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Access to transportation, residential segregation, and economic opportunity

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Abstract

The Housing Choice Voucher Program assists low-income families to afford decent housing and provide them with better economic opportunities. There is growing evidence that public transportation plays an important role in shaping the residential location choices of low-income households. However, transportation has not been a major focus of the research related to housing voucher programs. We develop a general equilibrium model of a city with multiple districts, decentralized employment, multiple commuting modes, and locally financed education. We compare housing vouchers with transportation vouchers with respect to poverty deconcentration, educational quality in each district, unskilled employment in the suburbs, and welfare.

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1 Introduction

Around 20% of inner cities and 7% of suburbs in U.S. metropolitan areas consisted of poor households in the period 1990-2000 (Margo (1992), Mieszkowski and Mills (1993), Mills and Lubuele (1997), Glaeser et al. (2008)). In order to deconcentrate poverty out of inner cities, government has implemented several affordable housing policies such as Experimental Housing Assistance, Moving to Opportunity for Fair Housing, and Welfare-to-Work Voucher programs. However, as noted in Blumenberg et al. (2014), Blumenberg et al. (2015), and Ellen (2020), these policies failed to deconcentrate poverty since poor households are also unable to afford automobiles which is necessary for a suburban life. In other words, as found in LeRoy and Sonstelie (1983) and Glaeser et al. (2008), availability of public transportation in inner cities may be the reason that attracts poor households to inner cities. Motivated by these, using a general equilibrium model, we quantitatively study in this paper two separate governmental policies (housing vouchers, transportation vouchers). We find that transportation voucher policy is more effective in deconcentrating poverty out of inner city at a lower cost compared to housing vouchers. Both policies cause concentration of poverty in some other district of the metropolitan area where the resulting poverty concentration is higher under transportation vouchers. We also analyze the effects of the two policies on households' employment locations, welfare levels, and the quality of education received by children.

To analyze these voucher policies, we employ a general equilibrium hybrid Tiebout model that unifies the local public good literature following Tiebout (1956) with the urban location theory literature following Alonso (1964), Mills (1972), and Muth (1969). More specifically, we set up a benchmark model of a closed city at which there are three school districts (west, inner city, east), two employment centers (central, suburban), and two modes of commuting (bus, automobile). School districts differ by property tax rate and education quality whereas employment centers differ by their locations and wages paid. The commute costs (fixed, variable) differ across travel modes. Households differ by their skill levels (skilled vs. unskilled) and they choose a school district and a location there to reside, business district to work, and mode of commute. Households also choose consumption of the numeraire good, house size, and leisure. Housing is produced by perfectly competitive firms using land and capital as inputs. Education in a school district is locally financed through housing property taxation where the tax rate is determined through majority rule. Education quality in a school district depends on per pupil public spending and peer effects. Land is owned by absentee landlords who hold auction at each location in each district to find out the highest bidder. Housing prices are determined in turn which depend on location and district characteristics. Bus transportation is publicly provided by the city government and is financed through consumption sales tax.

To determine the values of parameters, we calibrate our benchmark model so as to match certain statistics from 2018 U.S. data. Our calibrated model is consistent with several features of metropolitan areas such as imperfect income sorting across school districts, non-monotonic house rents over space, and capitalization of education quality and accessibility into house prices.

Using the calibrated model, we analyze housing voucher and transportation voucher policies. Both voucher types are provided only to unskilled households living in the inner city district where the poverty is concentrated and they are financed through income taxation. More specifically, housing voucher is a constant amount given to unskilled households to be used in renting a dwelling. On the other hand, both bus and automobile commuters are eligible for transportation voucher and the amount of voucher corresponds to some fraction of an unskilled household's total commuting cost by automobile. Since variable cost of commuting depends on distance to workplace in our model, then the monetary amount of transportation voucher may differ across households. The greater the distance to work from home, the greater the transportation voucher received.

Regarding previous literature, Leung et al. (2012) quantitatively compares public housing and housing voucher policies using an equilibrium model. They find that housing voucher is more efficient and implies higher welfare than public housing. Moreover, distribution of skilled vs. unskilled households in a school district does not change at all after housing voucher policy which confirms our findings. Gong and Leung (2019) extends the model of Leung et al. (2012) by introducing fertility decisions for households. Our paper mainly differs from Leung et al. (2012) and Gong and Leung (2019) in terms of analyzing not only housing vouchers but also transportation vouchers. Moreover, in our model, we have multiple business districts and multiple modes of commute differently from these papers. Different from our model, since fertility decisions of households is taken into consideration by Gong and Leung (2019), this causes parent's welfare and child's welfare to behave differently under public housing and housing voucher policies. Another paper by Yılmaz (2019) quantitatively analyzes automobile tax policy in a general equilibrium framework and finds that it decreases poverty concentration around the central business district. Different from Yılmaz (2019), we also analyze housing voucher policy and in our model we have more school districts and decentralized employment centers. Moreover, Borck and Wrede (2005) analyze the redistributional impacts of commuting subsidies whereas Brueckner (2005) and DeSalvo and Su (2008) studies the effect of commuting subsidies on urban sprawl. These papers are based on urban location models and do not consider community choice and local public good provision. Different from these papers, our paper studies the effect of transportation vouchers on the spatial distribution of households and educational quality.

Our paper is organized as follows. Section 2 explains our benchmark model. The details of the calibration procedure are provided in Section 3. The benchmark properties of our model is explained in Section 4. The voucher policies are analyzed in Section 5. Section 6 concludes our paper.

2 Benchmark Model

We consider a city, as illustrated in Figure 1, with decentralized workplaces on a x-y plane over which there are three school districts (west(w), inner city(n), and east(e)) and two business districts (central and suburban). The jobs in the city are offered at the central business district (CBD), which is located at the origin and a suburban employment ring (SBD), which is located on a circle of exogenously given radius $\overline{r}$ locations with a center at the origin. The city is located on a featureless plane, in which land pieces differ by the distance to workplaces and there is a radial transportation system in the city. Thus, land pieces on a circle have the same commuting distance to the workplaces and are identical. The y-axis forms the boundary between the east school district and the inner school district. The inner city school district is separated by the west school district through a semi-circle with exogenously given radius $\overline{r}_w$.[1] School districts differ by the housing property tax rate, per pupil public spending, and school quality. Due to differences in school districts, land pieces on a semi-circle within a school district are identical. The city has two modes of commuting: bus or car. Our model extends the model of Yılmaz (2019) by including decentralized workplaces and more school districts.

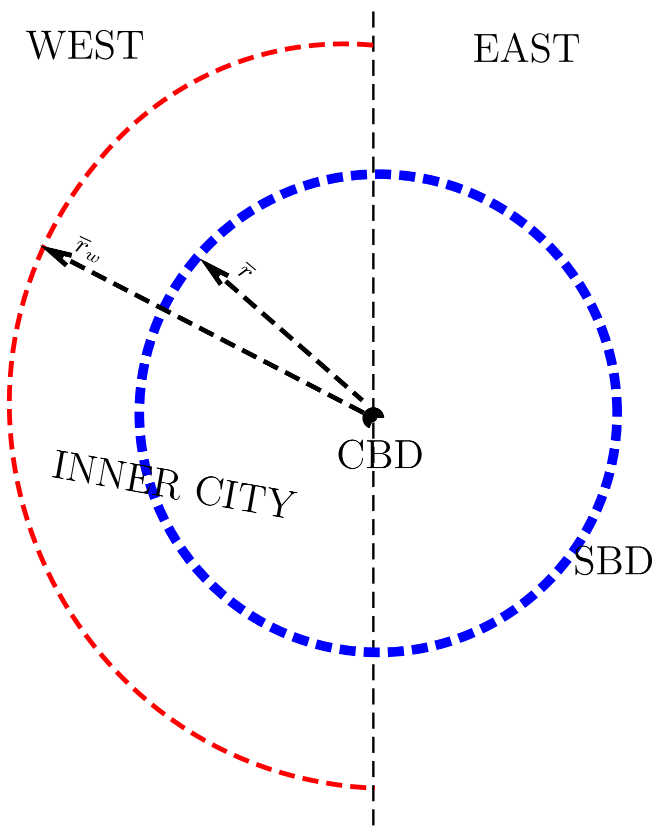

Figure 1: Structure of the city

[1]We calibrate $\overline{r} < \overline{r}_w$. Please see Section 3.

2.1 Households

Each household i consists of one parent and one school age child. Households differ by only the skills of parents. There are two skill types. A skilled parent (denoted with s) working in the business district $j \in \{cbd, sbd\}$ earn hourly wage $w_{s,j}$ and similarly an unskilled parent (denoted with u) earn hourly wage $w_{u,j}$. Both wages are exogenously given and $w_{s,j} > w_{u,j}$ for any j. Each child enrolls in the public school of the district of residence ($d \in \{w, n, e\}$). There is no private education available.[2]

The utility function of household i living in district d location r and working in the business district j is represented by a Cobb-Douglas form as follows:

$$U^i_{d,j} = q_d^{\alpha_i} h^i_{d,j}(r)^{\eta_i} z^i_{d,j}(r)^{\gamma_i} l^i_{d,j}(r)^{\delta}$$

where q_d denotes quality of public school, and $h^i_{d,j}(r)$, $z^i_{d,j}(r)$, $l^i_{d,j}(r)$ denote size of house, daily consumption of a numeraire good, daily leisure time (between 0 and 24 hours) of parent respectively.

Skilled households value public school quality more than unskilled households (i.e., $\alpha_s > \alpha_u > 0$). Similarly, valuation of house size, and valuation of numeraire good consumption depend also on skill type. More specifically, $\eta_i > 0 \in \{\eta_s, \eta_u\}$, $\gamma_i > 0 \in \{\gamma_s, \gamma_u\}$, and $\delta > 0$. The optimized budget shares of $h^i_{d,j}(r)$, $z^i_{d,j}(r)$, $l^i_{d,j}(r)$ are $\frac{\eta_i}{\eta_i+\gamma_i+\delta}$, $\frac{\gamma_i}{\eta_i+\gamma_i+\delta}$, and $\frac{\delta}{\eta_i+\gamma_i+\delta}$ respectively.

Parents commute to their workplaces every day using either bus (denoted with b) or automobile (denoted with a) transportation. Bus is available only for commuting to central business district whereas automobile is available for commuting to both business districts. Any household commuting by bus and working in the central business district spends $\frac{t^b}{2}$ hours per mile, incurs a fixed cost of f^b per day and a variable cost of $\frac{c^b}{2}$ per mile. It should be noted that time cost, fixed cost, and variable cost of commuting by bus is independent of household type. Therefore, in any school district, the total accounting cost of round-trip transportation using bus for any household is $f^b + c^b r$ where r is the distance between home and central business district. The total opportunity cost of commuting by bus is $t^b r w_{i,cbd}$ for household type $i\{s, u\}$.

Similarly, household i working in the business district $j \in \{cbd, sbd\}$ and commuting by automobile spends $\frac{t^a_j}{2}$ hours per mile (same for all households), incurs a fixed cost of f^a_i per day, and a variable cost of $\frac{c^a_i}{2}$ per mile. Thus, in any school district, the total accounting cost of round-trip transportation by automobile for household i is $f^a_i + c^a_i r_j(r)$ where $r_j(r)$ is the distance between home (located at r miles from CBD) and workplace j. If the household works in the central business district, then $r_{cbd}(r)$ is simply equal to r. If the household works in the suburban business district, then $r_{sbd}(r)$ is the Euclidean distance between home (located at r miles from CBD) and suburban

[2]Private schools can be introduced into our model following Hanushek et al. (2011).

business district (located at $\bar{r}$ miles from CBD).[3]

We assume commuting by automobile to central business district takes more time per mile (due to congestion) than to suburban business district: $t^a_{cbd} > t^a_{sbd}$. Moreover, transportation by automobile takes less time, requires higher fixed cost but cheaper in terms of variable cost: $t^a_{cbd} < t^b$, $f^a_i > f^b$, and $c^a_i > c^b\ \forall i \in \{s, u\}$. Moreover, assuming a skilled household rides a newer automobile than an unskilled household, then $f^a_s > f^a_u$ and $c^a_s < c^a_u$. Moreover, we assume marginal cost of commuting by bus is higher than that of automobile for CBD workers (i.e., $c^b + t^b w_{i,cbd} > c^a_i + t^a_{cbd} w_{i,cbd}$).

For household i working in business district j, living at location r in district d, and using commuting mode m, the gross income is given by:

$$W^i_{d,j}(r,m) = \underbrace{\left[24 - l^i_{d,j}(r) - t^m_j r_j(r)\right]}_{\equiv L^i_{d,j}(r,m)} w_{i,j},$$

where $L^i_{d,j}(r,m)$ is the daily time available for working.[4] It should be noted that time cost (or opportunity cost) of commuting is subtracted from total time endowment in finding $L^i_{d,j}(r,m)$. Household allocates gross income among numeraire consumption good expenditure, housing expenditure, and transportation expenditure. Thus, daily budget constraint of the household could be written as:

$$(1+\upsilon)z^i_{d,j}(r) + (1+\tau_d)R^*_d(r)h^i_{d,j}(r) + f^m_i + c^m_i r_j(r) = W^i_{d,j}(r,m), \tag{2}$$

where υ is the sales tax rate on consumption good, τ_d is the equilibrium housing property tax rate in district d, $R^*_d(r)$ is the equilibrium daily house rent per unit in district d at distance r miles from CBD. To decide on the mode of commute, consumption of the numeraire good, size of the dwelling, and leisure, household i that lives in district d location r and works in the business district j maximizes its utility subject to budget constraint (2) as follows:

$$V^i_{d,j}(r) = \max_{m,h,z,l}\ q_d^{\alpha_i} h^i_{d,j}(r)^{\eta_i} z^i_{d,j}(r)^{\gamma_i} l^i_{d,j}(r)^{\delta} \tag{3}$$

$$s.t. \qquad (1+\upsilon)z^i_{d,j}(r) + (1+\tau_d)R^*_d(r)h^i_{d,j}(r) + f^m_i + c^m_i r_j(r) = W^i_{d,j}(r,m),$$

where $V^i_{d,j}(r)$ is the indirect utility of the household.

Next, we characterize the solution of problem (3). Any household working in the suburban

[3] More formally, $r_j(r)$ is defined as:

$$r_j(r) = \begin{cases} r & \text{if } j = cbd, \\ |\bar{r} - r| & \text{if } j = sbd. \end{cases} \tag{1}$$

[4] We slightly abuse notation in defining $W^i_{d,j}(r,m)$ since it is undefined when mode of commute is bus and work location is SBD. We continue in this manner throughout the paper to save space.

business district commutes by automobile. Households working in the central business district choose the mode of commute. To determine this choice, let us define household's income net of commuting cost as:

$$Y_i(r_j(r), m) \equiv 24w_{i,j} - \left(f_i^m + \left(c_i^m + t_j^m w_{i,j}\right) r_j(r)\right).$$

Since mode of commute choice in problem (3) enters only through $Y_i(r_j(r), m)$, then household chooses that mode of commute which yields higher $Y_i(r_j(r), m)$. Then, the household chooses bus if and only if $Y_i(r_j(r), b) > Y_i(r_j(r), a)$ which is equivalent to $f^b + \left(c^b + t^b w_{i,j}\right) r_j(r) < f_i^a + \left(c_i^a + t_j^a w_{i,j}\right) r_j(r)$.[5] Since $r_j(r) = r$ for a household working in the central business district, then bus is chosen if the following condition is met:

$$r < \frac{f_i^a - f^b}{c^b + t^b w_{i,cbd} - (c_i^a + t_{cbd}^a w_{i,cbd})} \equiv r_{i,cbd}. \tag{4}$$

Thus, for household i working in the central business district and residing at location r, bus is chosen if $r < r_{i,cbd}$. The cutoff distance $r_{i,cbd}$ is positive since we assume $f_i^a > f^b$ and $c^b + t^b w_{i,cbd} > c_i^a + t_{cbd}^a w_{i,cbd}$. Moreover, $r_{i,cbd}$ depends on wage rate and thus on household's skill type. Since $t^b > t_{cbd}^a$, then $r_{i,cbd}$ is smaller for a skilled household compared to an unskilled household.

Regarding problem (3), household's mode of commute choice is therefore characterized. The optimal values of the remaining choice variables are as follows:

$$h_{d,j}^i(r) = \frac{\eta_i}{(\eta_i + \gamma_i + \delta)(1 + \tau_d)} \frac{Y_i^*(r_j(r))}{R_{d,j}^i(r)}, \tag{5}$$

$$z_{d,j}^i(r) = \frac{\gamma_i Y_i^*(r_j(r))}{(\eta_i + \gamma_i + \delta)(1 + \upsilon)}, \tag{6}$$

$$l_{d,j}^i(r) = \frac{\delta Y_i^*(r_j(r))}{(\eta_i + \gamma_i + \delta) w_{i,j}}, \tag{7}$$

where $Y_i^*(r_j(r))$ is defined for a CBD worker as:

$$Y_i^*(r_j(r)) = \begin{cases} 24w_{i,cbd} - \left(f^b + \left(c^b + t^b w_{i,cbd}\right) r\right) & \text{if } r < r_{i,cbd}, \\ 24w_{i,cbd} - \left(f_i^a + \left(c_i^a + t_{cbd}^a w_{i,cbd}\right) r\right) & \text{o.w.} \end{cases}$$

and for a SBD worker $Y_i^*(r_j(r)) = 24w_{i,sbd} - \left(f_i^a + \left(c_i^a + t_{sbd}^a w_{i,sbd}\right) r_j(r)\right)$.

Each household also chooses the workplace j, school district d and the location r that maximizes the utility function. More formally, the overall indirect utility function resulting from these choices can be expressed as:

$$V^i(\cdot) = \max_{d,j,r} V_{d,j}^i(r) \tag{8}$$

[5] $Y_i(r_j(r), a)$ and $Y_i(r_j(r), b)$ cannot be equal because of the assumptions made on the commuting mode parameters.

How do households determine their house bid-rent functions? Household i working in business district j and living in district d location r solves the following problem given q_d, τ_d, υ, and utility level $\overline{u}_i$:

$$R^i_{d,j}(r) = \max_{m,h,z,l} \left\{ \frac{Y_i(r_j(r),m) - (1+\upsilon)z^i_{d,j}(r) - w_{i,j}l^i_{d,j}(r)}{(1+\tau_d)h^i_{d,j}(r)} \middle| U^i_{d,j} = \overline{u}_i \right\}. \tag{9}$$

Following Solow (1973), problem (9) is the dual of problem (3) for which the solutions are given by (5), (6), and (7). Substituting these solutions into the objective function in (9) yields the following:

$$R^i_{d,j}(r) = \frac{k_i^{\frac{1}{\eta_i}}}{(1+\tau_d)(1+\upsilon)^{\frac{\gamma_i}{\eta_i}} w_{i,j}^{\frac{\delta}{\eta_i}}} q_d^{\frac{\alpha_i}{\eta_i}} Y_i^*(r_j(r))^{\frac{\eta_i+\gamma_i+\delta}{\eta_i}} \overline{u}_i^{-\frac{1}{\eta_i}} \tag{10}$$

where $k_i = \frac{\eta_i^{\eta_i}\gamma_i^{\gamma_i}\delta^{\delta}}{(\eta_i+\gamma_i+\delta)^{\eta_i+\gamma_i+\delta}}$. Therefore, $R^i_{d,j}(r)$ is decreasing (increasing) in r if $Y_i^*(r_j(r))$ is decreasing (increasing) in r. Also, $R^i_{d,j}(r)$ is convex in r since $\eta_i > 0$ and $\eta_i + \gamma_i + \delta = 1$.

In our model, we concentrate on the spatial equilibrium at which no household has an incentive to move to other locations, districts or workplaces. Therefore, household i receives the same utility $\overline{u}_i$ everywhere.

2.2 Housing

Housing space consumed by households is produced by perfectly competitive firms using capital (k) and land (x) as inputs:

$$h = Ak^b x^{1-b},$$

where $A > 0$ is the economy-wide factor productivity parameter, and $b \in (0,1)$ is the share of capital in the production. Capital is measured in dollars, and land is measured in square feet. Housing is produced at locations $r < r_{gd}$ where r_{gd} is the endogenous fringe distance in district d above which land is allocated for agricultural use. The firm in any district d location r maximizes its profit given by:

$$\max_{k,x} \Pi_d(r) = R^*_d(r)Ak_d(r)^b x_d(r)^{1-b} - k_d(r) - \Psi^*_d(r)x_d(r), \tag{11}$$

where $\Psi^*_d(r)$ is the equilibrium land rent per square foot.[6] In the long-run equilibrium, $\Pi_d(r) = 0$ because of perfect competition. Solving problem (11) and imposing the zero profit condition implies:

$$\Psi^i_{d,j}(r) = A^{\frac{1}{1-b}} b^{\frac{b}{1-b}} (1-b) R^i_{d,j}(r)^{\frac{1}{1-b}}, \tag{12}$$

[6] No housing is available at the ring $\overline{r}$ in both districts and at the semi-ring $\overline{r}_w$ in the west. We assume $\overline{r} < r_{gd}$ for each district d.

where $\Psi^i_{d,j}(r)$ is the land bid-rent construction firm offers in the district d location r in the land auction on behalf of household i working in the business district j. $R^i_{d,j}(r)$ is given by (10).

2.3 Land Market

Absentee landlords hold an auction for land at each r in each district. House construction firms (on behalf of households) and farmers participate in the auction and land goes to the highest bidder. Farmers' bid is an exogenously given constant $\overline{\Psi}_g$ at any location in any district. At the time of land auction, firms take as given each household's house bid-rent. Given the maximum house bid-rent at a location, a firm determines its bid for land using (12).

Now, let us characterize the equilibrium land bid-rent at location r in district d. In school district d, the landlord receives four bids from households and one bid from farmer for location r. And land is offered to the highest bid $\Psi^*_d(r)$ which can be expressed formally as follows:

$$\Psi^*_d(r) = \max\{\Psi^u_{d,cbd}(r), \Psi^u_{d,sbd}(r), \Psi^s_{d,cbd}(r), \Psi^s_{d,sbd}(r), \overline{\Psi}_g\} \qquad \forall d \in \{w, n, e\}.$$

Thus, r_{gd} can be defined as $\Psi^*_d(r_{gd}) = \overline{\Psi}_g$ for $\forall d \in \{w, n, e\}$. To be used later, let us define an equilibrium type function that reports the type of household to whom the land is assigned after the auction:

$$\theta^*_d(r) = \arg\max\{\Psi^u_{d,cbd}(r), \Psi^u_{d,sbd}(r), \Psi^s_{d,cbd}(r), \Psi^s_{d,sbd}(r), \overline{\Psi}_g\} \qquad \forall d \in \{w, n, e\}.$$

As an example, if $\theta^*_d(r) = \Psi^s_{d,cbd}(r)$ then skilled household working in the central business district wins the land auction in district d location r.

In our model, as in previous models such as Hanushek and Yilmaz (2007) and Yılmaz (2019), the spatial ordering of households can be determined by comparing the steepness of land bid-rent functions. Let us take two households i_1 and i_2 both bidding for houses in school district d and working in business district j. Household i_1 outbids household i_2 at locations closer to business district j if and only if the following condition holds at any location r^* such that $\Psi^{i_1}_{d,j}(r^*) = \Psi^{i_2}_{d,j}(r^*)$:

$$\frac{\partial \Psi^{i_1}_{d,j}(r^*)/\partial r}{\partial \Psi^{i_2}_{d,j}(r^*)/\partial r} = \frac{(\eta_{i_1} + \gamma_{i_1} + \delta)\,\eta_{i_2}}{(\eta_{i_2} + \gamma_{i_2} + \delta)\,\eta_{i_1}} \frac{Y^*_{i_2}(r_j(r))}{Y^*_{i_1}(r_j(r))} \frac{\left(c^{m_{i_1}}_{i_1} + t^{m_{i_1}}_j w_{i_1,j}\right)}{\left(c^{m_{i_2}}_{i_2} + t^{m_{i_2}}_j w_{i_2,j}\right)} > 1. \tag{13}$$

Based on (13), we can claim that household i_1 locates closer to business district j if its income is lower or its budget share of housing expenditure is lower or its marginal commuting cost is higher than household i_2 holding other things constant.

2.4 Population

The population of type $i \in \{s, u\}$ households ($\overline{N}_i$) is exogenously given implying a closed city. To write down the population constraint for type i households, first it should be noted that any location in a semi-ring around the CBD are identical in terms of land prices, education quality and distance. This implies that a particular semi-ring would be occupied by either identical households or farmers. Second, land market clears at each semi-ring in equilibrium. Thus, total land ($\pi r dr$) at semi-ring with size dr in any district is completely used for constructing houses if farmers are outbid by households. Given the land input demand $x^i_{d,j}(r)$ by household i, the population of type i households at semi-ring in district d location r can be found as $\frac{\pi r dr}{x^i_{d,j}(r)}$ if they outbid other households and farmers. Summing this fraction for all r, d, and j yields $\overline{N}_i$. More formally, population constraint for type i households in the economy is:

$$\sum_d \sum_j \int_{\Psi^*_d(r) > \overline{\Psi}_g} \frac{\pi r}{x^i_{d,j}(r)} I[\theta^*_d(r) = (i, j)] dr = \overline{N}_i, \tag{14}$$

where $I[\theta^*_d(r) = (i, j)]$ is an indicator function taking the value 1 if equilibrium occupant of location r in district d is the household i working in business district j, and 0 otherwise. In the population constraint, to capture the fact that households land bid-rent exceeds the farmers' bid in residential locations, we express the integral over the locations r that satisfy $\Psi^*_d(r) > \overline{\Psi}_g$.

2.5 Public Transportation

In our model, commuting by bus is the only public transportation type. The population of households using bus ($\overline{N}^{bus}$) is given by:

$$\overline{N}^{bus} = \sum_d \sum_i \int_0^{r_{i,cbd}} \frac{\pi r}{x^i_{d,cbd}(r)} I[\theta^*_d(r) = (i, cbd)] dr.$$

As indicated above, the distance cutoff $r_{i,cbd}$ below which a household chooses bus is smaller for a skilled household compared to an unskilled household (i.e., $r_{s,cbd} < r_{u,cbd}$).

Any household using bus for r miles pays an additional variable fee $c^b r$ on top of fixed fee f^b. Sales tax revenue collected from households' numeraire good consumption subsidizes the public transportation system. Total fee paid by households together with consumption sales tax revenue constitute total finances of public transportation system. Therefore, the budget constraint of city government regarding public transportation is given by:

$$f^b \overline{N}^{bus} + VC + TR = \overline{C}_k + \overline{c} \overline{N}^{bus}, \tag{15}$$

where VC denotes total variable cost paid by households for bus travel, TR denotes total consumption tax revenue collected, and $\overline{C}_k$ and $\bar{c}$ are the capital and marginal costs of operating public transportation system respectively. More formally, VC and TR are expressed below:

$$VC = \sum_d \sum_i \int_0^{r_{i,cbd}} \frac{c^b \pi r^2}{x^i_{d,cbd}(r)} I[\theta^*_d(r) = (i, cbd)]dr,$$

$$TR = \sum_d \sum_i \sum_j \int_{\Psi^*_d(r) > \overline{\Psi}_g} v z^i_{d,j}(r) I[\theta^*_d(r) = (i, j)]dr.$$

2.6 Schools

In a district, public school's expenditures are financed through local taxation of residential property. Local tax revenue is completely spent on the district's public school implying the following per pupil public expenditure:

$$e_d = \frac{\int_{\Psi^*_d(r) > \overline{\Psi}_g} \tau_d R^*_d(r) \pi r dr}{N_d},$$

where $N_d = N^s_d + N^u_d$ is the total population in district d. As in Yılmaz (2019), school quality in district d depends on e_d and peer effects as below:

$$q_d = \overline{q} + \underbrace{\left[c_0 \exp\left(-\frac{c_1 N^u_d}{N^s_d} \right) \right]}_{peer\ effect} e^{c_2}_d, \tag{16}$$

where $\overline{q} > 0$ is the minimum quality of education provided in any district, $c_0 > 0$, $c_1 > 0$, $0 < c_2 < 1$, and $\exp(\cdot)$ is the exponential function with base $e \approx 2.71828$. School quality is strictly concave in per pupil public spending which implies q_d rises at a decreasing rate as e_d rises. The term in brackets in (16) captures the peer effect which is found to affect school quality significantly by several studies such as Nechyba (2006), Soetevent (2006), and Sacerdote (2011). Therefore, in our formulation (16), peer effect rises with the population of skilled households and falls with the population of unskilled households which is similar to Benabou (1993).

2.7 Majority Voting

The residential property tax rate (τ_d) is determined through majority voting among the residents of district d. When voting, residents ignore the effect of their vote on aggregate variables such as land prices and the spatial distribution of different household types. Such voter myopia is common in the literature: Epple et al. (1984) and Epple et al. (1993). However, residents take into consideration the effect of their vote on per pupil public spending which they perceive as a direct measure of school quality. More formally, the preferred tax rate of household i living in district d location r and working in the business district j solves the following problem:

$$\max_{\tau_d^i} V_{d,j}^i(r) = \frac{k_i}{(1+\tau_d^i)^{\eta_i}(1+\upsilon)^{\gamma_i} w_{i,j}^{\delta}} \frac{\widetilde{q}_d^{\alpha_i} Y_i^*(r_j(r))^{\eta_i+\gamma_i+\delta}}{R_d^*(r)^{\eta_i}}.$$

$$s.t. \qquad \widetilde{q}_d = e_d,$$

$$e_d = \frac{\int_{\Psi_d^*(r) > \overline{\Psi}_g} \tau_d R_d^*(r) \pi r dr}{N_d}.$$

If $\eta_i > \alpha_i > 0$ for each i, then $V_{d,j}^i(r)$ is strictly concave for any household type implying single-peaked preferences. The shape of $V_{d,j}^i(r)$ over property tax rate is illustrated in Figure 2. Since preferences are single-peaked, existence of a unique majority voting outcome follows from Black (1948). Taking first order condition implies $\widetilde{\tau}_d^i = \frac{\alpha_i}{\eta_i - \alpha_i}$ which depends only on the type of household $i \in \{s, u\}$.[7] If $\alpha_s > \alpha_u$ and $\eta_s < \eta_u$, then $\widetilde{\tau}^s > \widetilde{\tau}^u$. Thus, in any district, the majority voting outcome would be either $\widetilde{\tau}^s$ or $\widetilde{\tau}^u$. Depending on the comparison of N_d^s and N_d^u, either $\widetilde{\tau}^s$ beats $\widetilde{\tau}^u$ or vice versa in district d. For instance, if $N_d^s > N_d^u$ then $\widetilde{\tau}^s$ is chosen through majority rule in district d.

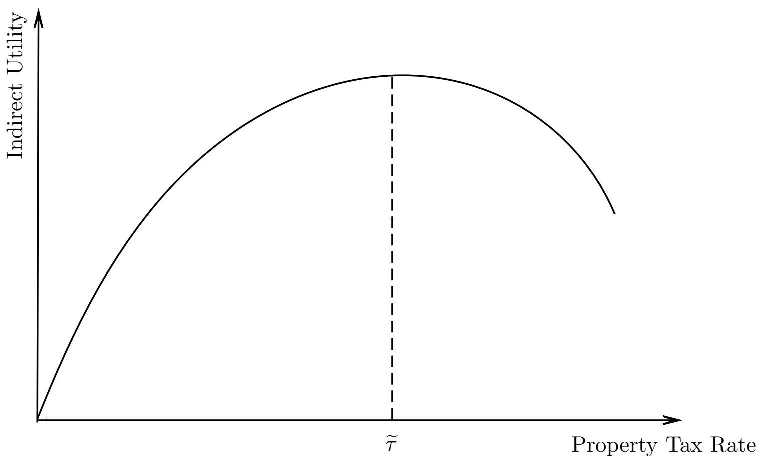

Figure 2: Single-peaked preferences

The timing of events is as follows in our model. In the current period, households make their school district, residential, workplace, consumption, and leisure choices taking as given the education and property tax packages. Then majority voting takes place. If the majority voting outcome differs from what households took as given, then households update their expectations and make their choices again. This process continues until majority voting outcome coincides with what households

[7]We suppress district subscript from preferred tax rate since it is independent of district.

expected at the time of decision making.

Definition 1. *A spatial equilibrium is a set of utility levels $\overline{u}_i^*$ for each $i \in \{s, u\}$, market house rent and land rent functions $(R_d^*(r), \Psi_d^*(r))$ for each $d \in \{w, n, e\}$, school quality and property tax rate pairs (q_d, τ_d) for each $d \in \{w, n, e\}$, and equilibrium type functions $\theta_d^*(r)$ for each $d \in \{w, n, e\}$ such that:*

- *Given $R_d^*(r)$ and (q_d, τ_d), households solve problems* (3) *and* (8).
- *Perfectly competitive housing construction firms solve the profit maximization problem* (11).
- *$\Psi_d^*(r)$ is determined in the land auction held by absentee landlords in each district d location r and land goes to the highest bidder. $R_d^*(r)$ is then determined by the zero profit condition of house construction firms.*
- *Identical households get the same utility independent of their districts, locations, and workplaces.*
- *The city is closed. Land market clears in each district d location r. Thus, population constraint* (14) *holds for each $i \in \{s, u\}$.*
- *τ_d is determined through majority voting and q_d is given by* (16).
- *The budget constraint* (15) *of city government for public transportation is balanced.*

3 Calibration

We calibrate the parameters of our model to match certain characteristics of an average U.S. city in 2018. Table 1 reports the calibrated values of parameters. We find the values of some of the parameters directly from data which are listed below:

- We set $\overline{r} = 5$ miles following Glaeser and Kahn (2004). Also, we set $\overline{r}_w = 6$ miles to clearly see the capitalization of local education quality on house rents.[8]
- To calibrate the hourly wages at central business district ($w_{u,cbd}$, $w_{s,cbd}$), we use median annual earnings data for high school (unskilled) and college (skilled) graduates in 2018 which are $37,960 and $62,296 respectively. Moreover, both high school and college graduates supplied around 40 hours of labor per week in 2018.[9] Combining these information implies $w_{u,cbd} \approx 18$ and $w_{s,cbd} \approx 30$. The hourly wages at the suburban business district is 6% less than those at the central business district following Ihlanfeldt (1992).

[8]We tried other values for $\overline{r}_w$ and results were similar.

[9]Labor supply data is obtained from Current Population Survey which is the main source of data used in calibration.

- Since both household types are assumed to work 40 hours per week, then,

$$\frac{\delta}{\eta_i + \gamma_i + \delta} = \delta = 1 - \frac{40w_i}{24 \times 7 \times w_i} \approx 0.76.$$

  We set since $\eta_i + \gamma_i + \delta = 1$ for any household i which implies $\eta_i + \gamma_i = 0.24$. Also, according to Consumer Expenditure Survey data, in 2018, 24% of earnings is spent on housing (shelter only) by a consumer with an annual income less than \$30,000 (unskilled). Then $\frac{\eta_u}{\eta_u+\gamma_u} \approx 0.24$ which combined with $\eta_i + \gamma_i = 0.24$ implies budget shares of housing expenditures and numeraire consumption goods for an unskilled household to be $\eta_u = 0.059$ and $\gamma_u = 0.181$, respectively. To find an unskilled household's valuation of education quality parameter α_u, we use our finding that $\tilde{\tau}^u = \frac{\alpha_u}{\eta_u - \alpha_u}$. Based on data, we set the preferred annual property tax rate of an unskilled household to be 1%, assuming 2% real interest rate.[10] Thus $\alpha_u = 0.02$.

- In 2019, the average fixed cost of commuting with a brand new automobile was around \$16.3 per day whereas the average variable cost was 39 cents per round trip mile.[11] Assuming an unskilled household rides an older automobile compared to a skilled household, we set $f_u^a = 14.7$, $f_s^a = 18.9$, $c_u^a = 0.89$, and $c_s^a = 0.44$. We assume fixed cost of transportation by bus is \$3 per mile since in the 2019 data, adult single-trip bus base fares for major metropolitan areas ranged between \$0.5 in Blacksburg, VA and \$9.2 in Woolbridge, VA.[12] Thus, we set $f^b = 2 \times \$3 = \$6$ per round trip mile. To calibrate time cost of commuting parameters, we assume an average commute speed by bus to be 11 mph, an average commute speed by automobile to the CBD be 25 mph and to SBD be 35 mph.[13] Based on this, we set $t_{cbd}^a = 0.08$, $t_{sbd}^a = 0.057$, and $t^b = 0.18$ hours per round trip mile.

- We set the fraction of skilled households to 35% which corresponds to the fraction with bachelor's degree or more among 25 years and older households in 2018. Thus, the fraction of unskilled households is 65%. Moreover, we set the city population in our model to be 2,000,000 households.

  We calibrate the remaining parameters of our model so as to match the following targets as close as possible.

- In our model, as the variable cost per mile of bus transportation rises, the fraction of bus commuters falls. Therefore, we pick the value of c^b to be 1.83 so that the resulting fraction of

[10] According to American Community Survey 2019, the median effective property tax rates varied from 0.27% to in Hawaii to 2.47% in New Jersey in 2018. The property tax rates are measured out of house values.

[11] For detailed information about the average variable cost of operating a brand new automobile 15,000 miles per year, please see Your Driving Costs; American Automobile Association, 2019.

[12] Source: The Public Transportation Fare Database, American Public Transportation Association.

[13] The average commuting speeds by automobile and by bus were 27.08 mph and 11.63 mph around 2019, respectively. Source: Summary of Travel Trends: National Household Travel Survey.

households that commute by bus is around 10%.[14]

- We choose the parameters of the education production function so as to match quality of education and degree of interaction between peer effect and educational spending targets. Thus, we obtain $\overline{q} = 8$, $c_0 = 0.69$, $c_1 = 0.006$, and $c_2 = 0.86$.

- We set the farmers' bid for land, $\overline{\Psi}_g$, to be \$18,200 per square mile per day so as to match a population density of approximately 3,406 households per square mile.[15] The resulting urban fringe distance, r_{gd}, is around 12 miles in the west school district and 15 miles in the east school district.

- We choose the value of η_s (the budget share of housing for skilled households) to be 0.046 so as to match income elasticity of lot size demand around 0.45. This implies that a skilled household spends 19.2% of earnings on housing which matches the data counterpart of 18% for households with annual income greater than \$70,000.[16] Moreover, given the above value of η_s, we set the value of $\alpha_s = 0.025$ so as to match a preferred tax rate of around 2.38% for a skilled household. Also, since $\eta_s + \gamma_s + \delta = 1$, then $\gamma_s = 0.194$.

- We set the values of house production parameters to be $A = 0.01$ and $b = 0.35$ so as to match house size-lot size ratio of approximately 0.25 at the fringe and approximately 0.5 around the central business district.

- In the data, the ratio of total fares collected to total operating expenses of running public transportation system is 36.1% in 2018.[17] So, we set the marginal cost parameter $\overline{c} = 26.6$ such that the model implied ratio of total fares to total variable cost is 36%. Moreover, in the data, total operating expenses account for 70% of total cost of running public transportation system. To match this fraction, we set $\overline{C}_k = \$2,402,908$ per day in our model. Moreover, we set consumption sales tax rate $\upsilon = 4\%$ so that the city budget for public transportation is balanced.

4 Benchmark Equilibrium

In this section, we describe the characteristics of benchmark equilibrium. Figure 3 shows gross market house rent and the spatial ordering of households in each school district. In the east school

[14]More precisely, the fraction of population who works within metropolitan area boundaries and commute by public transit was 10.9% around 2010. Source: American Community Survey.

[15]The median population per square mile is 3,544 in cities with population between 1,000,000 and 2,000,000. Source: County and City Data Book, 2007.

[16]Source: Consumer Expenditure Survey 2018, Bureau of Labor Statistics.

[17]Source: Public Transportation Fact Book, 2020.

Parameter	Value	Parameter	Value
$\overline{r}$	5	$\overline{r}_w$	6
$w_{u,cbd}$	18	$w_{s,cbd}$	30
δ	0.76	η_u	0.059
γ_u	0.181	α_u	0.02
f_u^a	14.7	f_s^a	18.9
c_u^a	0.89	c_s^a	0.44
f^b	6	c^b	1.83
t_{cbd}^a	0.08	t_{sbd}^a	0.057
t^b	0.18	c_0	0.69
c_1	0.006	c_2	0.86
$\overline{q}$	8	α_s	0.025
$\overline{\Psi}_g$	18,200	η_s	0.046
γ_s	0.194	A	0.01
b	0.35	$\overline{c}$	26.6
υ	4%	$\overline{C}_k$	2,402,908

Table 1: Calibrated parameter values

district, households that live at locations less than 3.7 miles work in the CBD and their rent payments increase as distance to from home to CBD decreases. This is expected since accessibility capitalizes into house rents. Moreover, in the east district, households that live at locations above 3.7 miles work in the SBD and they pay higher rents as distance from home to SBD falls which is again because of capitalization of accessibility into house rents. This explains also the behavior of house rents in the inner city and west school districts. House rent monotonically decreases over distance in the west school district since all households work in the SBD. On the other hand, house rent is not monotonic in the inner city and east school districts since CBD workers and SBD workers coexist in these districts. We also see that house rent jumps as one crosses the boundary between inner city and west school districts. This is because higher quality of education in the west school district capitalizes into house rents. Figure 3 also shows the spatial ordering of households which is determined by the comparison of the steepness of land bid-rents as explained above. There are three factors that determine the steepness of land bid-rents: i) income, ii) budget share of housing, iii) marginal commuting cost. Compared to an unskilled household, the first factor pushes a skilled household away from any business district (since $w_{s,j} > w_{u,j}$) whereas the second factor pulls a skilled household closer to any business district (since $\eta_u > \eta_s$). Moreover, for any two household working in the same business district, the one with higher marginal commuting cost is pulled closer to the business district.

For instance, in the inner city and east school districts, skilled households commuting by bus is located closer to CBD than unskilled households commuting by bus. In this case, the pull force (because of lower budget share of housing) towards CBD for skilled households quantitatively dom-

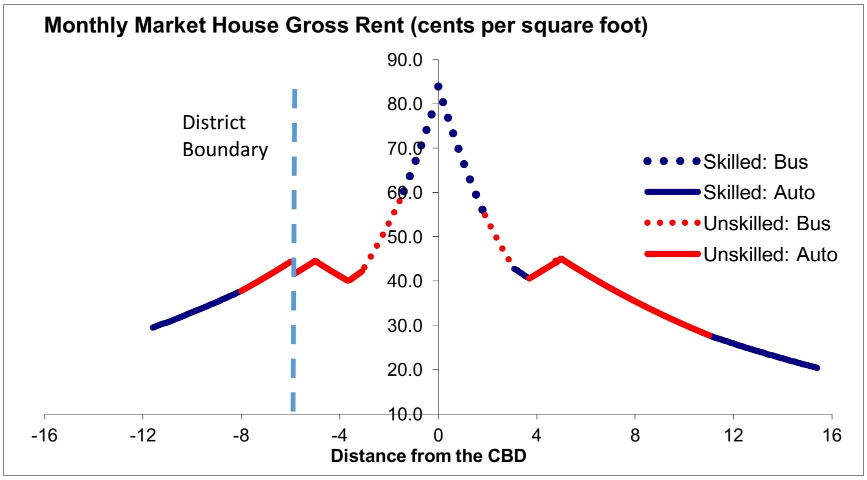

Figure 3: Monthly market house gross rent

inates the push force (because of higher income) away from CBD so that skilled households using bus locates closer to CBD than unskilled households using bus.

As another example, we also see from Figure 3 that in the east school district, skilled households using bus locates closer to CBD than skilled households using automobile where both work in the CBD. This is simply because marginal commuting cost by bus is higher than automobile.

Figure 3 also shows that all households working in the SBD in any district commute by automobile in equilibrium whereas most of the households working in the CBD commute by bus. Only in the east school district, we find skilled households working in the CBD who commute by automobile. Compared to unskilled households working in the CBD and using bus in the east district, these skilled households using bus are located farther away from CBD since their income is higher and marginal commuting cost is lower although they have lower budget share of housing.

We also find that an unskilled household working in the CBD uses bus if her home is located less than 2.9 miles. This cutoff is 1.9 for skilled households working in the CBD. This cutoff is smaller for skilled households since their wages are higher than unskilled households.

Figure 4 shows house size for each type of household. As seen, house size does not monotonically increase with distance although the trend is upward sloping. In our model's equilibrium, there exists skilled households living in downtown with houses which is consistent with data. As seen in Table 2, the quality of education, efficiency of education (peer effect), and per pupil public expenditure are highest in the west school district and lowest in the inner city school district. This is expected since skilled households constitute 59%, 8%, 33.1% of west, inner city, and east school districts respectively as seen in Table 3. Moreover, the equilibrium property tax rate in the west school district coincides with the preferred tax rate of skilled households since skilled households are majority there. With similar line of reasoning, the preferred tax rate of unskilled households is the equilibrium property

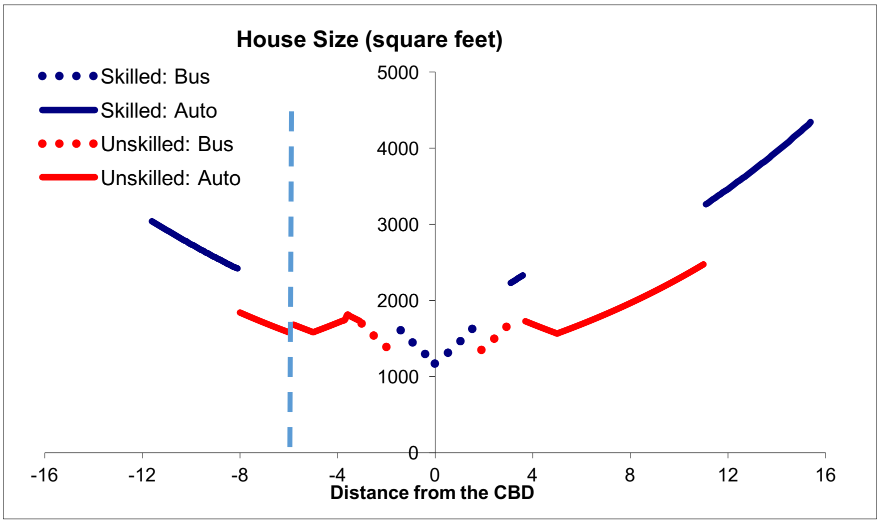

Figure 4: House size

	West	Inner City	East
Quality of Education	15	12	12.4
Property Tax Rate	2.38%	1.04%	1.04%
Peer Effect	5.76	5.65	5.74
Public Expenditure Per Pupil	5416	3057	3189
Average Rent	35.6	45.7	31.8

Table 2: District characteristics

tax rate in the inner city and east school districts. All households living in the west school district work in the SBD and commute by automobile. In the inner city school district, 40.8% of households work in the CBD out of which 78.2% commute by bus and 79.7% are unskilled. The remaining households (59.1%) in the inner city school district work in the SBD, commute by automobile, and they are all unskilled. In the east school district, 10.8% of households work in the CBD out of which 80% commute by bus and 49.2% are unskilled. The remaining households (89.1%) in the east school district work in the SBD out of which 68.9% are unskilled and they all commute by automobile. Moreover, Figure 5 shows the fraction of each group out of all households in the population across the districts. For instance, Figure 5 shows that 16.5% of all households in the city are skilled, live in the east school district, work in the SBD, and commute by automobile. From the Figure 5, we see that a majority of unskilled and skilled households working in the SBD and commuting by automobile live in the east school district.

	West	Inner City	East
Unskilled	40.99%	91.97%	66.81%
Skilled	59.01%	8.03%	33.19%

Table 3: Population distribution

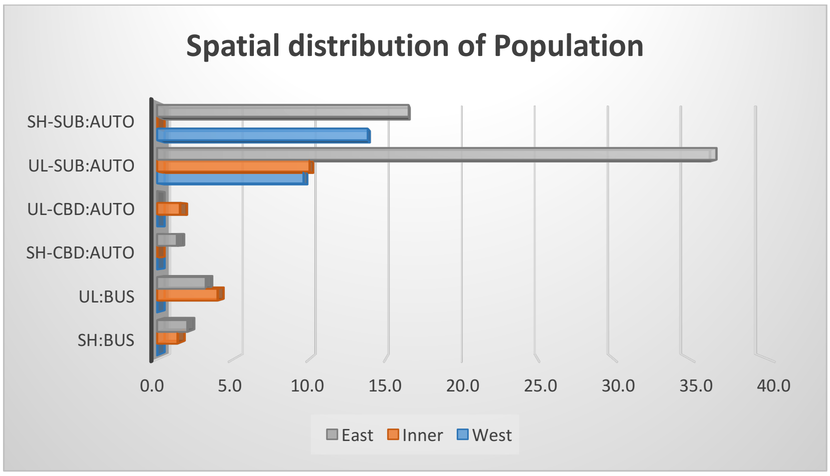

Figure 5: Spatial distribution of population

5 Policy Experiments

In the U.S., affordable housing has historically been a major policy concern. Government has enacted several policies such as Experimental Housing Assistance, Moving to Opportunity for Fair Housing, and Welfare-to-Work Voucher programs in order to eliminate poverty concentration in inner cities. However, as noted in Blumenberg et al. (2014) and Blumenberg et al. (2015), these affordable housing programs were not able to achieve the intended consequences because of ignoring spatial accessibility problems faced by poor households.

Motivated by these, in this section we analyze the impact of two separate public policies (housing vouchers and transportation vouchers) on poverty reduction in the inner city school district. In the benchmark equilibrium of our model, there is substantial concentration of poverty in the inner city district since 91.9% of its population consists of unskilled workers. Thus, our model's benchmark is a reasonable starting point for analyzing these public policies. Our benchmark provides an understanding of why those unskilled households reside in the school district with the worst education quality and whether those households do not have access to jobs at the suburban ring.

We assume the cost of both housing and transportation vouchers are financed through taxing incomes of all households where income tax rate is uniform across households. Income taxation distorts labor supply decisions of households. Moreover, only unskilled households living in the inner city district are eligible for both types of vouchers.

5.1 Housing Vouchers

In this section, we analyze the impact of a uniform housing voucher towards rent at the amount o^h dollars per unskilled household that reside in the inner city district at the benchmark equilibrium. Thus, the number of voucher recipients is exogenously given. The income tax rate (τ^h) adjusts so as to balance government's budget for housing vouchers:

$$O^h = \tau^h W^h$$

where O^h is the total housing voucher spending and W^h is the total gross income in the economy under voucher policy. Thus, the right hand side is the total income tax revenue.

The new budget constraint for a non-voucher recipient is same as (2) except that right hand side is now $(1-\tau^h)W^i_{d,j}(r,m)$ so that gross income is reduced by the amount of income tax. Moreover, for a voucher recipient, the new budget constraint is as below:

$$(1+\upsilon)z^i_{d,j}(r) + \max\{0, (1+\tau_d)R^*_d(r)h^i_{d,j}(r) - o^h\} + f^m_i + c^m_i r_j(r) = (1-\tau^h)W^i_{d,j}(r,m).$$

Thus, a voucher recipient's housing expenditure is reduced by the voucher amount. Also, for any voucher recipient, the housing expenditure will not be less than the voucher amount since higher housing expenditure implies higher utility.

We next numerically study the implications of a housing voucher worth of \$300 per month which corresponds to approximately 33% of average housing expenditure of unskilled households in the east school district.[18] The proportion of unskilled households who receive vouchers constitutes 23.8% of all unskilled households. The income tax rate required to finance voucher expenditures is 1.2%.

We find that housing voucher causes migration of unskilled households from inner city district to east district. Out of all unskilled households, the percentage that lives in each district under benchmark and voucher experiment is reported in Table 4. As seen there, as a result of housing voucher, approximately 3% of unskilled households move from inner city (a fall from 23.8% to 20.9%) to east district (a rise from 61.3% to 64.3%). This migration flow does not benefit unskilled households at all in terms of accessing better quality education since education quality is slightly better in the east school district than the inner city district as shown in Figure 7. This is consistent with the empirical findings of Blumenberg et al. (2014).

The recipients of housing vouchers locate farther away from the CBD compared to other unskilled households without vouchers. As seen in Figure 6, unskilled voucher recipients commuting by automobile to SBD locate in the area between the semi-rings with radius 8.41 and 11.38 miles from CBD

[18]Our results are robust to different voucher amounts.

	West	Inner City	East
Benchmark	14.79%	23.83%	61.38%
Housing Voucher	14.73%	20.94%	64.33%
Transportation Voucher	5.26%	17.1%	77.63%

Table 4: Distribution of unskilled households across districts

whereas non-voucher recipient unskilled households commuting by automobile to SBD locate in the area between the semi-rings with radius between 3.68 and 8.41 miles from CBD. This is because the voucher recipients experience a rise in income which causes their bid-rent curves to become flatter and as a result they locate farther away from CBD. However, the voucher amount is not high enough to induce unskilled voucher recipients to locate even farther away compared to skilled households commuting by automobile to SBD.

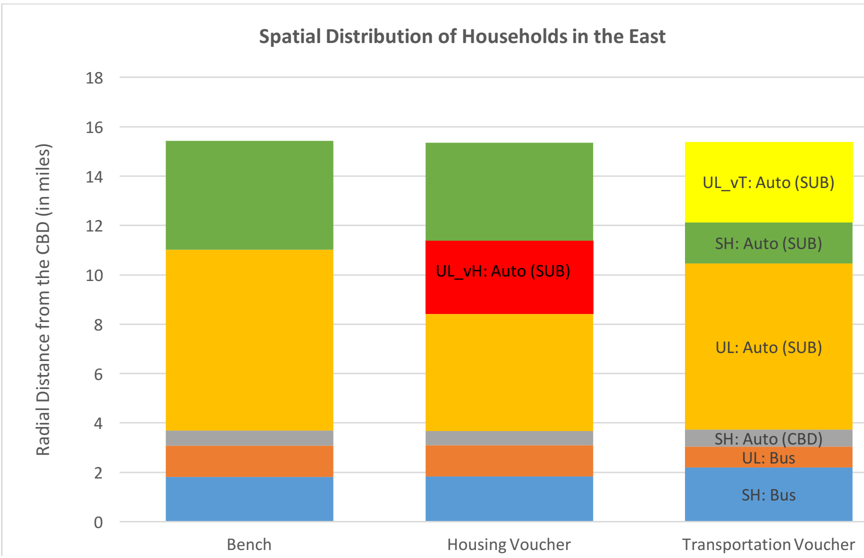

Figure 6: Spatial distribution of households in the east school district

Housing voucher would have been successful in terms of providing access to better quality education if a significant population of unskilled households had moved to west school district instead of east. Moreover, as we see from Figure 8, the voucher recipients that move to east school district, work in the SBD, and commute by automobile. So housing vouchers improve access to suburban jobs for the unskilled. Furthermore, after housing voucher, unskilled households living in the inner city district, working in the CBD, and commuting by automobile disappears and they are replaced by skilled households, working in the CBD, and commuting by automobile. This causes an increase in the quality of education and a decrease in the concentration of poverty in the inner city district. On the other hand, in the east district, the population of skilled households working in the SBD commuting by automobile falls after housing vouchers.

According to spatial mismatch hypothesis due to Kain (1968), poor households are bound to jobs

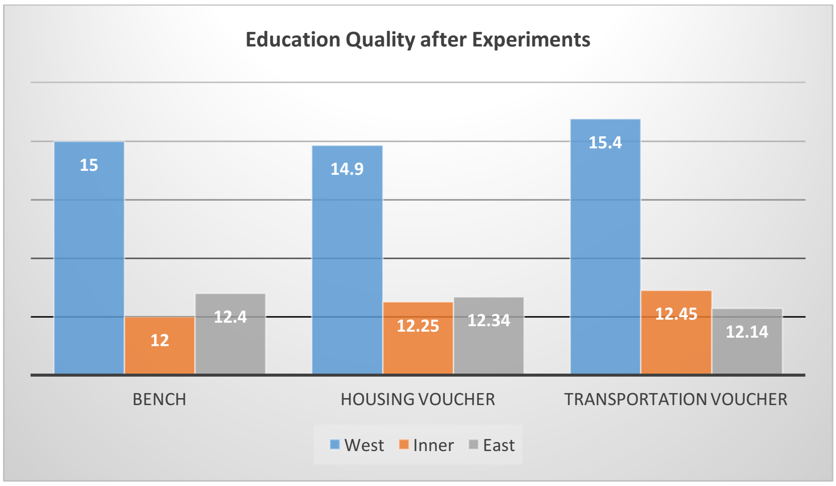

Figure 7: Education quality after experiments

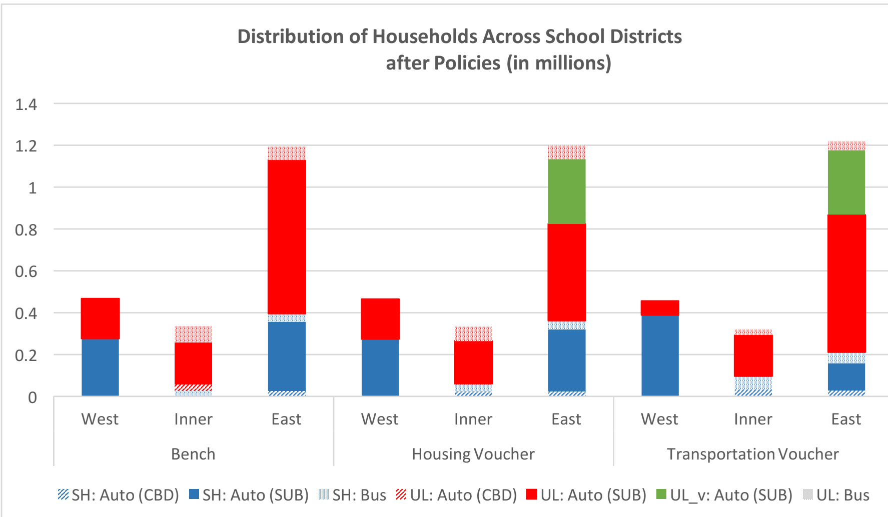

Figure 8: Distribution of households across school districts

in the city center although there is demand for unskilled labor in the suburban business district. One possible reason is that poor households are outbid by rich households in the suburban land market so that they are not able to rent a house there. In the context of our housing voucher experiment, we therefore study whether this policy enables unskilled households to find employment in the suburban business district. As shown in Figure 8, the unskilled household population working in the SBD does not change at all in the west district after policy. Thus, we concentrate on inner city and east districts. Table 5 shows for the inner city district, the percentage distribution of unskilled households across employment centers under benchmark and housing vouchers. Out of all unskilled households living in the inner city district, the percentage working in the suburban business district rises from 64.6% to 74.5% after housing vouchers are distributed. For the east district, we see a rise from 91.9%

	Inner City	East	Economy-wide
Benchmark	64.62%	91.97%	86.64%
Housing Voucher	74.58%	92.2%	89.66%
Transportation Voucher	87.89%	95.76%	94.64%

Table 5: Fraction of unskilled households employed in the SBD

	Benchmark	Housing Voucher	Transportation Voucher
Unskilled	11.04%	10.3%	5.36%
Skilled	9.56%	11.3%	16.96%

Table 6: Bus ridership

to 92.2%. Housing voucher also increases the economy-wide percentage of unskilled suburban workers (out of all unskilled households) from 86.6% to 89.6%. Therefore, we conclude that housing voucher policy increases suburban employment among unskilled workers although the increase is modest.

The rise in the fraction of unskilled households working in the SBD causes a decrease in the usage of public transportation among unskilled households after housing vouchers. This is because public transportation is not available for commuting to the SBD. As seen in Table 6, the economy-wide fraction of unskilled households riding bus (out of all unskilled households) decreases from 11% to 10.3%. Moreover, for the skilled households the fraction riding bus increases from 9.5% to 11.3%. This is consistent with our finding that the economy-wide fraction of skilled households employed in the CBD (out of all skilled households) increases from 13.3% to 18.4% after housing vouchers.

As noted earlier, several governmental policies were enacted in U.S. to reduce concentration of poverty in the inner cities. Based on our housing voucher experiment, we find that the fraction of unskilled households out of all households living in the inner city district, decreases from 91.9% to 81.3% whereas it increases from 66.8% to 69.7% in the east district. For the west district, there is small increase as seen in Table 7. Thus, we conclude that housing vouchers create more heterogeneous communities although there still exists significant poverty concentration in the inner city district.

We next analyze the welfare changes for each household type keeping in mind that identical households receive the same utility in equilibrium. As in Cooley and Hansen (1992), we measure welfare change as the percentage change in benchmark consumption so that household is equally better off as in the case of housing vouchers. If the required change in consumption is positive, then

	West	Inner City	East
Benchmark	40.99%	91.97%	66.81%
Housing Voucher	41.09%	81.33%	69.72%
Transportation Voucher	14.94%	69.39%	82.65%

Table 7: Fraction of unskilled households in each district

	Housing Voucher	Transportation Voucher
Unskilled without voucher	-1.5%	-0.2%
Skilled	-1.3%	-0.4%
Unskilled with voucher	13.3%	7.3%

Table 8: Percentage change in welfare compared to benchmark

household is better off under housing voucher policy. The results are reported in Table 8. Welfare losses for unskilled households without vouchers and skilled households are 1.5% and 1.3% respectively whereas unskilled households receiving vouchers welfare gain is 13.3%. This is expected since housing voucher redistributes income by taking away from unskilled households without vouchers and skilled households and giving it to unskilled households with vouchers. Moreover, unskilled households not receiving vouchers lose more welfare compared to skilled households. This is because marginal disutility of losing one unit of consumption is higher for the unskilled following the diminishing marginal utility principle.

5.2 Transportation Vouchers

In this section, we analyze transportation voucher policy as an alternative for improving the living conditions of unskilled workers in the inner city district. Only unskilled households residing in the inner city district at benchmark are eligible for transportation vouchers. Transportation vouchers can be used for both commuting by bus and automobile. More specifically, an unskilled household working in the business district j and living at location r receives κ fraction of the commuting cost by automobile in the form of transportation voucher. Formally, the transportation voucher $(o_j^t(r))$ received by an unskilled household can be expressed as below:

$$o_j^t(r) = \kappa \left(f_u^a + \left(c_u^a + t_j^a w_{u,j} \right) r_j(r) \right).$$

As a result, household's income net of commuting cost increases by the amount of voucher and the voucher received depends on the distance between home and work which implies different households receive different voucher payments. The larger the distance the bigger the face value of voucher is. Once again, total voucher spending (O^t) is financed by income taxation where income tax rate (τ^t) adjusts so as to balance government's budget constraint:

$$O^t = \tau^t W^t,$$

where W^t is the economy-wide total gross income. Once again income taxes are distortionary.

In our numerical analysis, we set $\kappa = 0.2$ so that 20% of total automobile commuting cost of an unskilled household is paid by government as a voucher.[19] The resulting income tax rate is $\tau^t = 0.7\%$. Moreover, transportation voucher recipients constitute 23.8% of all unskilled households.

After transportation vouchers, we find that unskilled households living in the west and inner city districts move to east district. As reported in Table 4, out of all unskilled households, the percentage living in the west and inner city districts fall by approximately 9.6% and 6.7% respectively whereas the percentage living in the east district rises by the sum 16.3%. The rise in the population of unskilled households in the east school district causes education quality to decrease there. The resulting quality of education in the east district is lowest among all districts as seen in Figure 7. Thus, the unskilled migrants are hurt in terms of accessing better education quality. Similar to housing vouchers, the transportation voucher recipients that move to east district work in the SBD and commute by automobile as seen in Figure 8. Moreover, in the inner city district, similar to housing vouchers the unskilled households working in the CBD commuting by automobile are replaced with skilled households working in the CBD commuting by automobile. On the other hand, in the east district, the population of skilled household working in the SBD commuting by automobile falls much more compared to housing vouchers.

Transportation voucher decreases the marginal commuting cost of recipients. This causes bid-rent curves of unskilled voucher recipients to become flatter and thus they locate farther away from the CBD compared to other unskilled households without vouchers. Thus, voucher recipients benefit from lower rents and bigger houses. As seen in Figure 6, unskilled voucher recipients commuting by automobile to SBD locate in the area between the semi-rings with radius 12.1 and 15.4 miles from CBD whereas non-voucher recipient unskilled households commuting by automobile to SBD locate in the area between the semi-rings with radius between 3.7 and 10.5 miles from CBD. Moreover, the unskilled voucher recipients reside even farther away compared to skilled households commuting by automobile to SBD. Thus, we infer that the push force caused by lower marginal commuting cost for unskilled voucher recipients is even stronger than the pull force caused by lower income compared to those skilled households. Furthermore, from Figure 6, we also see that unskilled transportation voucher recipients reside further away from CBD compared to unskilled housing voucher recipients.

One possible reason of spatial mismatch in the labor market is that traveling to employment centers located in the suburbs is costly for unskilled workers. Motivated by this, we analyze whether transportation voucher policy improves the employment of unskilled workers in the SBD. All of the unskilled households residing in the west district are employed in the SBD under both benchmark and transportation vouchers as seen in Figure 8. Then, Table 7 implies that the fraction of unskilled households working in the SBD falls significantly from 40.9% to 14.9% in the west district. In the inner city district, out of all unskilled households living there, the fraction working in the SBD rises

[19] We experimented with different voucher amounts and our results are similar.

from 64.6% to 87.8% as seen in Table 5. Moreover, in the east district, the fraction of unskilled SBD workers rises from 91.9% to 95.7%. For the city as a whole, the fraction of unskilled SBD workers (out of all unskilled workers) rises from 86.6% to 94.6%. Compared to housing vouchers, transportation voucher policy is more effective in terms of increasing unskilled worker employment in the SBD.

After transportation vouchers, public transportation usage decreases among unskilled households. This is because the fraction of unskilled households working in the SBD rises and public transportation is not available for commuting to the SBD. As seen in Table 6, the economy-wide fraction of unskilled households riding bus (out of all unskilled households) decreases from 11% to 5.3% which is a higher decrease compared to housing vouchers. Moreover, for the skilled households the fraction riding bus increases from 9.5% to 16.9% which is a higher increase compared to housing vouchers. This is expected since at the same time the economy-wide fraction of skilled households employed in the CBD (out of all skilled households) increases from 13.3% to 25.7% which is a higher increase compared to housing vouchers.

How about the impact of transportation vouchers on poverty concentration in the inner city district? As seen in Table 7, the fraction of unskilled households in the inner city district falls from 91.9% to 69.3% which implies a significant elimination of poverty concentration in the inner city district compared to housing vouchers. However, in the east district, the fraction of unskilled households rises from 66.8% to 82.6% which is higher compared to housing vouchers. Thus, transportation voucher policy decreases the poverty in the inner city district at the cost of increasing it in the east district. As a result, the educational quality rises in the inner city district and falls in the east district as seen in Figure 7.

In terms of welfare changes, the unskilled households without voucher and skilled households still lose but the loss is less compared to housing voucher policy. Similarly, the unskilled households with voucher still gain but the gain is less compared to housing voucher policy.

Compared to housing voucher policy, unskilled households without voucher and skilled households lose less welfare whereas unskilled households with voucher gain less welfare as seen in Table 8. This is expected since total housing voucher expenditure is more than the total transportation voucher expenditure and hence, more distortionary. More specifically, transportation voucher expenditure is 62% of housing voucher expenditure.

6 Conclusion

In this paper, we studied housing vouchers and transportation vouchers using a hybrid Tiebout model with multiple school districts, multiple business districts, and multiple modes of transportation. Our model combines the local public good model of Tiebout (1956) with urban location theory models of Alonso (1964), Mills (1972), and Muth (1969). We found a higher amount of unskilled worker migration out of inner city district under transportation voucher policy. As found in the empirical literature, the gains in terms of equality in educational opportunity is mediocre with housing vouchers. Housing vouchers affect the spatial ordering of households through income effect while transportation vouchers affect the spatial ordering through marginal cost of commuting. They generate different distortions and must be studied in a general equilibrium model. The migrants are hurt in terms of accessing higher quality of education under transportation voucher policy whereas they reach better quality of education under housing voucher policy. Moreover, transportation voucher policy increases the employment of unskilled workers in the suburban business district more compared to housing voucher policy. Furthermore, transportation voucher policy decreases poverty concentration more in the inner city district at the cost of increasing it more in the east district. Losers lose less welfare and winners gain less welfare under transportation voucher policy since total transportation voucher expenditure is less compared to housing voucher policy.

In our model, we ignored private schools. Existence of private schools may cause rich households to live in poor school districts and send their children to private schools. This may work towards decreasing the concentration of poverty in the inner cities as argued in Nechyba (2000) and Hanushek et al. (2011). In this context, private school voucher policy could also be studied in our model. This is left for future research. Moreover, in our model, we concentrated on the changes in the quality of education ignoring the effect of education on child's future income. For that sake, wages could be endogenized as in Hanushek et al. (2003) and then tax-transfer policies could be analyzed.

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