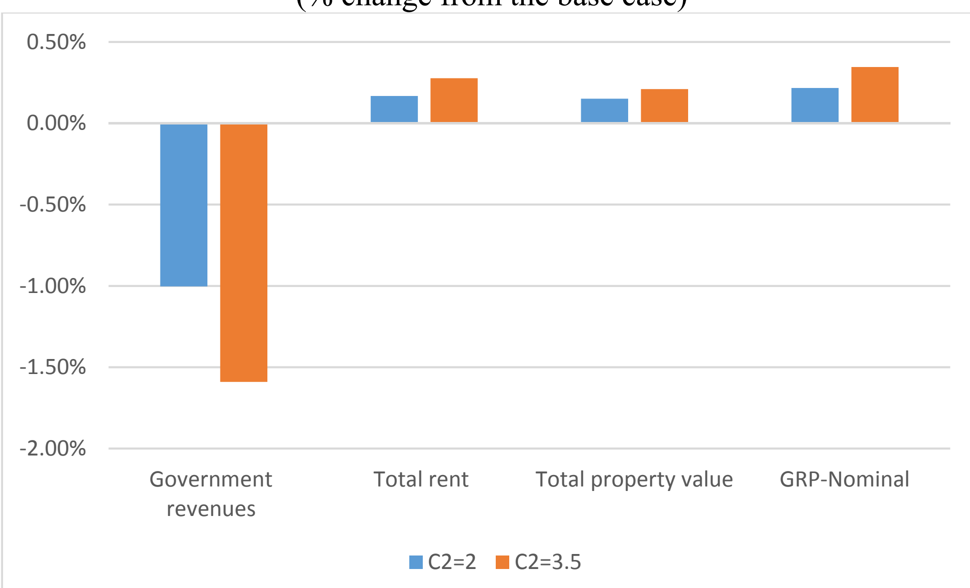



**Figure 2b.** Impacts of road expansion policy on economic activity
(% change from the base case)




### 5.1.2 Adding bus capacity

Bus capacity is increased by 91% across the study area. There are two cases possible based on whether the bus is completely owned (case 1) or partially owned/rented (case 2). We found that the results are mostly similar between these two cases. They only differ with respect to the operational and maintenance costs of new buses which affect the change in the value of social welfare per person. The results are shown in Tables A2 and A3.

The increase in bus supply moves more population to MB and more jobs to GB. Wages in MB increase but decrease in GB. Residential rent decreases in both MB and GB. With an unchanged price of goods and a decrease in real output, the demand for commercial floor space decreases and this causes a fall in commercial rents in both MB and GB.

The increase in bus supply not only improves ridership of bus but also of all the other modes except private vehicle. However, the biggest gain in ridership is for bus. Increase in bus supply has two opposing effects: on the one hand, a decrease in bus wait times which improves the travel time by bus and encourages people to switch from private vehicles, reducing congestion; on the other hand, if the increase in bus supply does not adequately improve bus ridership then the additional buses will cause traffic congestion to increase. The increase in bus ridership not only shifts people from private vehicle to bus but to the remaining modes also. As a result of this spillover, though travel time by bus decreases due to lower waiting times, travel time for all the other modes increases due to higher congestion caused by the additional buses. The traffic load increases for all origin to destination pairs. There is an increase in both aggregate VMT and gasoline consumption. Gas tax and public transit revenues increase but parking tax revenue decreases. As the majority of the population uses private vehicles for work and non-work trips, the resulting increase in trip costs reduces the disposable income. In the short run, reduction in disposable income reduces housing demand (by the income effect) and hence residential rents. This reduction in rents causes substitution (the substitution effect) favoring more housing consumption. Also non-work trips decrease which means that the cost of non-work trips has increased. This leads to further substitution in favor of housing consumption.

There is an increase in the stock of residential floor space in both MB and GB. The increase in the demand for housing results in an increase in the construction of new housing floor space in MB and GB. But the fall in the nominal value of output affects the construction and the stock of commercial floor space. The fall in the stock of commercial floor space frees up some land which is used for the construction of new housing floor space. The stock of vacant land increases which results in lower rents and values of vacant land.

For an average worker, the benefit of falling residential rents and an increase in the wage in MB is less than the adverse effect of a fall in the wage in GB and an increase in travel time. As a result, an average worker is worse-off. For an average non-worker, the increase in travel time increases the cost of trips thus reducing their non-work trips. This adverse impact is more than the benefit of a decrease in residential rent. As a result, an average non-worker is also worse-off. The social welfare decreases and decreases more with a more congestible road network, that is when $c_2 = 3.5$.

The key impacts on transport activities and city economy are presented in Figure 3a and 3b. As can be seen in Figure 3a, increased addition of buses without expanding road capacity and only adding buses will deteriorate the congestion situation by increasing travel times of all vehicles, and does not help reduce congestion in Beirut. Due to increased travel time, gasoline consumption by car increases. The higher gasoline tax revenue and the increased public transport revenue would increase total government revenues but it would certainly hurt the consumers. Consequently, total rental value, total property value and gross regional products of the city will all drop.

**Figure 3a.** Impacts of the bus addition on transportation activity
(% change from the base case)

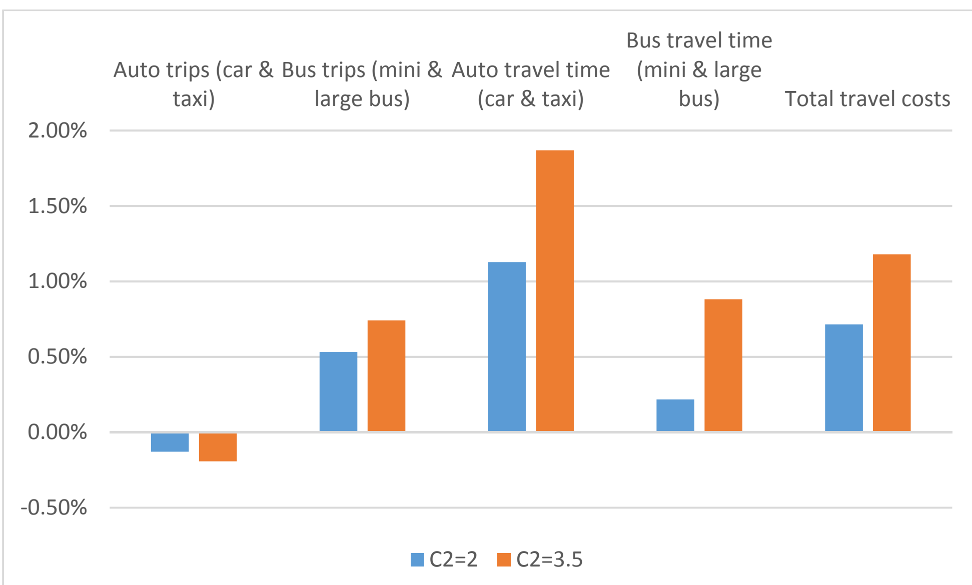
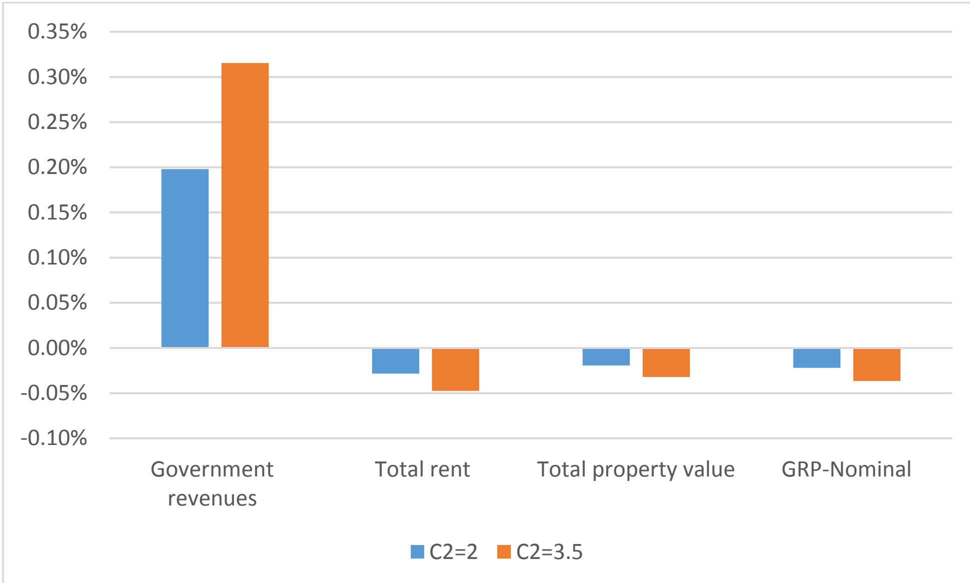


**Figure 3b.** Impacts of bus addition on economic activity
(% change from the base case)




### 5.1.3 Gasoline tax

This policy instrument considers doubling of excise tax on gasoline for the reason explained in scenario definition section above. The detailed results are shown in Table A4. The increase in the excise tax, shifts population to MB and jobs to GB. There is a decrease in wage and a decrease in the price of output and a lower nominal value of output in the region. This decreases the demand for commercial floor space and lowers commercial rents. Because floor space and labor are substitutes in production, wages are also lowered which reduces residential rent through the income effect.

The increase in the excise tax increases the operating cost for modes using gasoline (private vehicle, minibus and taxi service). For minibus and taxi service, we assumed that the increase in cost is not transferred to the rider. Under this situation, people switch from private vehicle to all other modes. Travel time for all modes decreases but the travel cost for private vehicles increases. As a result, non-work trips decrease along with VMT and gasoline consumption. Gas tax revenue and public transit revenue increase while parking tax revenue decreases.

As the majority of people use private vehicle for trips, the increase in the excise tax increases the cost of non-work trips. The increase in the excise tax dominates the decrease in output prices which makes the cost of non-work trips increase. The decrease in wage and disposable income reduces the demand for housing floor space (income effect) which reduces the residential rent. This rent reduction causes substitution in favor of demand for housing floor space (the substitution effect). Also with an increase in non-work trip cost, people will shift their demands at the margin from the composite good to residential floor space.

From this result, we find that the substitution effect of an increase in the excise tax dominates its income effect which results in an increase in the stock and construction of residential floor space. But the decrease in the population of GB plays an important role in reducing the aggregate demand for housing floor space even in the presence of a strong substitution effect. Hence the stock and construction of new residential housing decreases in GB. But a falling commercial rent, reduces both the stock and construction of commercial floor space in MB and GB. As expected the reduction in stock and construction of both residential and commercial floor space in GB, increases its stock of vacant land. Whereas in MB, the increase in vacant land due to the fall in commercial floor space stock is not fully utilized for the construction of new residential floor space. As a result vacant land increases in MB.

For the average worker, the benefit from the decrease in the price of output and residential rent, and the travel time decrease is outweighed by the decrease in wage and the increase in the cost of commute and shopping trips as the majority of them use private vehicles. Thus an average worker is worse-off. Non-workers are better off because the benefits outweigh the higher travel cost of non-work trips and non-workers have no commute costs. The social welfare however is lower overall. An increase in the exponent of the congestion function, i.e. $c_2 = 3.5$ which makes the change in social welfare less negative. The average worker is now better off as the effect of a decrease in traffic load and hence trip time and trip cost outweighs the negative effect of the tax.

The key transportation sector and city economic impacts of the increase in the gasoline excise tax are reflected in Figures 4a and 4b. The discussion of the results above explains the direction of impacts. The magnitudes of these impacts are also significant. The doubling of gasoline excise tax would increase total travel costs by 14%. As expected it would increase government revenues through increases in gasoline tax revenues and increased public transportation revenues. Although the tax on diesel, the main fuel used for public transportation vehicles, has not changed, public transport revenue still increases due to increase in public transportation trips caused by switching of passengers from private transportation to public transportation. This policy would however have a significant negative impact on the city's economy as rents, property values and gross regional products will drop. The drops on rents amount to 173 billion to 181 billion LBP and the drops on property value would be more than 2 trillion LBP. The nominal gross domestic product of the city drops by almost 200 billion LBP.

**Figure 4a.** Impacts of the increase in the excise tax on gasoline on transportation activity (% change from the base case)

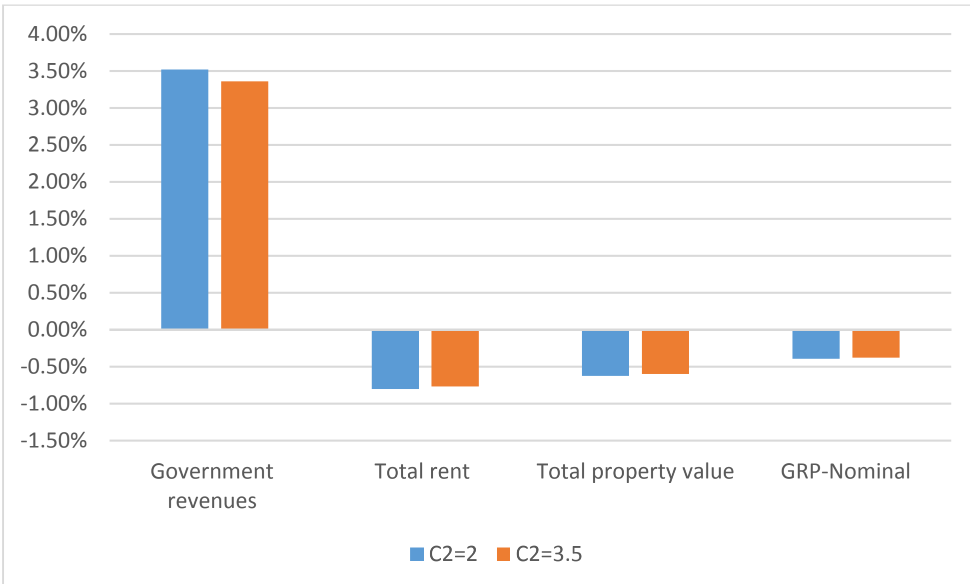
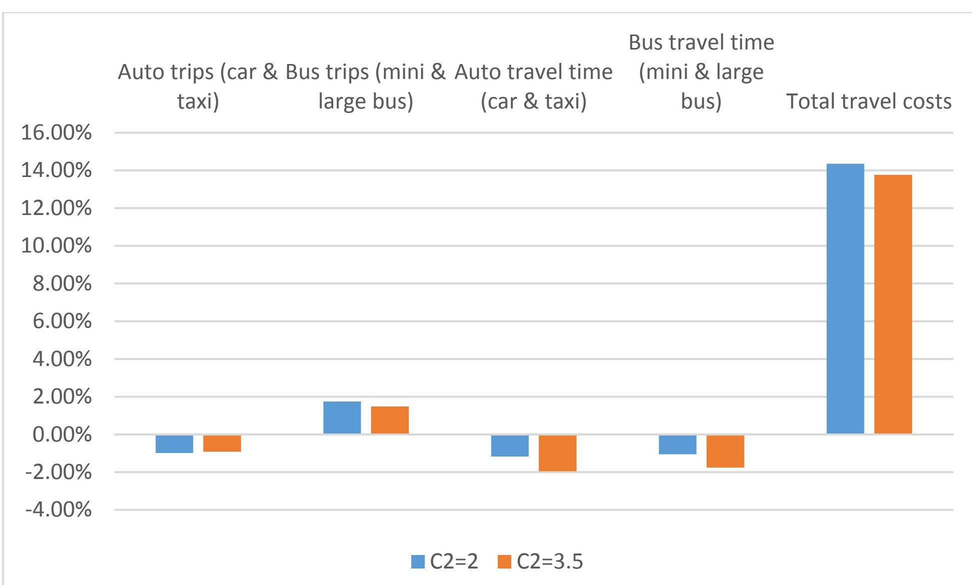



**Figure 4b.** Impacts of increase of excise tax on gasoline on urban economic activity (% change from the base case)



### 5.1.4 Parking cost

Under this policy, we increased the parking fees. As no specific number is given for parking fee increases, we have increased it by 10%, 15% and 25%. The detailed results are shown in Tables A5, A6 and A7. An increase in the parking tax, decentralizes both population and jobs to GB. Wages, rents and prices decrease. Due to the decrease in the value of nominal product, the demand for commercial floor space decreases which also decreases the commercial rent.

An increase in the parking tax, makes consumers switch from private vehicle to all other modes, improving the speed of all modes. The travel cost by private vehicle also decreases. Traffic load, VMT and gasoline consumption all decreased. Public transit and parking tax revenues increase at the expense of gas tax revenue.

As the majority of people use private vehicles for trips, the increase in parking tax increases the cost of non-work trips even when the gasoline cost of private vehicles decreases. As a result, there is a decrease in non-work trips. The increase in the parking tax dominates the decrease in output price which decreases the cost of non-work trips. The decrease in wage and disposable income reduces the demand for housing floor space (income effect) which reduces the residential rent. This rent reduction causes substitution in favor of demand for housing floor space (substitution effect). Also with an increase in the non-work trip cost, people shift their demand from the composite good to residential floor space.

The stock and construction of residential floor space increases in MB but decreases in GB. For MB, the substitution effect of the parking tax dominates its income effect and it is still strong enough to increase the stock and construction of residential floor space when the population moves out to GB. In GB, the residential stock and construction falls as the income effect of the parking tax dominates the substitution effect and an increase in population. Value and stock for commercial floor decrease in both MB and GB due to a fall in the nominal value of output. Decrease in commercial floor space stock frees up land for construction of new residential floor space in MB. But construction demand for new residential floor space is not enough to compensate for the land vacated due to the decrease in the stock of commercial floor space. As a result of that vacant land increases in MB. In GB, the stock of vacant land increases as the stock of both residential and commercial floor space decreases.

As most workers use private vehicle for trip purposes, an increase in the parking tax rate outweighs the benefit of a decrease in prices. Also the adverse impact on wages outweighs the benefit from the decrease in travel cost, travel time and residential rent. The average worker is worse-off. Non-workers are better off as the benefit of a decrease in travel cost, travel time and residential rent is more than the loss in the demand for non-work trips. An increase in the exponent of the congestion parameter to $c_2 = 3.5$ makes the change in social welfare less negative. The average worker is now better off as the effect of a decrease in traffic load and hence trip time and trip cost outweighs the negative effect of tax.

The key transportation sector and city economic impacts of 25% increase on parking fee are reflected in Figure 5a and 5b. The discussion of the results above explains the direction of impacts. The magnitude of impacts are also significant. The doubling of gasoline excise tax would increase total travel costs by more than 12%. This policy would have a significant negative impact on the city's economy as rents, property values and gross regional products will drop. Although the percentage drops on rents, property values and gross regional products are small, the absolute values are not. For example, 25% increase on parking fee would reduce the rents by more than 100 billion LBP and property value by more than 1 trillion LBP. The drop on nominal gross domestic products of the city would be more than 100 billion LBP.

**Figure 5a.** Impacts of 25% increase of parking fee on transportation activity (% change from the base case)

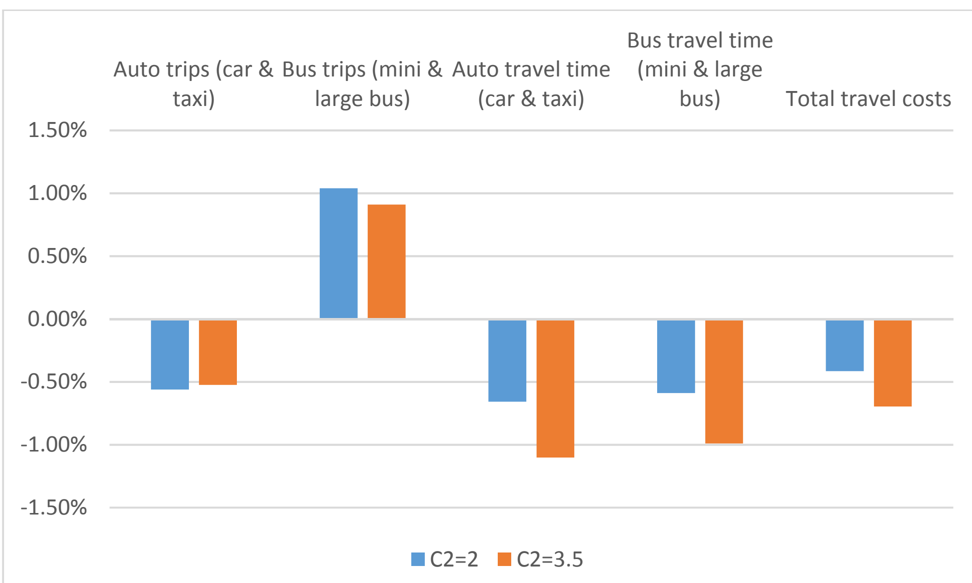
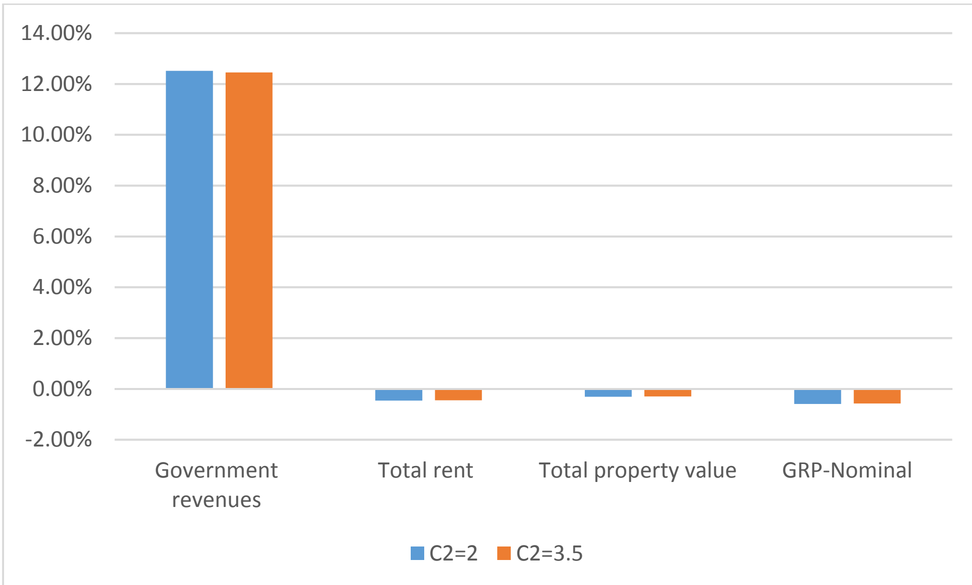


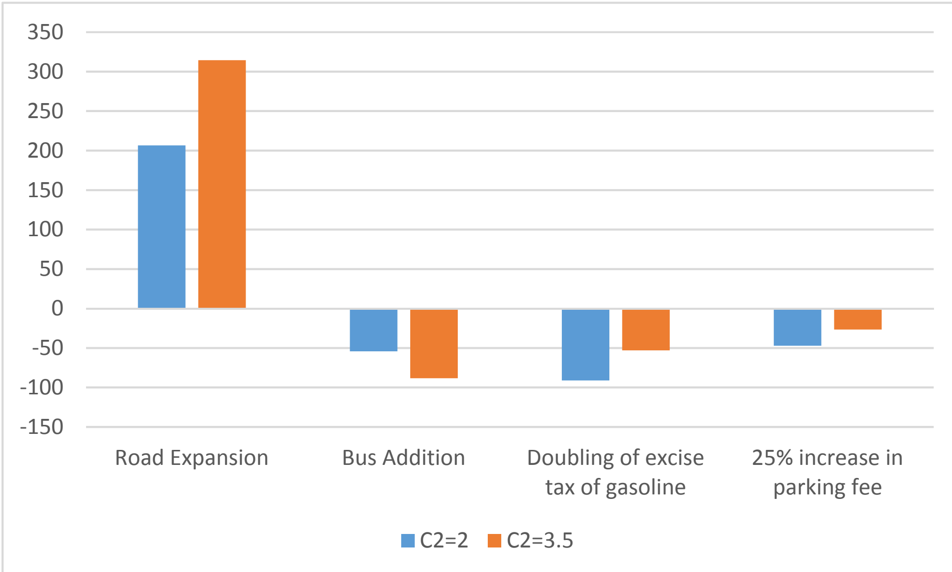
**Figure 5b.** Impacts of 25% increase of parking fee on urban economic activity (% change from the base case)




### 5.1.5 Social welfare impacts of policy instruments or investment activities

Figure 6 compares the effects of different policy instruments and investment actions on total social welfare. The impacts on social welfare calculated by the model include the effects of changes in total travel costs, total changes in rents, and total change in property values. Among the individual policies and investment activities, road expansion would increase the value of social welfare per person in the Greater Beirut Area by 200,000 to 300,000 LBP. All other policies and investment activities would reduce social welfare by varying amounts.

**Figure 6.** Social welfare costs of policy instruments ('000 LBP per person)




**5.2. Results from the simulations of the policy packages**

We have simulated the effects of three policy packages that contain a mix of demand side policy instruments and supply side investment activities. The supply side activities include the Bus Rapid Transit (BRT) or ring road as described in section 4.2, as well as other investment activity such as lane additions. These are combined with demand side instruments such as higher parking fees or gasoline excise taxes, as described in section 4.1. The policy packages selected for study were recommended for study in this paper by Ziad Nakat of the World Bank in Lebanon and by Maya Abou Zeid. They seem to have realistic chances of consideration by the city administration and implementation, based on our understanding of discussions in Lebanon's policy circles.

The first two policy packages involve the Bus Rapid Transit (BRT) system with 120 buses described in section 4.2. This proposed BRT is 90%-180% faster than all existing modes of transport. The targeted waiting time for the BRT bus will be 2-3 minutes. Additionally, bus network extension will include 250 regular buses that will improve the waiting and access/egress time by 10%-30%. Under Policy package 1, the parking tax increases by 25% in both MB and GB. Thus, the parking cost for work trips increased from 1,466.02 LBP to 1,832.5 LBP in MB and from 500 LBP to 625 LBP in GB. For non-work trips, parking cost increased from 984.25 LBP to 1,230.3 LBP in MB and from 500 LBP to 625 LBP in GB. The purpose of the parking tax increase is to discourage driving and by doing so divert even more car trips to the BRT.

Policy package 2 accompanies the BRT with highway lane additions instead of the parking tax increase. Since under any policy involving the BRT, road capacity is reduced to accommodate the BRT, car congestion on the remaining roads would increase. While Policy package 1 attempts to alleviate the higher congestion by increasing the parking tax, Policy package 2 attempts to alleviate the congestion by adding more road capacity for cars.

Policy package 3 is the ring road in GB described in section 4.2, accompanied with a 100% increase in the excise tax on gasoline. This amounts to a 16.5% increase in the after-tax gasoline price per liter.

### 5.2.1 Policy package 1: BRT buses, bus extension and parking fee increase

We simulated this policy package by introducing BRT buses as an alternative mode of transport which is 90%-180% faster than all existing modes of transport. The targeted waiting time for BRT bus will be 2-3 minutes. Bus network extension will improve the waiting and access/egress time by 10%-30%. The cost of implementing Policy 1 will be around 250 million USD which is 2% of the nominal gross product in the base year. Parking fee is increased by 25% in both MB and GB.

After the introduction of Policy package 1, there is an increase in social welfare per consumer. Welfare gains for workers and non-workers given in Table 5 are equivalent to 39% and 22% of their gross annual income. Both have greatly benefitted from reduction in travel time and travel cost for work and non-work trips. The speed of traffic improves by 139% and reduces congestion by 19%. The aggregate travel time in the Greater Beirut region is reduced by 43% which is equivalent to 24 minutes saved per trip.[10]

There is an increase in public transit and parking tax revenue at the expense of gas tax revenue. Even when people switched away to public transit, especially BRT buses, there is a marginal increase in tax revenue as the tax rate is high enough to recover the loss due to revenue reduction from private vehicles. Public transit revenue increased by 149% due to higher share of public transit users. Gas tax revenue decreased by 74 LBP per consumer as people switched away from gasoline driven modes to BRT buses. Also the decrease in gas tax revenue can be attributed

[10] Time saved per trip is total time saved divided by aggregate trips across all modes.

to parking tax being imposed on private vehicles which further reduces private vehicle use. All these factors improved traffic speed and reduced gasoline consumption and VMT. Improved travel time and reduced travel cost increased the disposable income for both workers and non-workers which resulted in a marginal increase in non-work trips by 0.03% and overall trips by 0.01% given in Table 5. Introduction of BRT created a mode share of 18% for BRT buses at the expense of all other modes.

From Table 6, we observe that some employment and population has moved into MB from GB. There is also an increase in labor supply relative to its demand which reduced the wage in MB but increased it in GB as labor supply decreases relative to its demand. In MB, rising rent encouraged the construction for new residential floor space to accommodate rising population. Whereas there is a negligible change in residential rent in GB and the stock of residential floor space decreased due to loss in population. There is an increase in nominal and real output which increased the demand for commercial floor space in both MB and GB. Increase in demand for commercial floor space also increased the rent of commercial floor space. Beirut, as a region, witnessed an increase in real estate value of 1.05% after the implementation of Policy package 1.

#### 5.2.2. Policy package 2: BRT buses, bus extension and lane addition

In Policy package 2, the parking tax in Policy package 1 is replaced by the construction of additional lanes. This would increase the road capacity in GB by less than 1%. Such lane additions will cost around 200 million USD i.e.1.5% of nominal gross product. So in total the cost of implementing Policy package 2 will be 3.5% of nominal gross product.

The welfare effects of both Policy package 1 and Policy package 2 are similar. The welfare of both workers and non-workers has increased as shown in Table 5. The welfare gains are equivalent to 40% and 22% of their gross annual income. The additional gains for workers under Policy package 2 relative to Policy package 1 are because traveling by private vehicle is less time consuming and less costly which is complementing the effect seen under the introduction of BRT and the regular bus network expansion. There is an increase in public transit revenue from the gas tax and the parking tax. Gas tax and parking tax revenue decreased by 74 LBP and 43 LBP as people switched to public transit especially BRT bus. Higher disposable income due to lower travel cost encouraged more non-work trips. Non-work trips under Policy package 2 are higher than under Policy package 1 as the higher parking tax under Policy package 1 reduced disposable income. Under package 2, 18% of the total trips are made in BRT buses with an associated decrease in VMT and gasoline consumption and is similar to Policy package 1 outcome. Traffic speed improved, traffic congestion decreased and travel time saved per trip is equivalent to 23 minutes.

From Table 6, we observe that both employment and population has moved into MB from GB, similar to Policy package 1. There is also an increase in labor supply relative to its demand which reduced the wage in MB but wage increases in GB as labor supply decreases relative to its demand. In both MB and GB, residential rent has increased. The price effect of higher residential rent will lower individual floor space demand. Also population in MB has increased which should increase the demand for residential floor space. At the margin, the price effect of the rent increase is greater than the effect of the population increase in MB. Such an effect discourages construction of new residential floor space and hence residential stock decreased in MB. Residential stock decreased in GB too due to the adverse price effect and the decrease in population. There is an increase in nominal and real output which increased the demand for commercial floor space in both MB and GB. The increase in the demand for commercial floor space also raised the rent of commercial floor space. Beirut as a region witnessed an increase in real estate values of 1.33% after the implementation of Policy package 2.

### 5.2.3. Policy package 3: Road capacity increase (Ring road, *Peripherique*) and gasoline tax increase

In Policy package 3, road capacity is increased in GB by building a ring road or 'Peripherique'. It will increase the road supply by 4.1%. The construction cost of this new road including expropriation of land is around 2 billion USD i.e. 15% of the nominal gross product of the base year.

After the implementation of Policy package 3, welfare is decreased as the cost of implementation far outweighs its benefits. Welfare gained by workers is around 6% of annual income and welfare lost by non-worker is lower than 1% of their non-wage income. On the one hand, increasing road capacity in GB encouraged trips by private vehicles, but on the other hand, higher gasoline tax discouraged traveling by private vehicle. At the margin, the result in Table 5 show that congestion has decreased whereas the mode choice shares remained more or less unchanged. So the improvement in speed by 11% is not due to changes in mode choice in favor of public transit but because of a decrease in non-work trips by 0.91% which reduced the overall traffic. Imposition of the higher gasoline tax outweighs the decrease in trip cost through improved traffic speed which reduces the disposable income and as such adversely affect the demand for non-work trips. There is a small decrease in public transit and parking tax revenue of 1 LBP and 3 LBP per person respectively. Gas tax increased marginally by 16 LBP only. Improved speed reduced VMT and gasoline consumption by 0.40% and 6% respectively. The travel time saved is around 5 minutes per trip.

In Table 6, we see that contrary to Policy packages 1 and 2, there is a decentralization of both population and employment to GB. Wage in MB increased as labor supply decreased relative to its demand, whereas wage decreases in GB. The higher gasoline tax lowered the disposable income which caused the residential rent to fall. In MB, the favorable price effect of the rent decrease and the higher wage outweighed the decrease in population. This resulted in an increase in the stock of residential floor space at the margin. In GB, higher population along with lower residential rent resulted in an increase in the stock of residential floor space. Fall in nominal gross product by 0.66% adversely affected the demand for commercial floor space and hence the commercial rent fell marginally by 0.46% and 0.19% in MB and GB respectively. Beirut as a region experienced a drop in real estate values after the implementation of Policy 3.

Figure 7 shows the percentage change in mode choice share under each of the three policies, while Figure 8 shows changes in traffic related variables and Figure 9 in economic variables. Public transit includes regular bus, minibus and BRT bus. Under Policy package 1 and Policy package 2 there is an increase in public transit ridership at the expense of private vehicle and taxi service. Whereas there is a marginal increase in the share of private vehicle at the expense of public transit and taxi service. In all the three policies, there is a decrease in gasoline consumption, VMT, total travel time and an increase in traffic speed. The magnitude of changes is higher under Policy package 1 and Policy package 2 in comparison to Policy package 3. Government revenue which includes public transit revenue, parking tax revenue and gasoline tax revenue increases under all the policy packages. Real estate values and gross product increased under Policy package 1 and Policy package 2 but both of them decreased under Policy package 3.

**TABLE 5:** Welfare and travel related results for all three policy packages

| **Welfare change (LBP/year/consumer)** | **Policy package 1: BRT + bus ext. & parking tax incr.** | **Policy package 2: BRT + bus ext. & land additions** | **Policy package 3: Ring road & gas. tax** |
|---|---|---|---|
| Total welfare | 2,496,441 | 2,345,318 | -1,796,943 |
| Consumer CV | 2,617,273 | 2,637,097 | 334,846 |
| Worker | 5,126,104 | 5,178,149 | 777,561 |
| Non-worker | 713,875 | 709,254 | -1,033 |
| Real Estate Value | 138,968 | 176,043 | -52,231 |
| **Sources of tax revenue (LBP/year/consumer)** | | | |
| Gas Tax | -74 | -74 | 16 |
| Public Transit | 199 | 198 | -1 |
| Parking Tax | 21 | -43 | -3 |
| **Cost of policy implementation (LBP/year/consumer)** | | | |
| BRT | 259,946 | 259,946 | 0 |
| Road construction | 0 | 207,957 | 2,079,570 |
| | | | |
| **Consumer Utility** | **% change from base** | | |
| Overall | 4.06 | 4.06 | 0.33 |
| Worker | 6.14 | 6.17 | 0.77 |
| Non-worker | 2.48 | 2.46 | 0 |
| **TRAVEL COMPONENTS** | **% change from base** | | |
| Trips | 0.01 | 0.28 | -0.50 |
| Non-Work Trips | 0.03 | 0.56 | -0.91 |
| Average Speed | 138.8 | 137.3 | 11 |
| Gasoline | -43 | -42.7 | -6 |
| VMT | -15.9 | -15.5 | -0.40 |
| Total Travel Time | -42.6 | -42.3 | -10 |

**TABLE 6:** Effects of the policy packages on employment, rent, wage and gross product

| | **Policy package 1: BRT+bus ext. & parking tax incr.** | **Policy package 2: BRT+bus ext. & lane add.** | **Policy package 3: Ring road & gas. tax** |
|---|---|---|---|
| **% changes from base** | | | |
| **Jobs** | | | |
| MB | 6.8 | 6.8 | -2.1 |
| GB | -3.1 | -3 | 1 |
| **Hourly Wage** | | | |
| MB | -5.1 | -4.5 | 1.5 |
| GB | 5.4 | 5.8 | -1.7 |
| **Annual Residential Rent** | | | |
| MB | 6.9 | 7.4 | -1.3 |
| GB | 0.01 | 0.51 | -0.4 |
| **Annual Commercial Rent** | | | |
| MB | 1 | 1.5 | -0.46 |
| GB | 0.53 | 0.64 | -0.19 |
| **Gross Product** | 1.7 | 2.3 | -0.66 |

**FIGURE 7:** Percentage change in mode choice share under the three policy packages

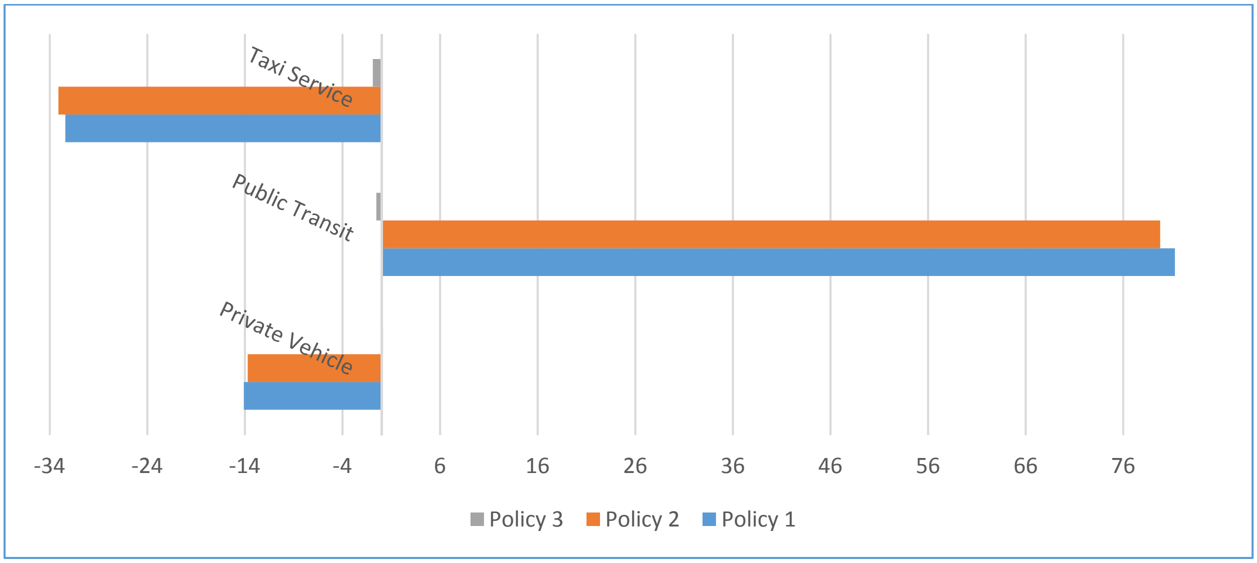



**FIGURE 8:** Percentage change in different traffic variables under the three policy packages

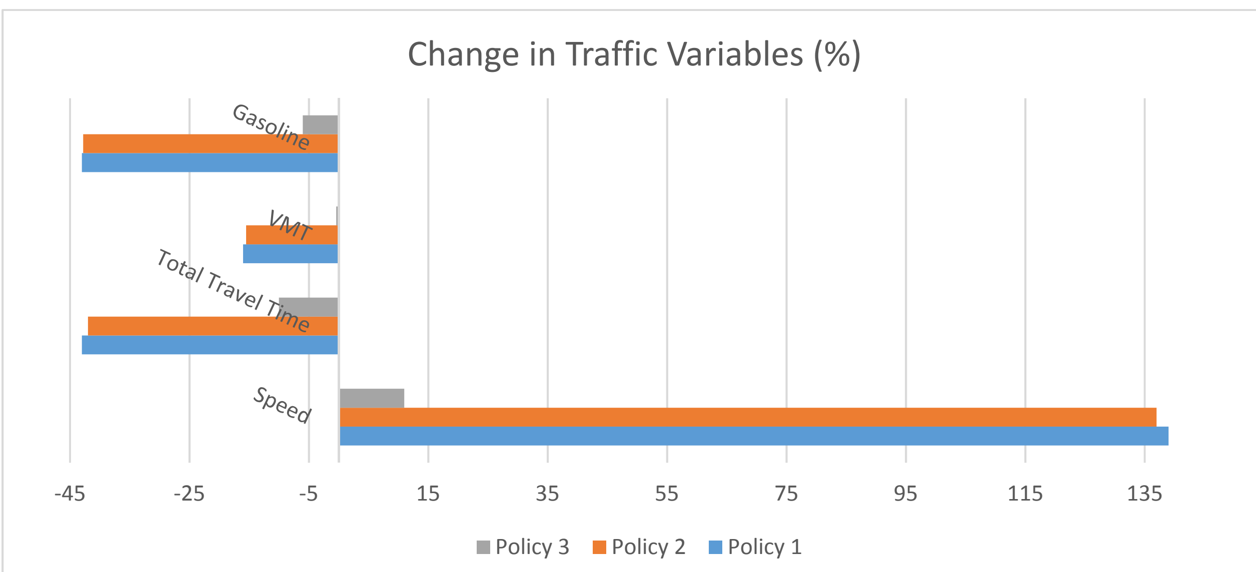
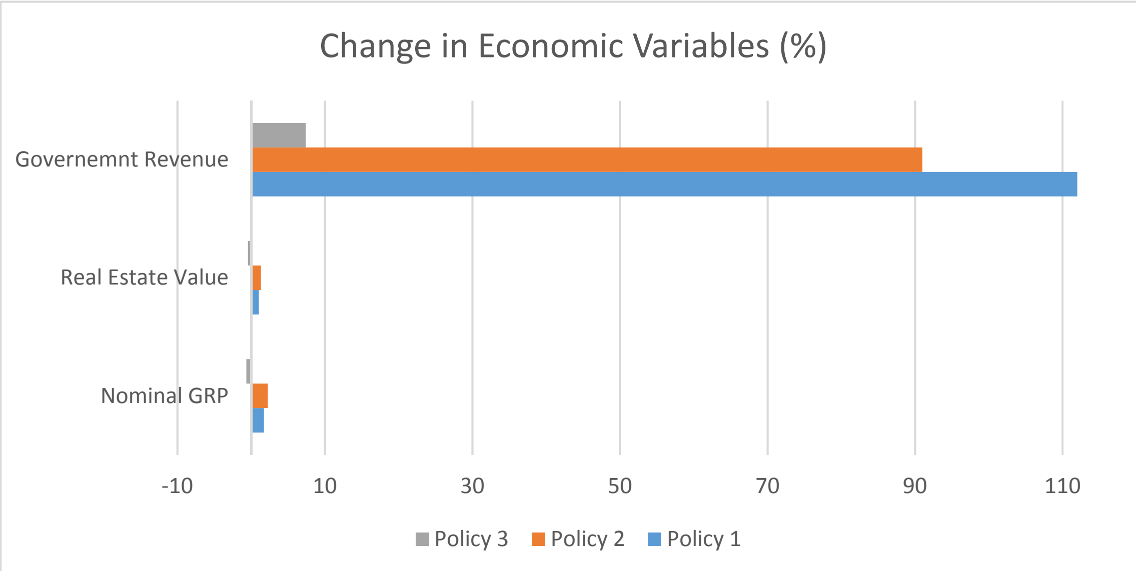


**FIGURE 9:** Percentage change in economic variables under the three policy packages




We did a further analysis in order to decompose the supply side from the demand side policy effects under each policy package. Recall that Policy package 1 includes the introduction of BRT buses together with a regular bus network extension on the supply side, and the demand side instrument of the parking fee increase. Policy package 2 includes the supply side policy of the introduction of BRT buses together with a regular bus network extension, and another supply side measure, highway lane addition in suburban GB. Policy package 3 includes a different supply side measure, the construction of a ring road in suburban GB, together with the increase in the gasoline tax as a demand side policy instrument. In Tables 7 and Table 8, which correspond to Tables 5 and 6, there are two runs (columns) reported for each policy. The first of these runs calculates the changes from the base situation when the supply side part of the policy is introduced, and the second run calculates the additional change when the other part of the policy is added (demand side for Policy package 1 and Policy package 3, and the other supply side part of Policy package 2).

The results show that the supply side instruments are responsible for a very large part of the improvements in total social welfare, and consumer welfare, while the demand side part of the package causes small changes in either direction depending on the policy. This is because the supply side policies and especially the BRT is very effective in directly speeding up public transportation, and indirectly travel by car, by getting car traffic off the roads. The 25% parking tax increase under Policy package 1 makes a small negative difference to consumer utility. This is because the parking tax increase is small and a poor substitute to pricing congestion with a Pigouvian congestion toll.

**TABLE 7:** Welfare and travel related results for all three policy packages.

| | **Policy package 1: BRT+bus ext. & parking tax incr.** | | **Policy package 2: BRT+bus ext.& lane add.** | | **Policy package 3: Ring road & gas. tax** | |
|---|---|---|---|---|---|---|
| **Welfare change (LBP/year/consumer)** | **BRT+regular bus extens.** | **Parking tax incr.** | **BRT+regular bus extens.** | **GB lane additions** | **Ring road** | **Gasoline tax incr.** |
| Total welfare | 2,541,129 | -44,688 | 2,541,129 | -195,811 | -1,738,447 | -58,496 |
| Consumer welfare | 2,626,094 | -8,821 | 2,626,094 | 11,003 | 313,188 | 21,658 |
| Worker | 5,152,197 | -26,093 | 5,152,197 | 25,952 | 733,142 | 44,419 |
| Non-worker | 709,591 | 4,284 | 709,591 | -337 | -5,423 | 4,390 |
| Real Estate Value | 174,899 | -35,931 | 174,899 | 1,144 | 27,941 | -80,172 |
| **Sources of tax revenue (LBP/year/consumer)** | | | | | | |
| Gas Tax | -73 | -1 | -73 | -1 | -4 | 20 |
| Public Transit | 198.7 | 0.3 | 198.7 | -0.3 | -2 | 1 |
| Parking Tax | -43 | 64 | -43 | 0 | 0.10 | -3.1 |
| **Cost of policy implementation (LBP/year/consumer)** | | | | | | |
| BRT | 259,946 | 0 | 259,946 | 0 | 0 | 0 |
| Road construction | 0 | 0 | 0 | 207,957 | 2,079,570 | 0 |
| | | | | | | |
| **TRAVEL COMPONENTS** | | | **% changes from base** | | | |
| Trips | 0.27 | -0.26 | 0.27 | 0.01 | 0.12 | -0.62 |
| Non-Work Trips | 0.55 | -0.52 | 0.55 | 0.01 | 0.23 | -1.1 |
| Average Speed | 136.6 | 2.2 | 136.6 | 0.7 | 9 | 2 |
| Gasoline | -42 | -1 | -42 | -0.7 | -4 | -2 |
| VMT | -15.6 | -0.3 | -15.6 | 0.11 | 0.39 | -0.79 |
| Total Travel Time | -42 | -0.6 | -42 | -0.3 | -7 | -3 |

Note: For each policy package, column 1 is change or % change from base and column 2 is change or % change from column 1

**TABLE 8:** Important results for all three policy packages

| | Policy package 1 | | Policy package 2 | | Policy package 3 | |
|---|---|---|---|---|---|---|
| | BRT+regular bus extens. | Parking tax incr. | BRT+regular bus extens. | GB lane Additions | Ring road | Gasoline tax incr. |
| **Population** | **% change from base** | | | | | |
| MB | 6.6 | 0 | 6.6 | 0 | -0.32 | 0.04 |
| GB | -3 | 0 | -3 | 0 | 0.14 | -0.01 |
| **Jobs** | | | | | | |
| MB | 6.9 | -0.1 | 6.9 | -0.1 | -1.9 | -0.2 |
| GB | -3.2 | 0.1 | -3.2 | 0.2 | 0.9 | 0.1 |
| **Hourly wage** | | | | | | |
| MB | -4.6 | -0.5 | -4.6 | 0.1 | 2.5 | -1 |
| GB | 5.8 | -0.4 | 5.8 | 0 | -0.7 | -1 |
| **Annual residential rent** | | | | | | |
| MB | 7.4 | -0.5 | 7.4 | 0 | -0.3 | -1 |
| GB | 0.51 | -0.5 | 0.5 | 0.01 | 0.6 | -0.2 |
| **Annual Commercial Rent** | | | | | | |
| MB | 1.4 | -0.4 | 1.4 | 0.1 | 0.4 | -0.86 |
| GB | 0.6 | -0.07 | 0.6 | 0.04 | 0.1 | -0.29 |
| **Gross Product** | 2.2 | -0.5 | 2.2 | 0.1 | 0.3 | -0.96 |

Note: For each policy package, column 1 is change or % change from base and column 2 is change or % change from column 1

Policy package 2 gives results very similar to policy package 1, except that in this case, the highway land additions have a small but net positive effect on consumer CV, but a negative effect on total welfare because of the cost of the additional lanes. The ring road under the third policy package increases consumer welfare but much less than the BRT because it is much less effective in alleviating congestion. Its total effect on welfare is negative because of its very high cost. The gasoline tax doubling under the same package has a notable additional effect on consumer welfare because it approximates well the effect of congestion pricing, much better than the parking tax does under the first policy package.

Table 9 presents the improvement in each of three different measures of congestion. The first two measures are utilized mostly by engineers and planners and measure congestion in physical terms. The first of these is the ratio of the composite traffic load per unit of road capacity or more commonly known as the flow-to-capacity ratio. Table 9 shows that this ratio is a very high 9-10 in the base case. It falls by 15-17.5% under the first two policy packages involving the BRT but falls much less under the third package involving the ring road.

The second measure is that popularized by the Texas Transportation Institute commonly known as the TTI index. It measures congestion as the ratio of actual travel time to free-flow travel time. We take free-flow travel time to be 100 km/hr. (62 miles per hour). The base value of this measure is in the 7.4-10.6 range, but it improves by 44-50% under the BRT (packages 1 and 2) and by only 6-13% under the ring road (package 3).

The third measure is the aggregate congestion externality, favored by economists. It is the total monetary value of the congestion delays caused by all traffic in LBP per year per consumer in the model. In the base year this amounts to 283,399 LBP per consumer per year (approximately 189 $ US). The aggregate amount is equivalent to 2.11% of the Beirut region's gross product and 3.96% of the per consumer income. Under the policy packages that include the BRT the aggregate congestion externality falls by about 53% but by only 5% under Policy package 3.

**TABLE 9:** Improvement in congestion measures relative to Base

| | **Base** | **Policy package 1** | **Policy package 2** | **Policy package 3** |
|---|---|---|---|---|
| | | **% changes from base** | | |
| **FLOW TO CAPACITY RATIO** | | | | |
| **MB-MB** | 10.02 | -17.78 | -17.45 | -1.72 |
| **MB-GB** | 9.04 | -16.19 | -16.14 | -3.26 |
| **GB-MB** | 9.14 | -17.15 | -16.86 | -2.11 |
| **GB-GB** | 9.31 | -15.51 | -15.47 | -3.75 |
| | | | | |
| **TTI INDEX FOR ROAD TRAFFIC** | | | | |
| **MB-MB** | 10.63 | -49.51 | -48.80 | -5.87 |
| **MB-GB** | 7.42 | -46.01 | -45.89 | -10.93 |
| **GB-MB** | 7.72 | -48.13 | -47.50 | -7.19 |
| **GB-GB** | 8.23 | -44.48 | -44.38 | -12.49 |
| **CONGESTION EXTERNALITY** | | | | |
| **Aggregate congestion externality (in billion LBP/year)** | 408.83 | -53.82 | -52.88 | -5.70 |
| **Congestion externality per consumer (LBP/year)** | 283,399 | -53.82 | -52.88 | -5.70 |
| **Congestion externality as a percent of Beirut gross product** | 2.11 | -54.61 | -53.91 | -5.07 |

In summary, under policy packages 1 and 2, the BRT is very effective. It reduces congestion as measured by the flow to capacity ratio by about 16%. It increases the Beirut region's gross product by 1.8% under package 1 and by 2.3% under package 2, implying an elasticity of gross product to congestion of 11-14% under these policies. Consumer welfare under both packages increases by about 4%, with almost all of this due to the BRT, implying an elasticity of consumer utility to congestion of about 25%. The congestion externality is reduced by about 54%, implying an elasticity of the congestion externality to congestion of 337.5%.

## 6. Conclusions

Beirut, like most growing cities, faces the unwelcome effects of traffic congestion resulting from a number of causes. It is critical to alleviate the problem by implementing effective policies, based on weighing their overall economic cost and benefit to society.  For this purpose, this study applied an empirical model based on microeconomic theory that accounts for consumption and production behavior related to transportation in the Greater Beirut Area (GBA). includes both Beirut Municipality (MB) and Greater Beirut (GB), the location of suburbs and exurbs. The model accounts for the origin and destination of trips and all their characteristics including trip type, trip frequency, vehicle fuel type, transportation mode, travel time and cost, real estate information, work and residential areas etc. We first simulated a number of supply and demand side measures aimed to reduce congestion individually, and compared these policies in terms of their impacts on the economy. This was followed by simulations of three plausible combination of these measures as well as with additional activities, based on our understanding of discussions in Lebanon's policy circles and the options being evaluated by the City Administration.

One of the key findings of the study is that individual supply side policies such as the expansion of roads or the introduction of a Bus Rapid Transit (BRT) system would be more beneficial for Beirut compared to individual demand side policies such as an increased gasoline tax or higher parking fees. Similarly, in the policy packages considered, most of the benefits come from the supply-side components.  This is because the supply side policies and especially the BRT are very effective in directly speeding up public transportation, and indirectly speeding up travel by car by getting car traffic off the roads. The introduction of the BRT with the expansion of the conventional bus systems to feed the BRT reduces congestion, as measured by the flow to capacity ratio, by about 16%. The reduction of costs caused by congestion would be more than 50%, while the gross product of the Beirut region would increase by 1.8%. The introduction of the BRT and the expansion of associated road network would have similar effects on congestion and on congestion costs and would increase the Beirut region's gross product by 2.3%. Social welfare, measured in terms of consumer utility, would increase by about 4%. On the other hand, demand side instruments such as increased gasoline taxes and parking fees, if implemented on their own, would have negative economic consequences including slight drops in gross national product and in welfare.

Considering that most past studies on transport congestion management focused mostly on demand side instruments, this study has brought additional insights comparing various policy instruments on both the demand and the supply sides. Some limitations should be kept in mind while interpreting the results and policy findings. Although we found that the BRT is a most promising option for addressing congestion in Beirut, it may, in the future, cause problems of over-crowding and other unintended negative social impacts.[11] In the future, congestion might occur again due to increased volume of vehicles and transport service demand as population of the city, income level and vehicle ownership would increase. Therefore, demand side options have an important role as complements to supply-sided measures in the longer-run. Another limitation is that we had to work on a high level of aggregation dividing Beirut into just two zones. The results would have been more precise had we divided the city into additional zones. However, detailed data needed to divide the city more regions for a more detailed study are not currently available.

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[11] For more on the limitation of BRT refer to Gilbert (2008) and Suzuki et. al. (2013).

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# APPENDIX A

## Detailed results from the simulations of various policy instruments and public projects

**Table A1:** Increase in road supply

| | | $c_2 = 2$ | | $c_2 = 3.5$ | |
|---|---|---|---|---|---|
| **Variables** | **BASE RESULTS** | **SIMULATED RESULT** | **CHANGES** | **SIMULATED RESULT** | **CHANGES** |
| **Price of Output (LBP)** | | | | | |
| MB | 10.00 | 10.05 | 0.501 | 10.10 | 1.004 |
| GB | 10.00 | 10.00 | -0.043 | 9.98 | -0.159 |
| **Hourly Wage (LBP/hr)** | | | | | |
| MB | 4,363.20 | 4,415.73 | 1.204 | 4,472.21 | 2.498 |
| GB | 3,452.04 | 3,443.33 | -0.252 | 3,429.29 | -0.659 |
| **Annual Residential Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 175,800 | 174,659 | -0.649 | 175,197 | -0.343 |
| GB | 83,550 | 83,993 | 0.531 | 84,051 | 0.600 |
| **Annual Commercial Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 426,750 | 427,626 | 0.205 | 428,242 | 0.350 |
| GB | 227,400 | 227,542 | 0.063 | 227,616 | 0.095 |
| **Annual Vacant Land Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 503,640 | 503,818 | 0.035 | 504,069 | 0.085 |
| GB | 73,350 | 73,414 | 0.088 | 73,440 | 0.122 |
| **Annual Value of Residential Stock (LBP/ Sq. Meter)** | | | | | |
| MB | 5,860,000 | 5,837,217 | -0.389 | 5,846,524 | -0.230 |
| GB | 2,785,000 | 2,792,868 | 0.283 | 2,794,085 | 0.326 |
| **Annual Value of Commercial Stock (LBP/ Sq. Meter)** | | | | | |
| MB | 8,535,000 | 8,549,537 | 0.170 | 8,561,937 | 0.316 |
| GB | 4,548,000 | 4,550,260 | 0.050 | 4,551,254 | 0.072 |
| **Annual Value of Vacant Land (LBP/ Sq. Meter)** | | | | | |
| MB | 16,788,000 | 16,793,920 | 0.035 | 16,802,304 | 0.085 |
| GB | 2,445,000 | 2,447,143 | 0.088 | 2,447,994 | 0.122 |

| | | | | | |
|---|---|---|---|---|---|
| **Stock of Residential Floor Space (Sq. Meters)** | | | | | |
| MB | 5,259,997 | 5,256,399 | -0.068 | 5,255,216 | -0.091 |
| GB | 21,342,698 | 21,368,233 | 0.120 | 21,368,668 | 0.122 |
| **Stock of Commercial Floor Space (Sq. Meters)** | | | | | |
| MB | 11,859,052 | 11,873,482 | 0.122 | 11,882,087 | 0.194 |
| GB | 37,501,072 | 37,540,416 | 0.105 | 37,564,055 | 0.168 |
| **Stock of Vacant Land (Sq. Meters)** | | | | | |
| MB | 4,650,000 | 4,650,017 | 0.000 | 4,648,977 | -0.022 |
| GB | 52,610,000 | 52,578,068 | -0.061 | 52,571,548 | -0.073 |
| **Employment by Workplace Location** | | | | | |
| MB | 198,839 | 197,158 | -0.845 | 195,096 | -1.882 |
| GB | 423,489 | 425,170 | 0.397 | 427,232 | 0.884 |
| **Population by Residence Location** | | | | | |
| MB | 445,184 | 443,714 | -0.330 | 443,758 | -0.320 |
| GB | 997,422 | 998,892 | 0.147 | 998,848 | 0.143 |
| **Private Vehicle Trips by (i,j)** | | | | | |
| MB-MB | 133,112 | 130,301 | -2.112 | 130,590 | -1.895 |
| MB-GB | 174,556 | 175,047 | 0.281 | 175,806 | 0.716 |
| GB-MB | 244,519 | 246,075 | 0.637 | 243,244 | -0.521 |
| GB-GB | 427,187 | 433,019 | 1.365 | 437,357 | 2.381 |
| **Bus Trips by (i,j)** | | | | | |
| MB-MB | 3,562.04 | 3,452.51 | -3.075 | 3,423.29 | -3.895 |
| MB-GB | 4,669.58 | 4,587.60 | -1.756 | 4,555.26 | -2.448 |
| GB-MB | 7,801.83 | 7,668.93 | -1.703 | 7,539.52 | -3.362 |
| GB-GB | 10,626 | 10,480 | -1.373 | 10,425 | -1.892 |
| **Mini Bus Trips by (i,j)** | | | | | |
| MB-MB | 22,186 | 21,531 | -2.956 | 21,374 | -3.663 |
| MB-GB | 29,085 | 28,626 | -1.578 | 28,457 | -2.157 |
| GB-MB | 48,594 | 47,861 | -1.510 | 47,083 | -3.110 |
| GB-GB | 66,183 | 65,436 | -1.128 | 65,179 | -1.516 |

| | | | | | |
|---|---|---|---|---|---|
| **Taxi Service Trips by (i,j)** | | | | | |
| MB-MB | 8,575 | 8,291 | -3.315 | 8,248 | -3.817 |
| MB-GB | 10,586 | 10,400 | -1.757 | 10,289 | -2.801 |
| GB-MB | 14,045 | 13,882 | -1.160 | 13,648 | -2.830 |
| GB-GB | 24,937 | 24,571 | -1.467 | 24,440 | -1.994 |
| **Trips by mode (m)** | | | | | |
| Private Vehicle | 979,372 | 984,442 | 0.518 | 986,997 | 0.778 |
| Bus | 26,659 | 26,189 | -1.764 | 25,943 | -2.687 |
| Mini Bus | 166,048 | 163,453 | -1.563 | 162,094 | -2.382 |
| Taxi Service | 58,143 | 57,148 | -1.718 | 56,624 | -2.612 |
| **Travel Time by Private Vehicle for (i,j) (Minutes)** | | | | | |
| MB-MB | 42.10 | 41.44 | -1.579 | 40.43 | -3.959 |
| MB-GB | 53.00 | 49.99 | -5.684 | 48.37 | -8.742 |
| GB-MB | 57.00 | 54.22 | -4.872 | 54.13 | -5.034 |
| GB-GB | 46.40 | 43.35 | -6.579 | 41.63 | -10.279 |
| **Travel Time by Bus for (i,j) (Minutes)** | | | | | |
| MB-MB | 77.60 | 76.64 | -1.243 | 75.18 | -3.117 |
| MB-GB | 98.30 | 93.93 | -4.441 | 91.59 | -6.830 |
| GB-MB | 104.20 | 100.17 | -3.867 | 100.04 | -3.996 |
| GB-GB | 88.80 | 84.37 | -4.986 | 81.88 | -7.790 |
| **Travel Time by MiniBus for (i,j) (Minutes)** | | | | | |
| MB-MB | 63.10 | 62.27 | -1.316 | 61.02 | -3.300 |
| MB-GB | 81.70 | 77.94 | -4.606 | 75.91 | -7.084 |
| GB-MB | 86.80 | 83.33 | -4.002 | 83.21 | -4.135 |
| GB-GB | 73.50 | 69.68 | -5.191 | 67.54 | -8.111 |
| **Travel Time by Taxi Service for (i,j) (Minutes)** | | | | | |
| MB-MB | 58.33 | 57.60 | -1.253 | 56.50 | -3.142 |
| MB-GB | 72.33 | 69.02 | -4.582 | 67.23 | -7.047 |
| GB-MB | 76.73 | 73.68 | -3.981 | 73.57 | -4.114 |
| GB-GB | 65.13 | 61.77 | -5.162 | 59.88 | -8.065 |

| | | | | | |
|---|---|---|---|---|---|
| **Monetary Travel Cost by Private Vehicle for (i,j) (LBP)** | | | | | |
| MB-MB | 1,701.39 | 1,688.46 | -0.760 | 1,668.48 | -1.934 |
| MB-GB | 2,527.46 | 2,439.28 | -3.489 | 2,390.02 | -5.438 |
| GB-MB | 2,674.59 | 2,596.40 | -2.923 | 2,593.73 | -3.023 |
| GB-GB | 2,119.76 | 2,038.11 | -3.852 | 1,989.76 | -6.133 |
| **PHIijm for BUS** | | | | | |
| MB-MB | 0.09 | 0.09 | 2.530 | 0.09 | 3.230 |
| MB-GB | 0.09 | 0.09 | 1.427 | 0.09 | 2.003 |
| GB-MB | 0.09 | 0.09 | 1.384 | 0.09 | 2.774 |
| GB-GB | 0.09 | 0.09 | 1.112 | 0.09 | 1.540 |
| **Traffic Load by (i,j)** | | | | | |
| MB-MB | 95,097 | 92,925 | -2.284 | 93,001 | -2.204 |
| MB-GB | 123,921 | 123,862 | -0.047 | 124,131 | 0.169 |
| GB-MB | 175,003 | 175,522 | 0.297 | 173,364 | -0.936 |
| GB-GB | 300,627 | 303,417 | 0.928 | 305,742 | 1.701 |
| **Weighted Rent by Location (LBP/ Sq. Meter)** | | | | | |
| MB | 382,538 | 382,841 | 0.079 | 383,384 | 0.221 |
| GB | 127,137 | 127,341 | 0.160 | 127,413 | 0.217 |
| **Weighted Value of Stocks by Location (LBP/ Sq. Meter)** | | | | | |
| MB | 9,651,538 | 9,655,120 | 0.037 | 9,665,347 | 0.143 |
| GB | 3,217,708 | 3,221,580 | 0.120 | 3,222,875 | 0.161 |
| **Construction of Residential Floor Space (Sq. Meters)** | | | | | |
| MB | 15,080 | 15,070 | -0.060 | 15,067 | -0.083 |
| GB | 218,712 | 218,840 | 0.058 | 218,833 | 0.055 |
| **Construction of Commercial Floor Space (Sq. Meters)** | | | | | |
| MB | 112,692 | 112,813 | 0.107 | 112,883 | 0.169 |
| GB | 1,324,943 | 1,325,588 | 0.049 | 1,326,084 | 0.086 |
| Aggregate rent in the Region (MB & GB) (LBP) | 22,497,353,364,096 | 22,535,043,952,048 | 0.168 | 22,559,587,472,476 | 0.277 |

| | | | | | |
|---|---|---|---|---|---|
| Aggregate value in the Region (MB & GB) (LBP) | 381,123,093,725,158 | 381,698,410,548,332 | 0.151 | 381,923,870,210,237 | 0.210 |
| Aggregate Daily Non-work Person Trips | 607,895 | 608,899 | 0.165 | 609,329 | 0.236 |
| Aggregate Daily Vehicle Miles Travelled (Kilometers) | 13,366,017 | 13,413,052 | 0.352 | 13,418,073 | 0.389 |
| Aggregate Daily Gasoline Consumption (Liters) | 1,620,915 | 1,573,554 | -2.922 | 1,550,120 | -4.368 |
| Gross Nominal Regional Product(LBP) | 19,412,277,163,440 | 19,454,338,571,108 | 0.217 | 19,479,454,336,360 | 0.346 |
| Gross Real Regional Product | 1,941,227,716,344 | 1,942,347,293,120 | 0.058 | 1,942,665,521,868 | 0.074 |
| **Inclusive Value** | | | | | |
| IV of worker | 9.18 | 9.22 | 0.478 | 9.24 | 0.713 |
| IV of non-worker | 10.53 | 10.53 | -0.006 | 10.53 | -0.017 |
| **Different Sources of Tax Revenue (LBP)** | | | | | |
| Gas Tax Revenue | 244,911,661 | 237,768,982 | -2.916 | 234,251,134 | -4.353 |
| Public Transit Revenue | 192,707,342 | 189,641,927 | -1.591 | 188,036,287 | -2.424 |
| Parking Tax Revenue | 468,083,192 | 469,206,982 | 0.240 | 469,004,957 | 0.197 |
| **Cost of Policy Implementation (LBP)** | | | | | |
| Cost of Building New Road | | 37,800,000,000 | | 37,800,000,000 | |
| **Compensating Variation (LBP)** | | | | | |
| CV for Worker | | 495,576 | | 732,041 | |
| CV for Non-worker | | -1,937.13 | | -5,382.82 | |

| | | | | |
|---|---|---|---|---|
| CV | 212,686 | | 312,735 | |
| **Social Welfare change per person by Region (LBP)** | | | | |
| SW for Road Policy | 206,417 | | 314,277 | |

**TABLE A2:** Increase in bus supply for case 1

| CASE 1 | | $c_2 = 2$ | | $c_2 = 3.5$ | |
|---|---|---|---|---|---|
| **Variables** | **BASE RESULTS** | **SIMULATED RESULT** | **CHANGES** | **SIMULATED RESULT** | **CHANGES** |
| **Price of Output (LBP)** | | | | | |
| MB | 10.00 | 10.00 | 0.000 | 10.00 | 0.000 |
| GB | 10.00 | 10.00 | 0.000 | 10.00 | 0.000 |
| **Hourly Wage (LBP/hr)** | | | | | |
| MB | 4,363.20 | 4,363.56 | 0.008 | 4,363.23 | 0.001 |
| GB | 3,452.04 | 3,450.80 | -0.036 | 3,450.21 | -0.053 |
| **Annual Residential Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 175,800 | 175,783 | -0.010 | 175,762 | -0.022 |
| GB | 83,550 | 83,523 | -0.033 | 83,508 | -0.051 |
| **Annual Commercial Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 426,750 | 426,634 | -0.027 | 426,560 | -0.045 |
| GB | 227,400 | 227,357 | -0.019 | 227,328 | -0.032 |
| **Annual Vacant Land Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 503,640 | 503,626 | -0.003 | 503,617 | -0.005 |
| GB | 73,350 | 73,345 | -0.007 | 73,341 | -0.012 |
| **Annual Value of Residential Stock (Sq. Meters)** | | | | | |
| MB | 5,860,000 | 5,859,815 | -0.003 | 5,859,592 | -0.007 |
| GB | 2,785,000 | 2,784,724 | -0.010 | 2,784,572 | -0.015 |
| **Annual Value of Commercial Stock (Sq. Meters)** | | | | | |
| MB | 8,535,000 | 8,533,855 | -0.013 | 8,533,130 | -0.022 |
| GB | 4,548,000 | 4,547,636 | -0.008 | 4,547,392 | -0.013 |
| **Annual Value of Vacant Land (Sq. Meters)** | | | | | |
| MB | 16,788,000 | 16,787,528 | -0.003 | 16,787,224 | -0.005 |
| The GB | 2,445,000 | 2,444,828 | -0.007 | 2,444,715 | -0.012 |
| **Stock of Residential Floor Space (Sq. Meters)** | | | | | |
| MB | 5,259,997 | 5,260,140 | 0.003 | 5,260,223 | 0.004 |
| GB | 21,342,698 | 21,342,884 | 0.001 | 21,343,160 | 0.002 |

| | | | | | |
|---|---|---|---|---|---|
| **Stock of Commercial Floor Space (Sq. Meters)** | | | | | |
| MB | 11,859,052 | 11,858,148 | -0.008 | 11,857,588 | -0.012 |
| GB | 37,501,072 | 37,491,129 | -0.027 | 37,484,361 | -0.045 |
| **Stock of Vacant Land (Sq. Meters)** | | | | | |
| MB | 4,650,000 | 4,650,088 | 0.002 | 4,650,149 | 0.003 |
| GB | 52,610,000 | 52,612,430 | 0.005 | 52,613,956 | 0.008 |
| **Employment by Workplace Location** | | | | | |
| MB | 198,839 | 198,728 | -0.056 | 198,691 | -0.075 |
| GB | 423,489 | 423,600 | 0.026 | 423,637 | 0.035 |
| **Population by Residence Location** | | | | | |
| MB | 445,184 | 445,216 | 0.007 | 445,224 | 0.009 |
| GB | 997,422 | 997,390 | -0.003 | 997,382 | -0.004 |
| **Private Vehicle Trips by (i,j)** | | | | | |
| MB-MB | 133,112 | 132,979 | -0.100 | 132,897 | -0.161 |
| MB-GB | 174,556 | 174,299 | -0.147 | 174,158 | -0.228 |
| GB-MB | 244,518 | 243,982 | -0.219 | 243,734 | -0.321 |
| GB-GB | 427,187 | 426,589 | -0.140 | 426,268 | -0.215 |
| **Bus Trips by (i,j)** | | | | | |
| MB-MB | 3,562.04 | 3,633.75 | 2.013 | 3,641.10 | 2.219 |
| MB-GB | 4,669.58 | 4,762.88 | 1.998 | 4,773.19 | 2.219 |
| GB-MB | 7,801.83 | 7,952.02 | 1.925 | 7,968.75 | 2.139 |
| GB-GB | 10,626 | 10,861 | 2.210 | 10,887 | 2.462 |
| **Mini Bus Trips by (i,j)** | | | | | |
| MB-MB | 22,186 | 22,245 | 0.262 | 22,284 | 0.440 |
| MB-GB | 29,085 | 29,165 | 0.277 | 29,223 | 0.474 |
| GB-MB | 48,594 | 48,717 | 0.252 | 48,811 | 0.445 |
| GB-GB | 66,183 | 66,396 | 0.323 | 66,548 | 0.551 |
| **Taxi Service Trips by (i,j)** | | | | | |
| MB-MB | 8,575.04 | 8,602.29 | 0.318 | 8,620.42 | 0.529 |
| MB-GB | 10,586 | 10,618 | 0.310 | 10,642 | 0.533 |

| | | | | | |
|---|---|---|---|---|---|
| GB-MB | 14,045 | 14,080 | 0.250 | 14,108 | 0.449 |
| GB-GB | 24,937 | 25,028 | 0.363 | 25,091 | 0.618 |
| **Trips by mode (m)** | | | | | |
| Private Vehicle | 979,372 | 977,850 | -0.155 | 977,057 | -0.236 |
| Bus | 26,659 | 27,209 | 2.063 | 27,270 | 2.293 |
| Mini Bus | 166,048 | 166,523 | 0.286 | 166,865 | 0.492 |
| Taxi Service | 58,142.77 | 58,328 | 0.319 | 58,462 | 0.549 |
| **Travel Time by Private Vehicle for (i,j) (Minutes)** | | | | | |
| MB-MB | 42.10 | 42.63 | 1.255 | 42.98 | 2.092 |
| MB-GB | 53.00 | 53.66 | 1.239 | 54.10 | 2.066 |
| GB-MB | 57.00 | 57.78 | 1.363 | 58.27 | 2.222 |
| GB-GB | 46.40 | 46.97 | 1.221 | 47.35 | 2.040 |
| **Travel Time by Bus for (i,j) (Minutes)** | | | | | |
| MB-MB | 77.60 | 77.10 | -0.643 | 77.61 | 0.016 |
| MB-GB | 98.30 | 97.89 | -0.420 | 98.52 | 0.226 |
| GB-MB | 104.20 | 103.96 | -0.228 | 104.67 | 0.454 |
| GB-GB | 88.80 | 88.26 | -0.611 | 88.81 | 0.010 |
| **Travel Time by MiniBus for (i,j) (Minutes)** | | | | | |
| MB-MB | 63.10 | 63.76 | 1.046 | 64.20 | 1.744 |
| MB-GB | 81.70 | 82.52 | 1.004 | 83.07 | 1.674 |
| GB-MB | 86.80 | 87.77 | 1.120 | 88.38 | 1.825 |
| GB-GB | 73.50 | 74.21 | 0.963 | 74.68 | 1.610 |
| **Travel Time by Taxi Service for (i,j) (Minutes)** | | | | | |
| MB-MB | 58.33 | 58.91 | 0.996 | 59.30 | 1.661 |
| MB-GB | 72.33 | 73.05 | 0.999 | 73.53 | 1.666 |
| GB-MB | 76.73 | 77.58 | 1.114 | 78.12 | 1.816 |
| GB-GB | 65.13 | 65.75 | 0.958 | 66.17 | 1.601 |
| **Monetary Travel Cost by Private Vehicle for (i,j) (LBP)** | | | | | |
| MB-MB | 1,701.39 | 1,711.48 | 0.593 | 1,718.13 | 0.984 |
| MB-GB | 2,527.46 | 2,546.09 | 0.737 | 2,558.43 | 1.225 |

| | | | | | |
|---|---|---|---|---|---|
| GB-MB | 2,674.59 | 2,695.83 | 0.794 | 2,709.08 | 1.289 |
| GB-GB | 2,119.76 | 2,134.32 | 0.687 | 2,143.99 | 1.143 |
| **Monetary Travel Cost by Bus for (i,j) (LBP)** | | | | | |
| MB-MB | 1,000 | 1,000 | 0.000 | 1,000 | 0.000 |
| MB-GB | 1,000 | 1,000 | 0.000 | 1,000 | 0.000 |
| GB-MB | 1,000 | 1,000 | 0.000 | 1,000 | 0.000 |
| GB-GB | 1,000 | 1,000 | 0.000 | 1,000 | 0.000 |
| **Monetary Travel Cost by MiniBus for (i,j) (LBP)** | | | | | |
| MB-MB | 1,000 | 1,000 | 0.000 | 1,000 | 0.000 |
| MB-GB | 1,000 | 1,000 | 0.000 | 1,000 | 0.000 |
| GB-MB | 1,000 | 1,000 | 0.000 | 1,000 | 0.000 |
| GB-GB | 1,000 | 1,000 | 0.000 | 1,000 | 0.000 |
| **Monetary Travel Cost by Taxi Service for (i,j) (LBP)** | | | | | |
| MB-MB | 2,000 | 2,000 | 0.000 | 2,000 | 0.000 |
| MB-GB | 4,000 | 4,000 | 0.000 | 4,000 | 0.000 |
| GB-MB | 4,000 | 4,000 | 0.000 | 4,000 | 0.000 |
| GB-GB | 4,000 | 4,000 | 0.000 | 4,000 | 0.000 |
| **PHIijm for BUS** | | | | | |
| MB-MB | 0.09 | 0.17 | 87.889 | 0.17 | 87.586 |
| MB-GB | 0.09 | 0.18 | 98.868 | 0.18 | 98.525 |
| GB-MB | 0.09 | 0.18 | 98.982 | 0.18 | 98.648 |
| GB-GB | 0.09 | 0.18 | 98.538 | 0.18 | 98.147 |
| **Waiting Time for Bus by (i,j) (Minutes)** | | | | | |
| MB-MB | 6.50 | 5.23 | -19.476 | 5.23 | -19.476 |
| MB-GB | 6.50 | 5.14 | -20.991 | 5.14 | -20.991 |
| GB-MB | 6.50 | 5.14 | -20.991 | 5.14 | -20.991 |
| GB-GB | 6.50 | 5.14 | -20.991 | 5.14 | -20.991 |
| **Traffic Load by (i,j)** | | | | | |
| MB-MB | 95,097 | 95,650 | 0.582 | 95,635 | 0.565 |
| MB-GB | 123,921 | 124,688 | 0.619 | 124,649 | 0.588 |

| | | | | | |
|---|---|---|---|---|---|
| GB-MB | 175,003 | 176,194 | 0.681 | 176,108 | 0.632 |
| GB-GB | 300,627 | 302,394 | 0.588 | 302,323 | 0.564 |
| **Weighted Rent by Location (LBP/ Sq. Meter)** | | | | | |
| MB | 382,538 | 382,465 | -0.019 | 382,416 | -0.032 |
| GB | 127,137 | 127,104 | -0.025 | 127,083 | -0.042 |
| **Weighted Value of Stocks by Location (LBP/ Sq. Meter)** | | | | | |
| MB | 9,651,538 | 9,650,819 | -0.007 | 9,650,339 | -0.012 |
| GB | 3,217,708 | 3,217,316 | -0.012 | 3,217,059 | -0.020 |
| **Construction of Residential Floor Space (Sq. Meters)** | | | | | |
| MB | 15,080 | 15,080 | 0.003 | 15,080 | 0.004 |
| GB | 218,712 | 218,717 | 0.002 | 218,721 | 0.004 |
| **Construction of Commercial Floor Space (Sq. Meters)** | | | | | |
| MB | 112,692 | 112,685 | -0.006 | 112,681 | -0.011 |
| GB | 1,324,943 | 1,324,731 | -0.016 | 1,324,586 | -0.027 |
| Aggregate rent in the Region (MB & GB) (LBP) | 22,497,353,364,096 | 22,490,960,182,319 | -0.028 | 22,486,748,829,329 | -0.047 |
| Aggregate value in the Region (MB & GB) (LBP) | 381,123,093,725,158 | 381,049,377,069,417 | -0.019 | 381,000,537,011,336 | -0.032 |
| Aggregate Daily Non-work Person Trips | 607,895 | 607,582 | -0.051 | 607,326 | -0.094 |
| Aggregate Daily Vehicle Miles Travelled (Kilometers) | 13,366,017 | 13,401,835 | 0.268 | 13,395,584 | 0.221 |
| Aggregate Daily Gasoline Consumption (Liters) | 1,620,915 | 1,643,303 | 1.381 | 1,650,228 | 1.808 |

| | | | | | |
|---|---|---|---|---|---|
| Gross Nominal Regional Product(LBP) | 19,412,277,163,440 | 19,407,987,283,461 | -0.022 | 19,405,181,567,267 | -0.037 |
| Gross Real Regional Product | 1,941,227,716,344 | 1,940,798,728,346 | -0.022 | 1,940,518,156,727 | -0.037 |
| **Inclusive Value** | | | | | |
| IV of worker | 9.18 | 9.17 | -0.104 | 9.16 | -0.173 |
| IV of non-worker | 10.53 | 10.53 | -0.002 | 10.53 | -0.003 |
| **Different Sources of Tax Revenue (LBP)** | | | | | |
| Gas Tax Revenue | 244,911,661 | 246,427,103 | 0.619 | 247,462,824 | 1.042 |
| Public Transit Revenue | 192,707,342 | 193,732,208 | 0.532 | 194,135,243 | 0.741 |
| Parking Tax Revenue | 468,083,192 | 467,335,484 | -0.160 | 466,959,861 | -0.240 |
| Cost of New Bus under Case 1 | | 5,306,776,450 | | 5,306,776,450 | |
| **Compensating Variation (LBP)** | | | | | |
| CV for Worker | | -110,527 | | -184,801 | |
| CV for Non-worker | | -678.92 | | -1,120.84 | |
| CV | | -48,067 | | -80,359 | |
| **Social Welfare change per person by Region (LBP)** | | | | | |
| SW for Bus Supply in Case 1 | | -54,299 | | -88,283 | |

**TABLE A3:** Increase in bus supply for Case 2

| **CASE 2** | | $c_2 = 2$ | | $c_2 = 3.5$ | |
|---|---|---|---|---|---|
| **Variables** | **BASE RESULTS** | **SIMULATED RESULT** | **CHANGES** | **SIMULATED RESULT** | **CHANGES** |
| **Price of Output (LBP)** | | | | | |
| MB | 10.00 | 10.00 | 0.000 | 10.00 | 0.000 |
| GB | 10.00 | 10.00 | 0.000 | 10.00 | 0.000 |
| **Hourly Wage (LBP/hr)** | | | | | |
| MB | 4,363.20 | 4,363.56 | 0.008 | 4,363.23 | 0.001 |
| GB | 3,452.04 | 3,450.80 | -0.036 | 3,450.21 | -0.053 |
| **Annual Residential Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 175,800 | 175,783 | -0.010 | 175,762 | -0.022 |
| GB | 83,550 | 83,523 | -0.033 | 83,508 | -0.051 |
| **Annual Commercial Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 426,750 | 426,634 | -0.027 | 426,560 | -0.045 |
| GB | 227,400 | 227,357 | -0.019 | 227,328 | -0.032 |
| **Annual Vacant Land Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 503,640 | 503,626 | -0.003 | 503,617 | -0.005 |
| GB | 73,350 | 73,345 | -0.007 | 73,341 | -0.012 |
| **Annual Value of Residential Stock (LBP/ Sq. Meter)** | | | | | |
| MB | 5,860,000 | 5,859,815 | -0.003 | 5,859,592 | -0.007 |
| GB | 2,785,000 | 2,784,724 | -0.010 | 2,784,572 | -0.015 |
| **Annual Value of Commercial Stock (LBP/ Sq. Meter)** | | | | | |
| MB | 8,535,000 | 8,533,855 | -0.013 | 8,533,130 | -0.022 |
| GB | 4,548,000 | 4,547,636 | -0.008 | 4,547,392 | -0.013 |
| **Annual Value of Vacant Land (LBP/ Sq. Meter)** | | | | | |
| MB | 16,788,000 | 16,787,528 | -0.003 | 16,787,224 | -0.005 |
| GB | 2,445,000 | 2,444,828 | -0.007 | 2,444,715 | -0.012 |
| **Stock of Residential Floor Space (Sq. Meters)** | | | | | |
| MB | 5,259,997 | 5,260,140 | 0.003 | 5,260,223 | 0.004 |
| GB | 21,342,698 | 21,342,884 | 0.001 | 21,343,160 | 0.002 |

| | | | | | |
|---|---|---|---|---|---|
| **Stock of Commercial Floor Space (Sq. Meters)** | | | | | |
| MB | 11,859,052 | 11,858,148 | -0.008 | 11,857,588 | -0.012 |
| GB | 37,501,072 | 37,491,129 | -0.027 | 37,484,361 | -0.045 |
| **Stock of Vacant Land (Sq. Meters)** | | | | | |
| MB | 4,650,000 | 4,650,088 | 0.002 | 4,650,149 | 0.003 |
| GB | 52,610,000 | 52,612,430 | 0.005 | 52,613,956 | 0.008 |
| **Employment by Workplace Location** | | | | | |
| MB | 198,839 | 198,728 | -0.056 | 198,691 | -0.075 |
| GB | 423,489 | 423,600 | 0.026 | 423,637 | 0.035 |
| **Population by Residence Location** | | | | | |
| MB | 445,184 | 445,216 | 0.007 | 445,224 | 0.009 |
| GB | 997,422 | 997,390 | -0.003 | 997,382 | -0.004 |
| **Private Vehicle Trips by (i,j)** | | | | | |
| MB-MB | 133,112 | 132,979 | -0.100 | 132,897 | -0.161 |
| MB-GB | 174,556 | 174,299 | -0.147 | 174,158 | -0.228 |
| GB-MB | 244,518 | 243,982 | -0.219 | 243,734 | -0.321 |
| GB-GB | 427,187 | 426,589 | -0.140 | 426,268 | -0.215 |
| **Bus Trips by (i,j)** | | | | | |
| MB-MB | 3,562.04 | 3,633.75 | 2.013 | 3,641.10 | 2.219 |
| MB-GB | 4,669.58 | 4,762.88 | 1.998 | 4,773.19 | 2.219 |
| GB-MB | 7,801.83 | 7,952.02 | 1.925 | 7,968.75 | 2.139 |
| GB-GB | 10,626 | 10,861 | 2.210 | 10,887 | 2.462 |
| **Mini Bus Trips by (i,j)** | | | | | |
| MB-MB | 22,186 | 22,245 | 0.262 | 22,284 | 0.440 |
| MB-GB | 29,085 | 29,165 | 0.277 | 29,223 | 0.474 |
| GB-MB | 48,594 | 48,717 | 0.252 | 48,811 | 0.445 |
| GB-GB | 66,183 | 66,396 | 0.323 | 66,548 | 0.551 |
| **Taxi Service Trips by (i,j)** | | | | | |
| MB-MB | 8,575 | 8,602 | 0.318 | 8,620 | 0.529 |
| MB-GB | 10,586 | 10,618 | 0.310 | 10,642 | 0.533 |

| | | | | | |
|---|---|---|---|---|---|
| GB-MB | 14,045 | 14,080 | 0.250 | 14,108 | 0.449 |
| GB-GB | 24,937 | 25,028 | 0.363 | 25,091 | 0.618 |
| **Trips by mode (m)** | | | | | |
| Private Vehicle | 979,372 | 977,850 | -0.155 | 977,057 | -0.236 |
| Bus | 26,659 | 27,209 | 2.063 | 27,270 | 2.293 |
| Mini Bus | 166,048 | 166,523 | 0.286 | 166,865 | 0.492 |
| Taxi Service | 58,143 | 58,328 | 0.319 | 58,462 | 0.549 |
| **Travel Time by Private Vehicle for (i,j) (Minutes)** | | | | | |
| MB-MB | 42.10 | 42.63 | 1.255 | 42.98 | 2.092 |
| MB-GB | 53.00 | 53.66 | 1.239 | 54.10 | 2.066 |
| GB-MB | 57.00 | 57.78 | 1.363 | 58.27 | 2.222 |
| GB-GB | 46.40 | 46.97 | 1.221 | 47.35 | 2.040 |
| **Travel Time by Bus for (i,j) (Minutes)** | | | | | |
| MB-MB | 77.60 | 77.10 | -0.643 | 77.61 | 0.016 |
| MB-GB | 98.30 | 97.89 | -0.420 | 98.52 | 0.226 |
| GB-MB | 104.20 | 103.96 | -0.228 | 104.67 | 0.454 |
| GB-GB | 88.80 | 88.26 | -0.611 | 88.81 | 0.010 |
| **Travel Time by MiniBus for (i,j) (Minutes)** | | | | | |
| MB-MB | 63.10 | 63.76 | 1.046 | 64.20 | 1.744 |
| MB-GB | 81.70 | 82.52 | 1.004 | 83.07 | 1.674 |
| GB-MB | 86.80 | 87.77 | 1.120 | 88.38 | 1.825 |
| GB-GB | 73.50 | 74.21 | 0.963 | 74.68 | 1.610 |
| **Travel Time by Taxi Service for (i,j) (Minutes)** | | | | | |
| MB-MB | 58.33 | 58.91 | 0.996 | 59.30 | 1.661 |
| MB-GB | 72.33 | 73.05 | 0.999 | 73.53 | 1.666 |
| GB-MB | 76.73 | 77.58 | 1.114 | 78.12 | 1.816 |
| GB-GB | 65.13 | 65.75 | 0.958 | 66.17 | 1.601 |
| **Monetary Travel Cost by Private Vehicle for (i,j) (LBP)** | | | | | |
| MB-MB | 1,701.39 | 1,711.48 | 0.593 | 1,718.13 | 0.984 |
| MB-GB | 2,527.46 | 2,546.09 | 0.737 | 2,558.43 | 1.225 |

| | | | | | |
|---|---|---|---|---|---|
| GB-MB | 2,674.59 | 2,695.83 | 0.794 | 2,709.08 | 1.289 |
| GB-GB | 2,119.76 | 2,134.32 | 0.687 | 2,143.99 | 1.143 |
| **Monetary Travel Cost by Bus for (i,j) (LBP)** | | | | | |
| MB-MB | 1,000 | 1,000 | 0.000 | 1,000 | 0.000 |
| MB-GB | 1,000 | 1,000 | 0.000 | 1,000 | 0.000 |
| GB-MB | 1,000 | 1,000 | 0.000 | 1,000 | 0.000 |
| GB-GB | 1,000 | 1,000 | 0.000 | 1,000 | 0.000 |
| **Monetary Travel Cost by MiniBus for (i,j) (LBP)** | | | | | |
| MB-MB | 1,000 | 1,000 | 0.000 | 1,000 | 0.000 |
| MB-GB | 1,000 | 1,000 | 0.000 | 1,000 | 0.000 |
| GB-MB | 1,000 | 1,000 | 0.000 | 1,000 | 0.000 |
| GB-GB | 1,000 | 1,000 | 0.000 | 1,000 | 0.000 |
| **Monetary Travel Cost by Taxi Service for (i,j) (LBP)** | | | | | |
| MB-MB | 2,000 | 2,000 | 0.000 | 2,000 | 0.000 |
| MB-GB | 4,000 | 4,000 | 0.000 | 4,000 | 0.000 |
| GB-MB | 4,000 | 4,000 | 0.000 | 4,000 | 0.000 |
| GB-GB | 4,000 | 4,000 | 0.000 | 4,000 | 0.000 |
| **PHIijm for BUS** | | | | | |
| MB-MB | 0.09 | 0.17 | 87.889 | 0.17 | 87.586 |
| MB-GB | 0.09 | 0.18 | 98.868 | 0.18 | 98.525 |
| GB-MB | 0.09 | 0.18 | 98.982 | 0.18 | 98.648 |
| GB-GB | 0.09 | 0.18 | 98.538 | 0.18 | 98.147 |
| **Waiting Time for Bus by (i,j) (Minutes)** | | | | | |
| MB-MB | 6.50 | 5.23 | -19.476 | 5.23 | -19.476 |
| MB-GB | 6.50 | 5.14 | -20.991 | 5.14 | -20.991 |
| GB-MB | 6.50 | 5.14 | -20.991 | 5.14 | -20.991 |
| GB-GB | 6.50 | 5.14 | -20.991 | 5.14 | -20.991 |
| **Traffic Load by (i,j)** | | | | | |
| MB-MB | 95,097 | 95,650 | 0.582 | 95,635 | 0.565 |
| MB-GB | 123,921 | 124,688 | 0.619 | 124,649 | 0.588 |

| | | | | | |
|---|---|---|---|---|---|
| GB-MB | 175,003 | 176,194 | 0.681 | 176,108 | 0.632 |
| GB-GB | 300,627 | 302,394 | 0.588 | 302,323 | 0.564 |
| **Weighted Rent by Location (LBP/ Sq. Meter)** | | | | | |
| MB | 382,538 | 382,465 | -0.019 | 382,416 | -0.032 |
| GB | 127,137 | 127,104 | -0.025 | 127,083 | -0.042 |
| **Weighted Value of Stocks by Location (LBP/ Sq. Meter)** | | | | | |
| MB | 9,651,538 | 9,650,819 | -0.007 | 9,650,339 | -0.012 |
| GB | 3,217,708 | 3,217,316 | -0.012 | 3,217,059 | -0.020 |
| **Construction of Residential Floor Space (Sq. Meters)** | | | | | |
| MB | 15,080 | 15,080 | 0.003 | 15,080 | 0.004 |
| GB | 218,712 | 218,717 | 0.002 | 218,721 | 0.004 |
| **Construction of Commercial Floor Space (Sq. Meters)** | | | | | |
| MB | 112,692 | 112,685 | -0.006 | 112,681 | -0.011 |
| GB | 1,324,943 | 1,324,731 | -0.016 | 1,324,586 | -0.027 |
| Aggregate rent in the Region (MB & GB) (LBP) | 22,497,353,364,096 | 22,490,960,182,319 | -0.028 | 22,486,748,829,329 | -0.047 |
| Aggregate value in the Region (MB & GB) (LBP) | 381,123,093,725,158 | 381,049,377,069,417 | -0.019 | 381,000,537,011,336 | -0.032 |
| Aggregate Daily Non-work Person Trips | 607,895 | 607,582 | -0.051 | 607,326 | -0.094 |
| Aggregate Daily Vehicle Miles Travelled (Kilometers) | 13,366,017 | 13,401,835 | 0.268 | 13,395,584 | 0.221 |
| Aggregate Daily Gasoline Consumption (Liters) | 1,620,915 | 1,643,303 | 1.381 | 1,650,228 | 1.808 |

| | | | | | |
|---|---|---|---|---|---|
| Gross Nominal Regional Product(LBP) | 19,412,277,163,440 | 19,407,987,283,461 | -0.022 | 19,405,181,567,267 | -0.037 |
| Gross Real Regional Product | 1,941,227,716,344.00 | 1,940,798,728,346.09 | -0.022 | 1,940,518,156,726.73 | -0.037 |
| **Inclusive Value** | | | | | |
| IV of worker | 9.18 | 9.17 | -0.104 | 9.16 | -0.173 |
| IV of non-worker | 10.53 | 10.53 | -0.002 | 10.53 | -0.003 |
| **Different Sources of Tax Revenue (LBP)** | | | | | |
| Gas Tax Revenue | 244,911,661 | 246,427,103 | 0.619 | 247,462,824 | 1.042 |
| Public Transit Revenue | 192,707,342 | 193,732,208 | 0.532 | 194,135,243 | 0.741 |
| Parking Tax Revenue | 468,083,192 | 467,335,484 | -0.160 | 466,959,861 | -0.240 |
| Cost of New Bus under Case 2 | | 3,595,927,707 | | 3,595,927,707 | |
| **Compensating Variation (LBP)** | | | | | |
| CV for Worker | | -110,527 | | -184,801 | |
| CV for Non-worker | | -678.92 | | -1,120.84 | |
| CV | | -48,067 | | -80,359 | |
| **Social Welfare change per person by Region (LBP)** | | | | | |
| SW for Bus Supply in Case 2 | | -53,113 | | -87,098 | |

**TABLE A4:** Increase in the excise tax on gasoline

| | | $c_2 = 2$ | | $c_2 = 3.5$ | |
|---|---|---|---|---|---|
| **Variables** | **BASE RESULTS** | **SIMULATED RESULT** | **CHANGES** | **SIMULATED RESULT** | **CHANGES** |
| **Price of Output (LBP)** | | | | | |
| MB | 10.00 | 9.91 | -0.867 | 9.92 | -0.824 |
| GB | 10.00 | 9.95 | -0.495 | 9.95 | -0.478 |
| **Hourly Wage (LBP/hr)** | | | | | |
| MB | 4,363.20 | 4,318.86 | -1.016 | 4,321.93 | -0.946 |
| GB | 3,452.04 | 3,417.20 | -1.009 | 3,418.14 | -0.982 |
| **Annual Residential Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 175,800 | 174,055 | -0.992 | 174,096 | -0.969 |
| GB | 83,550 | 82,707 | -1.009 | 82,7478 | -0.960 |
| **Annual Commercial Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 426,750 | 423,315 | -0.805 | 423,457 | -0.772 |
| GB | 227,400 | 226,768 | -0.278 | 226,794 | -0.266 |
| **Annual Vacant Land Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 503,640 | 502,224 | -0.281 | 502,281 | -0.270 |
| GB | 73,350 | 73,067 | -0.385 | 73,079 | -0.369 |
| **Annual Value of Residential Stock (LBP/ Sq. Meter)** | | | | | |
| MB | 5,860,000 | 5,825,348 | -0.591 | 5,826,200 | -0.577 |
| GB | 2,785,000 | 2,768,826 | -0.581 | 2,769,599 | -0.553 |
| **Annual Value of Commercial Stock (LBP/ Sq. Meter)** | | | | | |
| MB | 8,535,000 | 8,468,724 | -0.777 | 8,471,428 | -0.745 |
| GB | 4,548,000 | 4,537,304 | -0.235 | 4,537,748 | -0.225 |
| **Annual Value of Vacant Land (LBP/ Sq. Meter)** | | | | | |
| MB | 16,788,000 | 16,740,813 | -0.281 | 16,742,693 | -0.270 |
| GB | 2,445,000 | 2,435,576 | -0.385 | 2,435,982 | -0.369 |
| **Stock of Residential Floor Space (Sq. Meters)** | | | | | |
| MB | 5,259,997 | 5,267,482 | 0.142 | 5,267,139 | 0.136 |
| GB | 21,342,698 | 21,323,573 | -0.090 | 21,324,820 | -0.084 |

| | | | | | |
|---|---|---|---|---|---|
| **Stock of Commercial Floor Space (Sq. Meters)** | | | | | |
| MB | 11,859,052 | 11,811,646 | -0.400 | 11,813,648 | -0.383 |
| GB | 37,501,072 | 37,257,345 | -0.650 | 37,267,072 | -0.624 |
| **Stock of Vacant Land (Sq. Meters)** | | | | | |
| MB | 4,650,000 | 4,654,666 | 0.100 | 4,654,499 | 0.097 |
| GB | 52,610,000 | 52,689,669 | 0.151 | 52,686,078 | 0.145 |
| **Employment by Workplace Location** | | | | | |
| MB | 198,839 | 198,495 | -0.173 | 198,456 | -0.192 |
| GB | 423,489 | 423,834 | 0.081 | 423,872 | 0.090 |
| **Population by Residence Location** | | | | | |
| MB | 445,184 | 445,420 | 0.053 | 445,379 | 0.044 |
| GB | 997,422 | 997,186 | -0.024 | 997,227 | -0.020 |
| **Private Vehicle Trips by (i,j)** | | | | | |
| MB-MB | 133,112 | 132,055 | -0.794 | 132,063 | -0.788 |
| MB-GB | 174,556 | 172,495 | -1.181 | 172,666 | -1.083 |
| GB-MB | 244,518 | 241,648 | -1.174 | 241,876 | -1.081 |
| GB-GB | 427,187 | 421,981 | -1.219 | 422,486 | -1.100 |
| **Bus Trips by (i,j)** | | | | | |
| MB-MB | 3,562.04 | 3,628.07 | 1.854 | 3,617.18 | 1.548 |
| MB-GB | 4,669.58 | 4,743.92 | 1.592 | 4,731.16 | 1.319 |
| GB-MB | 7,801.83 | 7,948.23 | 1.876 | 7,925.53 | 1.585 |
| GB-GB | 10,625.67 | 10,791.29 | 1.559 | 10,760.14 | 1.266 |
| **Mini Bus Trips by (i,j)** | | | | | |
| MB-MB | 22,186 | 22,609 | 1.906 | 22,550 | 1.638 |
| MB-GB | 29,085 | 29,563 | 1.643 | 29,493 | 1.403 |
| GB-MB | 48,595 | 49,529 | 1.924 | 49,403 | 1.665 |
| GB-GB | 66,183 | 67,251 | 1.614 | 67,080 | 1.356 |
| **Taxi Service Trips by (i,j)** | | | | | |
| MB-MB | 8,575.04 | 8,718.62 | 1.674 | 8,692.71 | 1.372 |
| MB-GB | 10,586 | 10,760 | 1.644 | 10,731 | 1.376 |

| | | | | | |
|---|---|---|---|---|---|
| GB-MB | 14,045 | 14,270 | 1.601 | 14,235 | 1.350 |
| GB-GB | 24,937 | 25,326 | 1.558 | 25,254 | 1.272 |
| **Trips by mode (m)** | | | | | |
| Private Vehicle | 979,372 | 968,179 | -1.143 | 969,090 | -1.050 |
| Bus | 26,659 | 27,112 | 1.697 | 27,034 | 1.406 |
| Mini Bus | 166,048 | 168,952 | 1.749 | 168,526 | 1.492 |
| Taxi Service | 58,143 | 59,074 | 1.601 | 58,913 | 1.324 |
| **Travel Time by Private Vehicle for (i,j) (Minutes)** | | | | | |
| MB-MB | 42.10 | 41.64 | -1.102 | 41.30 | -1.907 |
| MB-GB | 53.00 | 52.26 | -1.403 | 51.78 | -2.311 |
| GB-MB | 57.00 | 56.25 | -1.324 | 55.75 | -2.191 |
| GB-GB | 46.40 | 45.72 | -1.470 | 45.29 | -2.392 |
| **Travel Time by Bus for (i,j) (Minutes)** | | | | | |
| MB-MB | 77.60 | 76.93 | -0.868 | 76.43 | -1.502 |
| MB-GB | 98.30 | 97.22 | -1.096 | 96.53 | -1.805 |
| GB-MB | 104.20 | 103.11 | -1.050 | 102.39 | -1.739 |
| GB-GB | 88.80 | 87.81 | -1.114 | 87.19 | -1.813 |
| **Travel Time by MiniBus for (i,j) (Minutes)** | | | | | |
| MB-MB | 63.10 | 62.52 | -0.919 | 62.10 | -1.590 |
| MB-GB | 81.70 | 80.77 | -1.137 | 80.17 | -1.872 |
| GB-MB | 86.80 | 85.86 | -1.087 | 85.24 | -1.800 |
| GB-GB | 73.50 | 72.65 | -1.160 | 72.11 | -1.887 |
| **Travel Time by Taxi Service for (i,j) (Minutes)** | | | | | |
| MB-MB | 58.33 | 57.82 | -0.875 | 57.45 | -1.514 |
| MB-GB | 72.33 | 71.51 | -1.131 | 70.98 | -1.863 |
| GB-MB | 76.73 | 75.90 | -1.082 | 75.36 | -1.791 |
| GB-GB | 65.13 | 64.38 | -1.153 | 63.91 | -1.877 |
| **Monetary Travel Cost by Private Vehicle for (i,j) (LBP)** | | | | | |
| MB-MB | 1,701.39 | 1,950.20 | 14.624 | 1,942.53 | 14.173 |
| MB-GB | 2,527.46 | 2,887.87 | 14.260 | 2,871.78 | 13.623 |

| | | | | | |
|---|---|---|---|---|---|
| GB-MB | 2,674.59 | 3,057.95 | 14.333 | 3,042.00 | 13.737 |
| GB-GB | 2,119.76 | 2,422.19 | 14.267 | 2,409.18 | 13.654 |
| **PHIijm for BUS** | | | | | |
| MB-MB | 0.09 | 0.09 | -1.459 | 0.09 | -1.221 |
| MB-GB | 0.09 | 0.09 | -1.256 | 0.09 | -1.043 |
| GB-MB | 0.09 | 0.09 | -1.476 | 0.09 | -1.251 |
| GB-GB | 0.09 | 0.09 | -1.230 | 0.09 | -1.001 |
| **Waiting Time for Bus by (i,j) (Minutes)** | | | | | |
| MB-MB | 6.50 | 6.50 | 0.000 | 6.50 | 0.000 |
| MB-GB | 6.50 | 6.50 | 0.000 | 6.50 | 0.000 |
| GB-MB | 6.50 | 6.50 | 0.000 | 6.50 | 0.000 |
| GB-GB | 6.50 | 6.50 | 0.000 | 6.50 | 0.000 |
| **Traffic Load by (i,j)** | | | | | |
| MB-MB | 95,097 | 94,762 | -0.352 | 94,720 | -0.397 |
| MB-GB | 123,921 | 123,046 | -0.705 | 123,094 | -0.667 |
| GB-MB | 175,003 | 173,838 | -0.665 | 173,896 | -0.632 |
| GB-GB | 300,627 | 298,320 | -0.767 | 298,485 | -0.712 |
| **Weighted Rent by Location (LBP/ Sq. Meter)** | | | | | |
| MB | 382,538 | 379,804 | -0.715 | 379,909 | -0.687 |
| GB | 127,137 | 126,379 | -0.596 | 126,411 | -0.571 |
| **Weighted Value of Stocks by Location (LBP/ Sq. Meter)** | | | | | |
| MB | 9,651,538 | 9,599,676 | -0.537 | 9,601,655 | -0.517 |
| GB | 3,217,708 | 3,203,172 | -0.452 | 3,203,798 | -0.432 |
| **Construction of Residential Floor Space (Sq. Meters)** | | | | | |
| MB | 15,080 | 15,100 | 0.138 | 15,099 | 0.132 |
| GB | 218,712 | 218,696 | -0.007 | 218,700 | -0.006 |
| **Construction of Commercial Floor Space (Sq. Meters)** | | | | | |
| MB | 112,692 | 112,308 | -0.341 | 112,324 | -0.327 |
| GB | 1,324,943 | 1,319,918 | -0.379 | 1,320,116 | -0.364 |
| Aggregate rent in the Region | 22,497,353,364,096 | 22,316,846,607,260 | -0.802 | 22,324,226,672,995 | -0.770 |

| | | | | | |
|---|---|---|---|---|---|
| (MB & GB) (LBP) | | | | | |
| Aggregate value in the Region (MB & GB) (LBP) | 381,123,093,725,158 | 378,735,702,091,739 | -0.626 | 378,836,336,729,149 | -0.600 |
| Aggregate Daily Non-work Person Trips | 607,895 | 600,989 | -1.136 | 601,235 | -1.095 |
| Aggregate Daily Vehicle Miles Travelled (Kilometers) | 13,366,017 | 13,256,140 | -0.822 | 13,263,235 | -0.769 |
| Aggregate Daily Gasoline Consumption (Liters) | 1,620,915 | 1,597,223 | -1.462 | 1,589,624 | -1.930 |
| Gross Nominal Regional Product(LBP) | 19,412,277,163,440 | 19,213,170,153,500 | -1.026 | 19,221,260,599,976 | -0.984 |
| Gross Real Regional Product | 1,941,227,716,344 | 1,933,565,558,741 | -0.395 | 1,933,869,589,083 | -0.379 |
| **Inclusive Value** | | | | | |
| IV of worker | 9.18 | 9.18 | -0.025 | 9.18 | 0.053 |
| IV of non-worker | 10.53 | 10.54 | 0.014 | 10.54 | 0.014 |
| **Different Sources of Tax Revenue (LBP)** | | | | | |
| Gas Tax Revenue | 244,911,661 | 278,217,557 | 13.599 | 276,895,716 | 13.059 |
| Public Transit Revenue | 192,707,342 | 196,063,838 | 1.742 | 195,560,167 | 1.480 |
| Parking Tax Revenue | 468,083,192 | 463,304,671 | -1.021 | 463,682,930 | -0.940 |
| **Compensating Variation (LBP)** | | | | | |
| CV for Worker | | -25,789 | | 55,000 | |
| CV for Non-worker | | 4,669.94 | | 4,454.85 | |

| | | | | |
|---|---|---|---|---|
| CV | -8,469.28 | | 26,260 | |
| **Social Welfare change per person by Region (LBP)** | | | | |
| SW for Fuel Tax Increase(Excise Tax) | -91,193 | | -52,977 | |

**TABLE A5:** 10% increase in the parking cost (parking tax rate) at different values of $c_2$

| 10% increase | | $c_2 = 2$ | | $c_2 = 3.5$ | |
|---|---|---|---|---|---|
| Variables | BASE RESULTS | 10% increase | CHANGES | 10% increase | CHANGES |
| **Price of Output (LBP)** | | | | | |
| MB | 10.00 | 9.98 | -0.210 | 9.98 | -0.211 |
| GB | 10.00 | 9.99 | -0.077 | 9.99 | -0.069 |
| **Hourly Wage (LBP/hr)** | | | | | |
| MB | 4,363.20 | 4,352.88 | -0.237 | 4,352.26 | -0.251 |
| GB | 3,452.04 | 3,445.66 | -0.185 | 3,446.30 | -0.166 |
| **Annual Residential Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 175,800 | 175,394 | -0.231 | 175,409 | -0.222 |
| GB | 83,550 | 83,376 | -0.208 | 83,383 | -0.200 |
| **Annual Commercial Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 426,750 | 425,782 | -0.227 | 425,806 | -0.221 |
| GB | 227,400 | 227,275 | -0.055 | 227,281 | -0.052 |
| **Annual Vacant Land Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 503,640 | 503,383 | -0.051 | 503,390 | -0.050 |
| GB | 73,350 | 73,313 | -0.050 | 73,315 | -0.048 |
| **Annual Value of Residential Stock (LBP/ Sq. Meter)** | | | | | |
| MB | 5,860,000 | 5,853,516 | -0.111 | 5,853,798 | -0.106 |
| GB | 2,785,000 | 2,782,350 | -0.095 | 2,782,446 | -0.092 |
| **Annual Value of Commercial Stock (LBP/ Sq. Meter)** | | | | | |
| MB | 8,535,000 | 8,519,355 | -0.183 | 8,519,770 | -0.178 |
| GB | 4,548,000 | 4,546,205 | -0.039 | 4,546,295 | -0.037 |
| **Annual Value of Vacant Land (LBP/ Sq. Meter)** | | | | | |
| MB | 16,788,000 | 16,779,426 | -0.051 | 16,779,670 | -0.050 |
| GB | 2,445,000 | 2,443,776 | -0.050 | 2,443,836 | -0.048 |
| **Stock of Residential Floor Space (Sq. Meters)** | | | | | |
| MB | 5,259,997 | 5,261,769 | 0.034 | 5,261,729 | 0.033 |
| GB | 21,342,698 | 21,338,552 | -0.019 | 21,338,586 | -0.019 |

| | | | | | |
|---|---|---|---|---|---|
| **Stock of Commercial Floor Space (Sq. Meters)** | | | | | |
| MB | 11,859,052 | 11,847,389 | -0.098 | 11,847,683 | -0.096 |
| GB | 37,501,072 | 37,457,703 | -0.116 | 37,459,981 | -0.110 |
| **Stock of Vacant Land (Sq. Meters)** | | | | | |
| MB | 4,650,000 | 4,651,224 | 0.026 | 4,651,188 | 0.026 |
| GB | 52,610,000 | 52,624,808 | 0.028 | 52,624,186 | 0.027 |
| **Employment by Workplace Location** | | | | | |
| MB | 198,839 | 198,635 | -0.103 | 198,651 | -0.095 |
| GB | 423,489 | 423,693 | 0.048 | 423,677 | 0.044 |
| **Population by Residence Location** | | | | | |
| MB | 445,184 | 445,136 | -0.011 | 445,131 | -0.012 |
| GB | 997,422 | 997,470 | 0.005 | 997,475 | 0.005 |
| **Private Vehicle Trips by (i,j)** | | | | | |
| MB-MB | 133,112 | 132,587 | -0.394 | 132,628 | -0.364 |
| MB-GB | 174,556 | 174,196 | -0.206 | 174,210 | -0.198 |
| GB-MB | 244,518 | 243,750 | -0.314 | 243,816 | -0.287 |
| GB-GB | 427,187 | 426,255 | -0.218 | 426,321 | -0.203 |
| **Bus Trips by (i,j)** | | | | | |
| MB-MB | 3,562.04 | 3,579.97 | 0.503 | 3,578 | 0.459 |
| MB-GB | 4,669.58 | 4,685.11 | 0.333 | 4,682 | 0.268 |
| GB-MB | 7,801.83 | 7,839.06 | 0.477 | 7,834.89 | 0.424 |
| GB-GB | 10,626 | 10,661 | 0.331 | 10,654 | 0.265 |
| **Mini Bus Trips by (i,j)** | | | | | |
| MB-MB | 22,186 | 22,301 | 0.518 | 22,294 | 0.483 |
| MB-GB | 29,085 | 29,184 | 0.342 | 29,168 | 0.285 |
| GB-MB | 48,594 | 48,831 | 0.488 | 48,809 | 0.442 |
| GB-GB | 66,183 | 66,409 | 0.342 | 66,370 | 0.283 |
| **Taxi Service Trips by (i,j)** | | | | | |
| MB-MB | 8,575.04 | 8,616 | 0.479 | 8,612.47 | 0.437 |

| | | | | | |
|---|---|---|---|---|---|
| MB-GB | 10,586 | 10,622 | 0.347 | 10,616 | 0.286 |
| GB-MB | 14,045 | 14,103 | 0.417 | 14,096 | 0.362 |
| GB-GB | 24,937 | 25,023 | 0.347 | 25,009 | 0.289 |
| **Trips by mode (m)** | | | | | |
| Private Vehicle | 979,372 | 976,788 | -0.264 | 976,974 | -0.245 |
| Bus | 26,659 | 26,765 | 0.397 | 26,749 | 0.338 |
| Mini Bus | 166,048 | 166,726 | 0.408 | 166,640 | 0.357 |
| Taxi Service | 58,143 | 58,366 | 0.383 | 58,333 | 0.328 |
| **Travel Time by Private Vehicle for (i,j) (Minutes)** | | | | | |
| MB-MB | 42.10 | 41.94 | -0.373 | 41.84 | -0.613 |
| MB-GB | 53.00 | 52.88 | -0.227 | 52.78 | -0.408 |
| GB-MB | 57.00 | 56.79 | -0.362 | 56.67 | -0.585 |
| GB-GB | 46.40 | 46.27 | -0.271 | 46.19 | -0.458 |
| **Travel Time by Bus for (i,j) (Minutes)** | | | | | |
| MB-MB | 77.60 | 77.37 | -0.294 | 77.23 | -0.483 |
| MB-GB | 98.30 | 98.13 | -0.177 | 97.99 | -0.319 |
| GB-MB | 104.20 | 103.90 | -0.287 | 103.72 | -0.465 |
| GB-GB | 88.80 | 88.62 | -0.206 | 88.49 | -0.347 |
| **Travel Time by MiniBus for (i,j) (Minutes)** | | | | | |
| MB-MB | 63.10 | 62.90 | -0.311 | 62.78 | -0.511 |
| MB-GB | 81.70 | 81.55 | -0.184 | 81.43 | -0.330 |
| GB-MB | 86.80 | 86.54 | -0.297 | 86.38 | -0.481 |
| GB-GB | 73.50 | 73.34 | -0.214 | 73.23 | -0.362 |
| **Travel Time by Taxi Service for (i,j) (Minutes)** | | | | | |
| MB-MB | 58.33 | 58.16 | -0.296 | 58.05 | -0.487 |
| MB-GB | 72.33 | 72.20 | -0.183 | 72.09 | -0.329 |
| GB-MB | 76.73 | 76.50 | -0.296 | 76.36 | -0.478 |
| GB-GB | 65.13 | 64.99 | -0.213 | 64.90 | -0.360 |
| **Monetary Travel Cost by Private Vehicle for (i,j) (LBP)** | | | | | |
| MB-MB | 1,701.39 | 1,698.36 | -0.178 | 1,696.40 | -0.293 |

| | | | | | |
|---|---|---|---|---|---|
| MB-GB | 2,527.46 | 2,524.02 | -0.136 | 2,521.28 | -0.244 |
| GB-MB | 2,674.59 | 2,668.91 | -0.213 | 2,665.38 | -0.344 |
| GB-GB | 2,119.76 | 2,116.49 | -0.154 | 2,114.24 | -0.260 |
| **PHIijm for BUS** | | | | | |
| MB-MB | 0.09 | 0.09 | -0.401 | 0.09 | -0.366 |
| MB-GB | 0.09 | 0.09 | -0.265 | 0.09 | -0.214 |
| GB-MB | 0.09 | 0.09 | -0.380 | 0.09 | -0.338 |
| GB-GB | 0.09 | 0.09 | -0.264 | 0.09 | -0.212 |
| **Traffic Load by (i,j)** | | | | | |
| MB-MB | 95,097 | 94,869 | -0.240 | 94,886 | -0.222 |
| MB-GB | 123,921 | 123,780 | -0.114 | 123,776 | -0.117 |
| GB-MB | 175,003 | 174,685 | -0.181 | 174,709 | -0.168 |
| GB-GB | 300,627 | 300,244 | -0.127 | 300,255 | -0.124 |
| **Weighted Rent by Location (LBP/ Sq. Meter)** | | | | | |
| MB | 382,538 | 381,824 | -0.187 | 381,843 | -0.182 |
| GB | 127,137 | 127,000 | -0.108 | 127,006 | -0.103 |
| **Weighted Value of Stocks by Location (LBP/ Sq. Meter)** | | | | | |
| MB | 9,651,538 | 9,640,310 | -0.116 | 9,640,636 | -0.113 |
| GB | 3,217,708 | 3,215,415 | -0.071 | 3,215,523 | -0.068 |
| **Construction of Residential Floor Space (Sq. Meters)** | | | | | |
| MB | 15,080 | 15,085 | 0.033 | 15,084 | 0.032 |
| GB | 218,712 | 218,705 | -0.003 | 218,704 | -0.003 |
| **Construction of Commercial Floor Space (Sq. Meters)** | | | | | |
| MB | 112,692 | 112,598 | -0.084 | 112,600 | -0.082 |
| GB | 1,324,943 | 1,324,056 | -0.067 | 1,324,104 | -0.063 |
| Aggregate rent in the Region (MB & GB) (LBP) | 22,497,353,364,096 | 22,459,072,488,221 | -0.170 | 22,460,475,931,621 | -0.164 |
| Aggregate value in the Region (MB & GB) (LBP) | 381,123,093,725,158 | 380,724,046,954,470 | -0.105 | 380,742,954,360,686 | -0.100 |

| | | | | | |
|---|---|---|---|---|---|
| Aggregate Daily Non-work Person Trips | 607,895 | 606,317 | -0.260 | 606,369 | -0.251 |
| Aggregate Daily Vehicle Miles Travelled (Kilometers) | 13,366,017 | 13,341,674 | -0.182 | 13,343,002 | -0.172 |
| Aggregate Daily Gasoline Consumption (Liters) | 1,620,915 | 1,615,710 | -0.321 | 1,613,993 | -0.427 |
| Gross Nominal Regional Product(LBP) | 19,412,277,163,440 | 19,371,640,021,402 | -0.209 | 19,373,209,527,108 | -0.201 |
| Gross Real Regional Product | 1,941,227,716,344 | 1,939,614,280,578 | -0.083 | 1,939,684,920,628 | -0.079 |
| **Inclusive Value** | | | | | |
| IV of worker | 9.18 | 9.18 | -0.007 | 9.18 | 0.010 |
| IV of non-worker | 10.53 | 10.54 | 0.003 | 10.54 | 0.003 |
| **Different Sources of Tax Revenue (LBP)** | | | | | |
| Gas Tax Revenue | 244,911,661 | 244,147,981 | -0.312 | 243,888,769 | -0.418 |
| Public Transit Revenue | 192,707,342 | 193,491,230 | 0.407 | 193,389,648 | 0.354 |
| Parking Tax Revenue | 468,083,192 | 513,521,977 | 9.707 | 513,630,552 | 9.731 |
| **Compensating Variation (LBP)** | | | | | |
| CV for Worker | | -7,162.67 | | 10,745 | |
| CV for Non-worker | | 1,018.17 | | 1,027.19 | |
| CV | | -2,510.97 | | 5,219.20 | |
| **Social Welfare change per person by Region (LBP)** | | | | | |
| SW for Parking Tax Increase (Tax Rate) | | -16,310 | | -7,924.91 | |

**TABLE A6:** 15% increase in the parking cost (parking tax rate) at different value of $c_2$

| 15% increase | | $c_2 = 2$ | | $c_2 = 3.5$ | |
|---|---|---|---|---|---|
| **Variables** | **BASE RESULTS** | **15% increase** | **CHANGES** | **15% increase** | **CHANGES** |
| **Price of Output (LBP)** | | | | | |
| MB | 10.00 | 9.97 | -0.344 | 9.97 | -0.345 |
| GB | 10.00 | 9.99 | -0.141 | 9.99 | -0.130 |
| **Hourly Wage (LBP/hr)** | | | | | |
| MB | 4,363.20 | 4,347.29 | -0.365 | 4,346.72 | -0.378 |
| GB | 3,452.04 | 3,441.11 | -0.316 | 3,441.94 | -0.293 |
| **Annual Residential Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 175,800 | 175,126 | -0.383 | 175,146 | -0.372 |
| GB | 83,550 | 83,269 | -0.336 | 83,279 | -0.325 |
| **Annual Commercial Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 426,750 | 425,288 | -0.343 | 425,320 | -0.335 |
| GB | 227,400 | 227,208 | -0.085 | 227,215 | -0.081 |
| **Annual Vacant Land Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 503,640 | 503,160 | -0.095 | 503,173 | -0.093 |
| GB | 73,350 | 73,281 | -0.093 | 73,285 | -0.089 |
| **Annual Value of Residential Stock (LBP/ Sq. Meter)** | | | | | |
| MB | 5,860,000 | 5,847,995 | -0.205 | 5,848,414 | -0.198 |
| GB | 2,785,000 | 2,780,200 | -0.172 | 2,780,371 | -0.166 |
| **Annual Value of Commercial Stock (LBP/ Sq. Meter)** | | | | | |
| MB | 8,535,000 | 8,508,828 | -0.307 | 8,509,459 | -0.299 |
| GB | 4,548,000 | 4,545,001 | -0.066 | 4,545,135 | -0.063 |
| **Annual Value of Vacant Land (LBP/ Sq. Meter)** | | | | | |
| MB | 16,788,000 | 16,772,003 | -0.095 | 16,772,420 | -0.093 |
| GB | 2,445,000 | 2,442,715 | -0.093 | 2,442,818 | -0.089 |
| **Stock of Residential Floor Space (Sq. Meters)** | | | | | |
| MB | 5,259,997 | 5,262,954 | 0.056 | 5,262,890 | 0.055 |
| GB | 21,342,698 | 21,334,773 | -0.037 | 21,334,912 | -0.036 |
| **Stock of Commercial Floor Space (Sq. Meters)** | | | | | |
| MB | 11,859,051 | 11,839,850 | -0.162 | 11,840,294 | -0.158 |
| GB | 37,501,072 | 37,431,066 | -0.187 | 37,434,280 | -0.178 |
| **Stock of Vacant Land (Sq. Meters)** | | | | | |
| MB | 4,650,000 | 4,651,971.74 | 0.042 | 4,651,920.79 | 0.041 |
| GB | 52,610,000 | 52,634,949.57 | 0.047 | 52,633,995.30 | 0.046 |
| **Employment by Workplace Location** | | | | | |
| MB | 198,839 | 198,556 | -0.142 | 198,582 | -0.129 |
| GB | 423,489 | 423,772 | 0.067 | 423,746 | 0.061 |
| **Population by Residence Location** | | | | | |
| MB | 445,184 | 445,129 | -0.012 | 445,123 | -0.014 |
| GB | 997,422 | 997,477 | 0.006 | 997,483 | 0.006 |
| **Private Vehicle Trips by (i,j)** | | | | | |
| MB-MB | 133,112 | 132,346 | -0.575 | 132,405 | -0.531 |
| MB-GB | 174,556 | 174,020 | -0.307 | 174,040 | -0.295 |
| GB-MB | 244,518 | 243,386 | -0.463 | 243,483 | -0.423 |
| GB-GB | 427,187 | 425,779 | -0.329 | 425,879 | -0.306 |
| **Bus Trips by (i,j)** | | | | | |
| MB-MB | 3,562.04 | 3,589.76 | 0.778 | 3,587.45 | 0.713 |
| MB-GB | 4,669.58 | 4,693.27 | 0.507 | 4,688.82 | 0.412 |
| GB-MB | 7,801.83 | 7,858.91 | 0.732 | 7,852.79 | 0.653 |
| GB-GB | 10,626 | 10,679 | 0.498 | 10,668 | 0.401 |
| **Mini Bus Trips by (i,j)** | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| MB-MB | 22,186 | 22,364 | 0.799 | 22,352 | 0.748 |
| MB-GB | 29,085 | 29,237 | 0.522 | 29,212 | 0.437 |
| GB-MB | 48,594 | 48,958 | 0.748 | 48,924 | 0.680 |
| GB-GB | 66,183 | 66,523 | 0.514 | 66,466 | 0.427 |
| **Taxi Service Trips by (i,j)** | | | | | |
| MB-MB | 8,575.04 | 8,638 | 0.739 | 8,633 | 0.678 |
| MB-GB | 10,586 | 10,640 | 0.518 | 10,631 | 0.426 |
| GB-MB | 14,045 | 14,135 | 0.639 | 14,124 | 0.559 |
| GB-GB | 24,937 | 25,064 | 0.510 | 25,042 | 0.422 |
| **Trips by mode (m)** | | | | | |
| Private Vehicle | 979,372 | 975,531 | -0.392 | 975,808 | -0.364 |
| Bus | 26,659 | 26,821 | 0.606 | 26,797 | 0.518 |
| Mini Bus | 166,048 | 167,081 | 0.622 | 166,954 | 0.546 |
| Taxi Service | 58,143 | 58,478 | 0.576 | 58,430 | 0.494 |
| **Travel Time by Private Vehicle for (i,j) (Minutes)** | | | | | |
| MB-MB | 42.10 | 41.87 | -0.539 | 41.73 | -0.884 |
| MB-GB | 53.00 | 52.82 | -0.336 | 52.68 | -0.604 |
| GB-MB | 57.00 | 56.70 | -0.524 | 56.52 | -0.845 |
| GB-GB | 46.40 | 46.21 | -0.407 | 46.08 | -0.686 |
| **Travel Time by Bus for (i,j) (Minutes)** | | | | | |
| MB-MB | 77.60 | 77.27 | -0.424 | 77.06 | -0.696 |
| MB-GB | 98.30 | 98.04 | -0.262 | 97.84 | -0.472 |
| GB-MB | 104.20 | 103.77 | -0.416 | 103.50 | -0.671 |
| GB-GB | 88.80 | 88.53 | -0.308 | 88.34 | -0.520 |
| **Travel Time by MiniBus for (i,j) (Minutes)** | | | | | |
| MB-MB | 63.10 | 62.82 | -0.449 | 62.63 | -0.737 |
| MB-GB | 81.70 | 81.48 | -0.272 | 81.30 | -0.489 |
| GB-MB | 86.80 | 86.43 | -0.430 | 86.20 | -0.694 |
| GB-GB | 73.50 | 73.26 | -0.321 | 73.10 | -0.541 |
| **Travel Time by Taxi Service for (i,j) (Minutes)** | | | | | |
| MB-MB | 58.33 | 58.08 | -0.427 | 57.92 | -0.702 |
| MB-GB | 72.33 | 72.13 | -0.271 | 71.98 | -0.487 |
| GB-MB | 76.73 | 76.40 | -0.428 | 76.20 | -0.691 |
| GB-GB | 65.13 | 64.92 | -0.319 | 64.78 | -0.538 |
| **Monetary Travel Cost by Private Vehicle for (i,j)** | | | | | |
| MB-MB | 1,701.39 | 1,697.01 | -0.257 | 1,694.18 | -0.424 |
| MB-GB | 2,527.46 | 2,522.37 | -0.201 | 2,518.30 | -0.362 |
| GB-MB | 2,674.59 | 2,666.36 | -0.308 | 2,661.28 | -0.498 |
| GB-GB | 2,119.76 | 2,114.87 | -0.231 | 2,111.49 | -0.390 |
| **PHIijm for BUS** | | | | | |
| MB-MB | 0.09 | 0.09 | -0.618 | 0.09 | -0.567 |
| MB-GB | 0.09 | 0.09 | -0.404 | 0.09 | -0.328 |
| GB-MB | 0.09 | 0.09 | -0.581 | 0.09 | -0.519 |
| GB-GB | 0.09 | 0.09 | -0.397 | 0.09 | -0.319 |
| **Traffic Load by (i,j)** | | | | | |
| MB-MB | 95,097 | 94,771 | -0.343 | 94,796 | -0.317 |
| MB-GB | 123,921 | 123,711.97 | -0.168 | 123,705.84 | -0.173 |
| GB-MB | 175,003 | 174,542.84 | -0.263 | 174,577.86 | -0.243 |
| GB-GB | 300,627 | 300,043.64 | -0.194 | 300,060.76 | -0.188 |
| **Weighted Rent by Location (LBP/ Sq. Meter)** | | | | | |
| MB | 382,538 | 381,420 | -0.292 | 381,447 | -0.285 |
| GB | 127,137 | 126,914 | -0.175 | 126,923 | -0.168 |
| **Weighted Value of Stocks by Location (LBP/ Sq. Meter)** | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| MB | 9,651,538 | 9,632,086 | -0.202 | 9,632,591 | -0.196 |
| GB | 3,217,708 | 3,213,724 | -0.124 | 3,213,894 | -0.119 |
| **Construction of Residential Floor Space (Sq. Meters)** | | | | | |
| MB | 15,080 | 15,088 | 0.055 | 15,088 | 0.054 |
| GB | 218,712 | 218,694 | -0.008 | 218,693 | -0.008 |
| **Construction of Commercial Floor Space (Sq. Meters)** | | | | | |
| MB | 112,692 | 112,537 | -0.138 | 112,541 | -0.135 |
| GB | 1,324,943 | 1,323,520 | -0.107 | 1,323,587 | -0.102 |
| Aggregate rent in the Region (MB & GB) (LBP) | 22,497,353,364,096 | 22,436,021,271,747 | -0.273 | 22,438,050,366,409 | -0.264 |
| Aggregate value in the Region (MB & GB) (LBP) | 381,123,093,725,158 | 380,447,372,601,201 | -0.177 | 380,476,099,037,097 | -0.170 |
| Aggregate Daily Non-work Person Trips | 607,895 | 605,582 | -0.380 | 605,661 | -0.367 |
| Aggregate Daily Vehicle Miles Travelled (Kilometers) | 13,366,017 | 13,329,973 | -0.270 | 13,331,951 | -0.255 |
| Aggregate Daily Gasoline Consumption (Liters) | 1,620,915 | 1,613,251 | -0.473 | 1,610,730 | -0.628 |
| Gross Nominal Regional Product (LBP) | 19,412,277,163,440 | 19,345,488,291,329 | -0.344 | 19,347,820,222,946 | -0.332 |
| Gross Real Regional Product | 1,941,227,716,344 | 1,938,745,203,265 | -0.128 | 1,938,850,154,243 | -0.122 |
| **Inclusive Value** | | | | | |
| IV of worker | 9.18 | 9.18 | -0.011 | 9.18 | 0.014 |
| IV of non-worker | 10.53 | 10.54 | 0.007 | 10.54 | 0.007 |
| **Different Sources of Tax Revenue (LBP)** | | | | | |
| Gas Tax Revenue | 244,911,661 | 243,789,427 | -0.458 | 243,409,146 | -0.613 |
| Public Transit Revenue | 192,707,342 | 193,901,473 | 0.620 | 193,751,634 | 0.542 |
| Parking Tax Revenue | 468,083,192 | 536,177,039 | 14.547 | 536,345,100 | 14.583 |
| **Compensating Variation (LBP)** | | | | | |
| CV for Worker | | -11,139 | | 15,212 | |

| | | | | |
|---|---|---|---|---|
| CV for Non-worker | 2,326.50 | | 2,334.66 | |
| CV | -3,482.54 | | 7,889.74 | |
| **Social Welfare change per person by Region (LBP)** | | | | |
| SW for Parking Tax Increase (Tax Rate) | -26,855 | | -14,488 | |

**TABLE A7:** 25% increase in the parking cost (parking tax) at different values of $c_2$

| 25% increase | | $c_2 = 2$ | | $c_2 = 3.5$ | |
|---|---|---|---|---|---|
| **Variables** | **BASE RESULTS** | **25% increase** | **CHANGES** | **25% increase** | **CHANGES** |
| **Price of Output (LBP)** | | | | | |
| MB | 10.00 | 9.94 | -0.581 | 9.94 | -0.58 |
| GB | 10.00 | 9.97 | -0.257 | 9.98 | -0.24 |
| **Hourly Wage (LBP/hr)** | | | | | |
| MB | 4,363.20 | 4,336.33 | -0.616 | 4,335.71 | -0.63 |
| GB | 3,452.04 | 3,432.92 | -0.554 | 3,434.14 | -0.52 |
| **Annual Residential Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 175,800 | 174,626 | -0.668 | 174,658 | -0.65 |
| GB | 83,550 | 83,068 | -0.577 | 83,085 | -0.56 |
| **Annual Commercial Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 426,750 | 424,332 | -0.567 | 424,388 | -0.55 |
| GB | 227,400 | 227,079 | -0.141 | 227,092 | -0.14 |
| **Annual Vacant Land Rent (LBP/ Sq. Meter)** | | | | | |
| MB | 503,640 | 502,723 | -0.182 | 502,746 | -0.18 |
| GB | 73,350 | 73,218 | -0.180 | 73,224 | -0.17 |
| **Annual Value of Residential Stock (LBP/ Sq. Meter)** | | | | | |
| MB | 5,860,000 | 5,837,549 | -0.383 | 5,838,229 | -0.37 |
| GB | 2,785,000 | 2,776,171 | -0.317 | 2,776,479 | -0.31 |
| **Annual Value of Commercial Stock (LBP/ Sq. Meter)** | | | | | |
| MB | 8,535,000 | 8,489,311 | -0.535 | 8,490,388 | -0.52 |
| GB | 4,548,000 | 4,542,736 | -0.116 | 4,542,955 | -0.11 |
| **Annual Value of Vacant Land (LBP/ Sq. Meter)** | | | | | |
| MB | 16,788,000 | 16,757,427 | -0.182 | 16,758,192 | -0.18 |
| GB | 2,445,000 | 2,440,610 | -0.180 | 2,440,796 | -0.17 |
| **Stock of Residential Floor Space (Sq. Meters)** | | | | | |
| MB | 5,259,997 | 5,265,171 | 0.098 | 5,265,058 | 0.10 |
| GB | 21,342,698 | 21,328,126 | -0.068 | 21,328,428 | -0.07 |
| **Stock of Commercial Floor Space (Sq. Meters)** | | | | | |
| MB | 11,859,052 | 11,825,989 | -0.279 | 11,826,746 | -0.27 |
| GB | 37,501,072 | 37,381,629 | -0.319 | 37,386,709 | -0.30 |
| **Stock of Vacant Land (Sq. Meters)** | | | | | |
| MB | 4,650,000 | 4,653,304 | 0.071 | 4,653,223 | 0.07 |
| GB | 52,610,000 | 52,653,460 | 0.083 | 52,651,883 | 0.08 |
| **Employment by Workplace Location** | | | | | |
| MB | 198,839 | 198,402 | -0.220 | 198,462 | -0.19 |
| GB | 423,489 | 423,926 | 0.103 | 423,866 | 0.09 |
| **Population by Residence Location** | | | | | |
| MB | 445,184 | 445,109 | -0.017 | 445,099 | -0.02 |
| GB | 997,422 | 997,497 | 0.008 | 997,507 | 0.01 |
| **Private Vehicle Trips by (i,j)** | | | | | |
| MB-MB | 133,112 | 131,840 | -0.955 | 131,937 | -0.88 |
| MB-GB | 174,556 | 173,669 | -0.508 | 173,702 | -0.49 |
| GB-MB | 244,518 | 242,630 | -0.772 | 242,795 | -0.70 |
| GB-GB | 427,187 | 424,846 | -0.548 | 425,013 | -0.51 |
| **Bus Trips by (i,j)** | | | | | |
| MB-MB | 3,562.04 | 3,609 | 1.305 | 3,604.65 | 1.20 |
| MB-GB | 4,669.58 | 4,710 | 0.858 | 4,702.28 | 0.70 |
| GB-MB | 7,801.83 | 7,897 | 1.222 | 7,886.90 | 1.09 |
| GB-GB | 10,625.67 | 10,715 | 0.838 | 10,697 | 0.68 |
| **Mini Bus Trips by (i,j)** | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| MB-MB | 22,186.43 | 22,484 | 1.340 | 22,465 | 1.25 |
| MB-GB | 29,084.82 | 29,341 | 0.882 | 29,301 | 0.74 |
| GB-MB | 48,594.26 | 49,201 | 1.249 | 49,146 | 1.13 |
| GB-GB | 66,182.72 | 66,755 | 0.864 | 66,659 | 0.72 |
| **Taxi Service Trips by (i,j)** | | | | | |
| MB-MB | 8,575.04 | 8,681.55 | 1.242 | 8,672.98 | 1.14 |
| MB-GB | 10,586 | 10,677 | 0.863 | 10,660 | 0.71 |
| GB-MB | 14,045 | 14,196 | 1.074 | 14,178 | 0.95 |
| GB-GB | 24,937 | 25,147 | 0.843 | 25,110 | 0.69 |
| **Trips by mode (m)** | | | | | |
| Private Vehicle | 979,372 | 972,985 | -0.652 | 973,448 | -0.60 |
| Bus | 26,659 | 26,930 | 1.016 | 26,891 | 0.87 |
| Mini Bus | 166,048 | 167,781 | 1.043 | 167,570 | 0.92 |
| Taxi Service | 58,143 | 58,702 | 0.961 | 58,622 | 0.82 |
| **Travel Time by Private Vehicle for (i,j) (Minutes)** | | | | | |
| MB-MB | 42.10 | 41.72 | -0.891 | 41.49 | -1.46 |
| MB-GB | 53.00 | 52.71 | -0.551 | 52.47 | -0.99 |
| GB-MB | 57.00 | 56.50 | -0.870 | 56.20 | -1.40 |
| GB-GB | 46.40 | 46.09 | -0.674 | 45.87 | -1.14 |
| **Travel Time by Bus for (i,j) (Minutes)** | | | | | |
| MB-MB | 77.60 | 77.06 | -0.701 | 76.71 | -1.15 |
| MB-GB | 98.30 | 97.88 | -0.431 | 97.54 | -0.78 |
| GB-MB | 104.20 | 103.48 | -0.690 | 103.04 | -1.11 |
| GB-GB | 88.80 | 88.35 | -0.511 | 88.03 | -0.86 |
| **Travel Time by MiniBus for (i,j) (Minutes)** | | | | | |
| MB-MB | 63.10 | 62.63 | -0.743 | 62.33 | -1.22 |
| MB-GB | 81.70 | 81.34 | -0.447 | 81.04 | -0.81 |
| GB-MB | 86.80 | 86.18 | -0.714 | 85.80 | -1.15 |
| GB-GB | 73.50 | 73.11 | -0.532 | 72.84 | -0.90 |
| **Travel Time by Taxi Service for (i,j) (Minutes)** | | | | | |
| MB-MB | 58.33 | 57.92 | -0.707 | 57.65 | -1.16 |
| MB-GB | 72.33 | 72.01 | -0.444 | 71.75 | -0.80 |
| GB-MB | 76.73 | 76.18 | -0.711 | 75.85 | -1.14 |
| GB-GB | 65.13 | 64.79 | -0.529 | 64.55 | -0.89 |
| **Monetary Travel Cost by Private Vehicle for (i,j) (LBP)** | | | | | |
| MB-MB | 1,701.39 | 1,694.13 | -0.427 | 1,689.45 | -0.70 |
| MB-GB | 2,527.46 | 2,519.10 | -0.331 | 2,512.35 | -0.60 |
| GB-MB | 2,674.59 | 2,660.89 | -0.512 | 2,652.52 | -0.83 |
| GB-GB | 2,119.76 | 2,111.63 | -0.383 | 2,106.03 | -0.65 |
| **PHIijm for BUS** | | | | | |
| MB-MB | 0.09 | 0.09 | -1.032 | 0.09 | -0.95 |
| MB-GB | 0.09 | 0.09 | -0.681 | 0.09 | -0.56 |
| GB-MB | 0.09 | 0.09 | -0.967 | 0.09 | -0.86 |
| GB-GB | 0.09 | 0.09 | -0.665 | 0.09 | -0.54 |
| **Waiting Time for Bus by (i,j) (Minutes)** | | | | | |
| MB-MB | 6.50 | 6.50 | 0.000 | 6.50 | 0.00 |
| MB-GB | 6.50 | 6.50 | 0.000 | 6.50 | 0.00 |
| GB-MB | 6.50 | 6.50 | 0.000 | 6.50 | 0.00 |
| GB-GB | 6.50 | 6.50 | 0.000 | 6.50 | 0.00 |
| **Traffic Load by (i,j)** | | | | | |
| MB-MB | 95,097 | 94,557 | -0.568 | 94,599 | -0.52 |
| MB-GB | 123,921 | 123,578 | -0.277 | 123,567 | -0.29 |
| GB-MB | 175,003 | 174,238 | -0.437 | 174,298 | -0.40 |

| | | | | | |
|---|---|---|---|---|---|
| GB-GB | 300,627 | 299,657 | -0.323 | 299,685 | -0.31 |
| **Weighted Rent by Location (LBP/ Sq. Meter)** | | | | | |
| MB | 382,538 | 380,644 | -0.495 | 380,690 | -0.48 |
| GB | 127,137 | 126,752 | -0.303 | 126,767 | -0.29 |
| **Weighted Value of Stocks by Location (LBP/ Sq. Meter)** | | | | | |
| MB | 9,651,538 | 9,616,590 | -0.362 | 9,617,458 | -0.35 |
| GB | 3,217,708 | 3,210,504 | -0.224 | 3,210,794 | -0.21 |
| **Construction of Residential Floor Space (Sq. Meters)** | | | | | |
| MB | 15,080 | 15,094 | 0.095 | 15,094 | 0.09 |
| GB | 218,712 | 218,675 | -0.017 | 218,675 | -0.02 |
| **Construction of Commercial Floor Space (Sq. Meters)** | | | | | |
| MB | 112,692 | 112,425 | -0.238 | 112,431 | -0.23 |
| GB | 1,324,943 | 1,322,521 | -0.183 | 1,322,626 | -0.17 |
| Aggregate rent in the Region (MB & GB) (LBP) | 22,497,353,364,096 | 22,392,372,315,685 | -0.467 | 22,395,747,224,886 | -0.45 |
| Aggregate value in the Region (MB & GB) (LBP) | 381,123,093,725,158 | 379,924,373,073,074 | -0.315 | 379,972,335,325,608 | -0.30 |
| Aggregate Daily Non-work Person Trips | 607,895 | 604,070 | -0.629 | 604,203 | -0.61 |
| Aggregate Daily Vehicle Miles Travelled (Kilometers) | 13,366,017 | 13,306,172 | -0.448 | 13,309,479 | -0.42 |
| Aggregate Daily Gasoline Consumption (Liters) | 1,620,915 | 1,608,214 | -0.784 | 1,604,048 | -1.04 |
| Gross Nominal Regional Product(LBP) | 19,412,277,163,440 | 19,297,008,461,800 | -0.594 | 19,300,797,485,184 | -0.57 |
| Gross Real Regional Product | 1,941,227,716,344 | 1,937,008,174,561 | -0.217 | 1,937,179,763,597 | -0.21 |
| **Inclusive Value** | | | | | |
| IV of worker | 9.18 | 9.18 | -0.018 | 9.18 | 0.02 |
| IV of non-worker | 10.53 | 10.54 | 0.013 | 10.54 | 0.01 |
| **Different Sources of Tax Revenue (LBP)** | | | | | |
| Gas Tax Revenue | 244,911,661 | 243,053,201 | -0.759 | 242,424,669 | -1.02 |
| Public Transit Revenue | 192,707,342 | 194,710,904 | 1.040 | 194,461,213 | 0.91 |
| Parking Tax Revenue | 468,083,192 | 581,278,757 | 24.183 | 581,587,680 | 24.25 |
| **Compensating Variation (LBP)** | | | | | |

| | | | | |
|---|---|---|---|---|
| CV for Worker | -19,041 | | 24,400 | |
| CV for Non-worker | 4,358.17 | | 4,360.95 | |
| CV | -5,735.92 | | 13,005 | |
| **Social Welfare change per person by Region (LBP)** | | | | |
| SW for Parking Tax Increase (Tax Rate) | -47,204 | | -26,801 | |

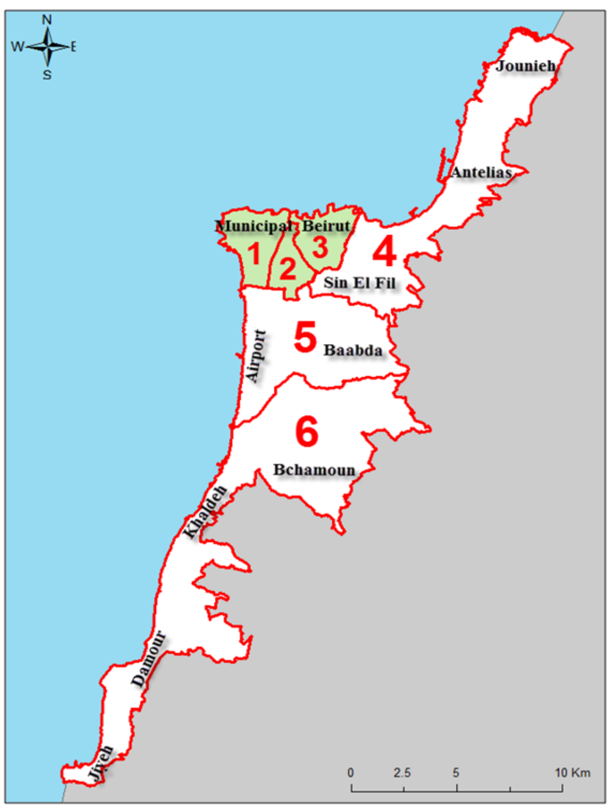
# Appendix B

# Data and Assumptions

## B1. Study Area and Base Year

This study focuses on the capital Beirut and its suburbs, an area that is experiencing severe congestion, attributed mostly to the large number of cars on the road entering Beirut every day. In particular, the study area consists of two large zones: (i) Municipal Beirut – MB (districts 1, 2, and 3), and (ii) Greater Beirut – GB (districts 4, 5, and 6) excluding Municipal Beirut and extended to Jounieh in the north and to Jiyyeh in the south, as shown in Figure B1. The congestion north of Municipal Beirut extends as far as Jounieh at least, justifying the extension of Greater Beirut as a study area till Jounieh. Moreover, a previous research study (Chalak et al., 2016) conducted a transportation survey in 2013 among commuters residing and working in the same study area used here, and so data from the Chalak et al. (2016) study are used as needed here. For this reason, 2013 is considered to be the base year of the current study even though not all the needed data items are readily available for 2013.

**Figure B1.** Beirut Study Area Map



## B2. Travel Characterization

### B2.1 Modes of Commuting

The current modes of commuting in Lebanon are private car, bus (with capacity of 24-33 passengers), minibus or van (with capacity of 14 passengers), shared taxi or jitney (known locally as service, with capacity of 4 passengers), private taxi, walk, bike, and motorcycle. The first four modes are the most widely used for trip making in Beirut and constitute the focus of this study. A recent study by IBI Group and TEAM (2009) reports the following modal split in the study area: private car: 80.6%, taxi-Service: 6.7% (6% service and 0.7% private taxi), minibus or van (with capacity of 14 passengers; often driver owned and operated): 10.9%, and bus: 1.75%. Most of the buses and minibuses are operated by the private sector in an unregulated manner.

### B2.2 Travel Attributes by Mode

Travel time data for car trips in the peak hour is based on reported travel times "on a bad day" from a 2013 survey (Chalak et al., 2016) which was conducted with car commuters who reside and work in the study area, weighted by zone-to-zone number of AM peak hour trips at the population level. The numbers were verified through a personal interview with Mr. Rami Semaan from TMS Consult, 2016. No travel time data from a transport model were available for this study due to the proprietary nature of such data. The in-vehicle travel time for the other modes is computed by applying a factor to the car in-vehicle travel time, suggested by the public transport revitalization study by IBI Group and TEAM (2009): 1.45 for bus, 1.25 for minibus, and 1.10 for taxi-service. Average waiting times for bus and minibus (assumed to be half the headway) and access/egress times are determined based on personal observation and measurements. We got the average waiting time and access/egress time for taxi-service are obtained from the public transport revitalization from the same study (see Table B1).

The total cost of a one-way commute by car is the sum of the fuel cost and half the daily parking rate. There are no tolls in Beirut. Car average daily parking costs were derived from the 2013 survey (Chalak et al., 2016), weighted by the number of trips to each of the districts to get the averages for MB and GBA with further adjustment based on judgement. The average car fuel efficiency is assumed to be 170 km/20 liters of fuel or 0.1176 liter/km driven as in the IBI Group and TEAM (2009) study. Fuel cost (gasoline for passenger cars) is then computed as the product of the fuel efficiency, the gasoline price of 33,000 LBP/20 liters (or 1,650 LBP/liter) in 2013, and the distance to work (km). The bus and minibus fares are the standard fares in operation. Taxi-service fare is based on the service fare (which is decided based on trip distance) since the private taxi share of trips is very small. Distance is based on reported distance from the 2013 survey, weighted as in the method used to calculate travel time. The average speed of traffic is calculated as the average distance divided by the average in-vehicle travel time by the corresponding mode and verified using several sources.

**Table B1.** Travel time, average speed and cost of transportation in Beirut

| **Attribute** | **MB to MB** | **GB to MB** | **MB to GB** | **GB to GB** |
|---|---|---|---|---|
| Car in-vehicle time (min) | 42.1 | 57.0 | 53.0 | 46.4 |
| Car door-to-door time (min) | 45.6 | 60.1 | 54.4 | 48.2 |
| Bus in-vehicle time (min) | 61.1 | 82.7 | 76.8 | 67.3 |
| Minibus in-vehicle time (min) | 52.6 | 71.3 | 66.2 | 58.0 |
| Taxi-service in-vehicle time (min) | 46.3 | 62.7 | 58.3 | 51.1 |
| Bus waiting time (min) | 6.5 | 6.5 | 6.5 | 6.5 |
| Minibus waiting time (min) | 0.5 | 0.5 | 0.5 | 0.5 |
| Taxi-service waiting time (min) | 6 | 6 | 6 | 6 |
| Bus access + egress time (min) | 10 | 15 | 15 | 15 |
| Minibus access + egress time (min) | 10 | 15 | 15 | 15 |
| Taxi-service access + egress time (min) | 6.03 | 8.03 | 8.03 | 8.03 |
| Car daily parking cost, including free parking (LBP) | 1,466.1 | 1,466.1 | 500 | 500 |
| Car fuel cost (LBP) | 1,282.8 | 2,394.6 | 2,319.2 | 1,828.5 |
| Car cost per vehicle trip (LBP) | 2,015.8 | 3,127.6 | 2,569.2 | 2,078.5 |
| Bus fare (LBP) | 1,000 | 1,000 | 1,000 | 1,000 |
| Minibus fare (LBP) | 1,000 | 1,000 | 1,000 | 1,000 |
| Taxi-service fare (LBP) | 2,000 | 4,000 | 4,000 | 4,000 |
| Distance (km) | 6.6 | 12.3 | 11.9 | 9.4 |
| Car speed (km/h) | 9.4 | 13.0 | 13.5 | 12.2 |
| Bus speed (km/h) | 6.5 | 9.0 | 9.3 | 8.4 |
| Minibus speed (km/h) | 7.5 | 10.4 | 10.8 | 9.7 |
| Jitney speed (km/h) | 8.6 | 11.8 | 12.3 | 11.1 |

1 USD = 1,500 LBP (Lebanese Pounds)

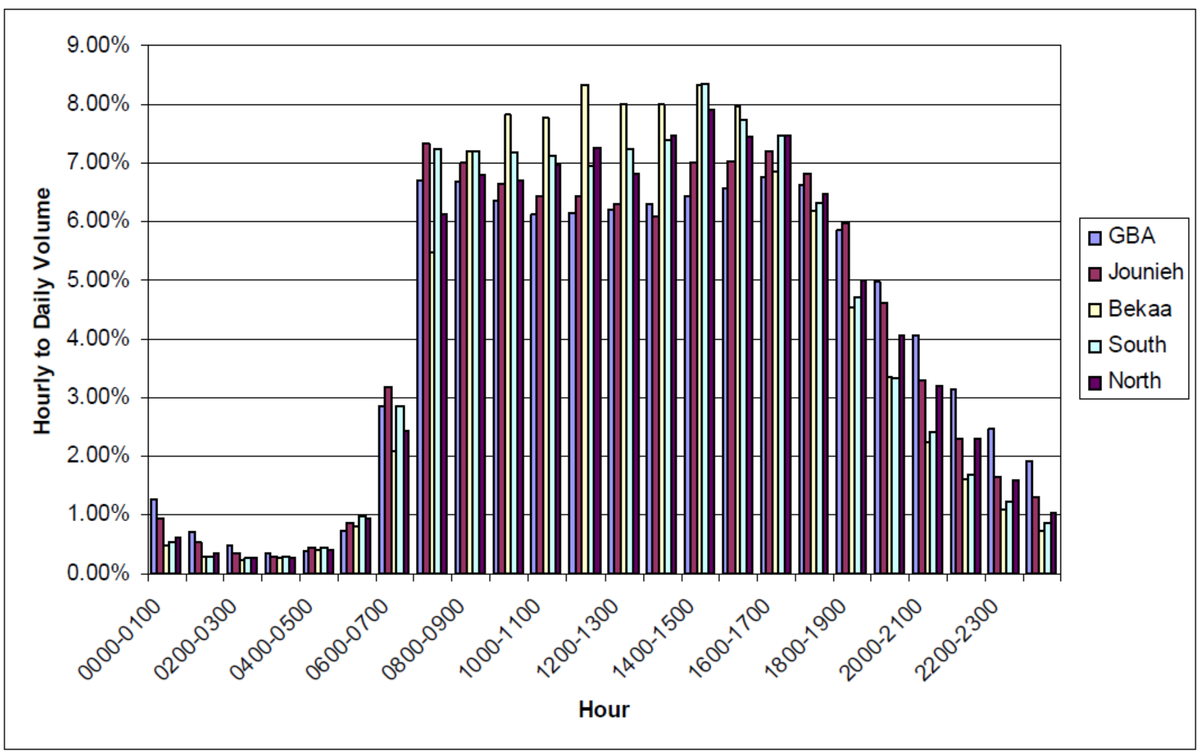
*Source: MOE (2005); IBI Group and TEAM (2009); TMS Consult (2016)*

*Note: that the total travel time by bus, minibus, and taxi-service can be computed as the sum of in-vehicle travel time (Section 2.2), waiting time (Section 3), and access-egress times (Section 6).*

### B2.3 Car Type, fuel type, unit fuel consumption and prices

According to the Association of Car Importers in Lebanon for the year 2014 (UNDP/First Climate/ECODIT, 2016), the distribution of white plate passenger cars in Lebanon by car size[12] is as follows: 16.24% small cars, 51.35% midsize cars, and 32.41% large cars. 51.25% of cars are manufactured before year 2000, while 48.75% are manufactured after 1999. Passenger cars run on gasoline. Buses run on diesel and minibuses run on gasoline. Based on data as of June 2013, fuels prices are 1,650 LBP/liter and 1,250 LBP/liter for gasoline and diesel, respectively. Buses and minibuses have a fuel consumption rate of about 0.25 liter/km (MoE/UNDP/GEF, 2015). Based on IBI Group and TEAM (2009), the car occupancy rate is 1.7 (including driver), the bus occupancy rate is 11.20 (excluding driver), the minibus occupancy rate is 5.93 (excluding driver), and the shared and exclusive taxi occupancy rate is 1.18 (excluding driver). Based on the same study, the distribution of peaking factors is presented in **Error! Reference source not found.**.

**Figure B2.** Hourly volume as a percent of daily volume




*Source: IBI Group and TEAM (2009)*

[12] Small vehicles are classified as vehicles with weight < 1 ton, engine size ≤ 1.4 liters, engine output < 15 HP. Midsize vehicles are those with weight 1 to 1.5 tons, engine size 1.4 to 2.3 liters, engine output 15 to 24 HP. Large vehicles are those with weight > 1.5 tons, engine size > 2.3 liters, engine output > 24 HP.

## B2.4 Number trips by mode and origin and destinations

AM peak hour trips (from 7-8 AM) by car are based on data used in Chalak et al. (2016). Assuming that the same number of trips will be made in the PM peak hour in the reverse direction, and using a peaking factor of 6.71% for the AM peak as a percentage of daily trips, the daily trip patterns by car are derived. Person trips are obtained from car trips using an average car occupancy of 1.7 as mentioned above. Total daily person trips by all motorized modes is obtained knowing that car person trips constitute 80.6% of all trips in the study area (IBI Group and TEAM, 2009). Finally, work and made by residents in the study area are obtained knowing the total employment in the study area and number of jobs occupied by non-residents, and non-work trips are then the balance between daily trips for all purposes and daily work trips (see Table B2a). External trips made by non-residents and by residents of the study area (with one trip end inside the study area and another trip end outside the study area) are obtained by applying factors to the internal trips made by residents, where these factors are derived from DAR-IAURIF (2005). The percentage of jobs in the study area occupied by non-residents and the distribution of non-resident trips by work or non-work purposes are obtained from Harris and IBI Group (2003). The external trip matrices are presented in Table B2(b).

**Table B2.** Number trips by mode and origin and destinations

**(a) Internal trips**

| Attribute | MB to MB | GB to MB | MB to GB | GB to GB |
|---|---|---|---|---|
| AM peak hour vehicle trips by car | 21,587 | 18,406 | 16,144 | 23,296 |
| Daily vehicle trips by car | 321,714 | 257,452 | 257,452 | 347,183 |
| Daily person trips by car | 546,914 | 437,668 | 437,668 | 590,212 |
| Daily person trips by all motorized modes | 678,553 | 543,012 | 543,012 | 732,272 |
| Total daily person work trips | 120,072 | 197,595 | 197,595 | 398,888 |
| Total daily person non-work trips | 558,481 | 345,417 | 345,417 | 333,384 |

**(b) External trips**

| | Outside study area to MB | Outside study area to GB | MB to outside study area | GB to outside study area |
|---|---|---|---|---|
| Daily trips by non-residents | 122,339 | 136,949 | 122,339 | 136,949 |
| Daily work trips by non-residents | 40,006 | 75,118 | 40,006 | 75,118 |
| Daily non-work trips by non-residents | 82,334 | 61,830 | 82,334 | 61,830 |
| Daily trips by residents | 42,285 | 44,144 | 42,285 | 44,144 |
| Daily work trips by residents | 24,525 | 25,604 | 24,525 | 25,604 |
| Daily non-work trips by residents | 17,760 | 18,541 | 17,760 | 18,541 |

*Source: Author's estimations based on various sources*

### B3. Socioeconomic and demographic data

Data on the income of employed individuals and on household income is obtained from the Central Administration of Statistics (CAS) from its Living Conditions Survey that was conducted in 2007 (CAS, 2007). The population and employment estimates were supplied by Mr. Rami Semaan from TMS Consult and have been estimated based on 2014 data (excluding Syrian refugees and Palestinian refugee camps population). Missing data for certain zones of the study area were inferred based on population and employment density maps. The number of workers and non-workers is inferred from the work and non-work trip patterns discussed before and validated with CAS (2007). The number of households is calculated given the population estimate and the average household size from CAS (2007). The socioeconomic and demographic data are presented in Table B3.

**Table B3.** Socioeconomic and demographic data

| Characteristic | Municipal Beirut | Greater Beirut |
|---|---|---|
| Average employed individual's monthly salary (LBP) | 909,000 | 719,174 |
| Median employed individual's monthly salary (LBP) | 700,000 | - |
| Average household monthly salary (LBP) | 1,586,200 | 1,189,436 |
| Population, 2014 | 445,282 | 882,231 |
| Households, 2014 | 118,742 | 220,183 |
| Number of residing workers, 2014 | 183,359 | 323,845 |
| Number of residing non-workers, 2014 | 261,923 | 558,386 |
| Employment, 2014 | 198,839 | 373,360 |

### B4. Public transportation and infrastructure

Roads are classified as international roads, primary roads, secondary roads, and local roads. The total length and area of roads by type in the study area are obtained from personal communication with Dr. Hani Al-Naghi using GIS and are shown in Table B4.

**Table B4.** Road length and area by road class in Municipal Beirut and Greater Beirut

| | Municipal Beirut | | Greater Beirut | |
|---|---|---|---|---|
| **Road Class** | **Length (m)** | **Area ($m^2$)** | **Length (m)** | **Areas ($m^2$)** |
| International Roads | 32,578 | 410,483 | 121,838 | 1,535,159 |
| Primary Roads | 42,681 | 373,459 | 90,816 | 794,640 |
| Secondary Roads | 96,701 | 986,350 | 377,123 | 3,846,655 |
| Local Roads | 288,619 | 1,904,885 | 1,684,713 | 11,119,106 |
| **Total** | **460,579** | **3,675,177** | **2,274,490** | **17,295,559** |

Data about average road construction cost estimates in US dollars per square meter were obtained from personal communication with Mr. Walid Osman (Ministry of Public Works and Transport).

**Table B5.** Road construction costs by road class

| Road Class | Construction Cost Estimate ($/m$^2$) |
|---|---|
| International Roads | $35 |
| Primary Roads | $25 |
| Secondary Roads | $20 |
| Local Roads | $16 |

*Note: These numbers exclude costs of side infrastructure (walls, channels, culverts, barriers, etc.) but include VAT*

There are 18 bus/minibus lines serving Beirut and GB and some outlying areas, most of which are unregulated and privately owned. Based on personal observation as well as on Farhat (2015), we categorize bus/minibus operation into three types as follows: (i) Case 1 (14 lines): There is one main operator of the bus line, and bus drivers are employees for the main operator. (ii) Case 2 (3 lines): The bus/minibus vehicles are privately owned or rented by individual drivers who pay a parking fee for parking operators. The revenues from ticket sales constitute the daily revenue for the drivers; (iii) Case 3 (1 line): Similar to case 2, but the drivers do not pay a parking fee.

For a Case 1 line, the costs and revenues pertain to the main operator of the line. For a Case 2 or Case 3 line, the costs and revenues are those that pertain to the individual drivers on these lines; they are summed up across vehicles operating on a daily basis on a certain line to arrive at a total cost and revenue figure for the corresponding line. A number of assumptions are employed in the calculation of costs and revenues, based on interviews with bus/minibus drivers, articles available online, and judgment to match some controls (e.g. the total number of buses operating on a line). These assumptions pertain to type of vehicle used (bus or minibus) on a line, headway, hours of operation, number of round trips per day, average route speed, number of days of operation per month, and various operational cost and revenue related parameters. Given the route length, the average route speed and headway, and number of shifts per day on a given bus/minibus, the estimated number of buses/minibuses on each line are estimated in Table B6.

**Table B6.** Number of buses and minibuses by route

| Line Number | Case (1,2,3) | Number of buses/day | Number of minibuses/day | Total vehicles/day |
|---|---|---|---|---|
| 1 | 2 | 11 | 169 | 180 |
| 2 | 1 | 16 | - | 16 |
| 3 | 1 | 9 | - | 9 |
| 4 | 2 | 11 | 167 | 178 |
| 5 | 1 | 15 | - | 15 |
| 6a | 1 | 21 | - | 21 |
| 6b | 1 | 14 | - | 14 |
| 7 | 1 | 49 | - | 49 |
| 9 | 1 | 5 | - | 5 |
| 12 | 1 | 5 | - | 5 |
| 14 | 1 | 17 | - | 17 |
| 15a | 1 | 15 | - | 15 |
| 15b | 1 | 13 | - | 13 |
| 15c | 1 | 13 | - | 13 |
| 16 | 1 | 16 | - | 16 |
| 24 | 1 | 4 | - | 4 |
| A | 2 | 11 | 180 | 191 |
| Cola-Tripoli | 3 | 30 | 475 | 505 |
| | **Total** | 275 | 991 | 1,226 |

Based on interviews we conducted with bus and minibus drivers, the cost of a new bus (generally Mitsubishi) is around $94,000. And the cost of a new minibus is around $37,000 (excluding the cost of the red plate).

### B5. Land Use and Real Estate Data

Table B7 summarizes for each of MB and GB the total area of these districts, the area occupied by buildings by type, the unusable land (including existing roads), and the land area that can be further developed in each district. The total land area is obtained from a GIS file of the zones in the study area (with the addition of the area of reclaimed land in the sea in Municipal Beirut as well as in Greater Beirut). The land area occupied by buildings was computed using Google Earth as the plan view/roof area, excluding parking lots, green spaces, and any open spaces within a building. Some of the remaining land area that is not yet developed is unusable for further development such as public parks, graveyards, rivers, the airport field, and the golf course. Palestinian refugee camps were not included in the “unusable land” because their areas were incorporated under built up spaces. The total unusable area also includes empty spaces within buildings and setbacks which were estimated using an average investment ratio for each zone based on the "Building Law and Regulations in Lebanon" issued in 1995 by the Order of Engineers and Architects (OEA). Note that the residential category includes land area occupied by Palestinian refugee camps. The latter constitute 18,416 $m^2$ in Municipal Beirut and 867,048 $m^2$ in Greater Beirut.

**Table B7.** Developed, Unusable, and Developable Land Area in Municipal and Greater Beirut

| Land type | Municipal Beirut | Greater Beirut |
|---|---|---|
| Total Area ($km^2$) | 20.45 | 150.55 |
| Total Building Areas ($km^2$) | 7.723 | 25.753 |
| Industrial ($m^2$) | 208,351 | 2,073,515 |
| Commercial ($m^2$) | 1,400,325 | 4,091,208 |
| Mixed Residential ($m^2$) | 1,212,557 | 2,136,980 |
| Residential ($m^2$) | 4,516,119 | 15,995,164 |
| Public & Government ($m^2$) | 385,502 | 1,456,489 |
| Built/Zone (%) | 38% | 17% |
| Unusable Land Area Including Roads ($km^2$) | 8.072 | 72.192 |
| Land Area that Can Be Further Developed ($km^2$) | 4.65 | 52.61 |

**Land value and rental prices**: Land value price estimates were derived based on interviews with real estate agents. The figure for MB is relatively high and this is driven mostly by very high prices in the Beirut Central District and seafront area of Municipal Beirut. Purchase prices of residential apartments were obtained from RAMCO for MB (based on analysis by RAMCO of 345 residential buildings under construction in Municipal Beirut in 2015 as reported in Blominvest Bank, 2015; Delmendo, 2015; iLoubnan.info, 2015). The prices for GB are obtained from INFOPRO Research, who compiled based on limited data for selected Beirut suburbs but these pricing data were validated through interviews with real estate agents. Based on personal communication with RAMCO researchers and other real estate agents, the annual rental values were estimated to be, on average, around 3% of the purchase price of an apartment. All pricing data are for year 2013.
For office buildings, rental prices were obtained from a real estate agent for MB and was validated with sources.[13] The rental values of office buildings in GB vary between 100 and 150 \$/$m^2$/year, and we use the average of this range as representative of office rental prices in Greater Beirut.

The average dwelling size for first floor apartments under construction in Beirut was obtained from RAMCO, and for GB from interviews with several real estate agents based on the most currently sellable apartments. The value for MB is significantly higher than that for GB due to the fact that

[13] See, for example,
http://investinlebanon.gov.lb/en/doing_business/cost_of_doing_business?catId=54&businessId=234.

high income neighborhoods in Municipal Beirut (the sea front, Solidere, Ain Mreisseh, Ramleh Baida, etc.) have apartments with larger areas because their market targets are buyers from the Gulf; many of these high-end apartments remain vacant and they drive upwards the average size of apartments in Municipal Beirut. Data on housing and rental prices are summarized in Table B8.

**Table B8.** Housing and rental prices

| Data item | Municipal Beirut | Greater Beirut |
|---|---|---|
| Land value $/m$^2$ (in 2013) | 11,192 | 1,630 |
| Rental price/m$^2$/year for residential apartments (in 2013) | 117.2 | 55.7 |
| Rental price/m$^2$/year for retail (in 2014) | 375 | 178.2 |
| Rental price/m$^2$/year for office (in 2013) | 194 | 125 |
| Average dwelling size (m$^2$) | 238 | 154 |

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