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Urban Transportation and Inter-Jurisdictional Competition

WP 17-10

Santiago M. Pinto
Federal Reserve Bank of Richmond

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Santiago M. Pinto*

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Abstract

It is well-known that competition for factors of production, including competition for residents, affects the public services provided in the communities. This paper considers the determination of local investment in urban transport systems. Many specialists question the effectiveness of the current U.S. top-to-bottom transportation institutional arrangement in which the federal government plays a dominant role and recommend a shift toward a decentralized organization. We examine how such a shift would affect the levels of transport investment. Specifically, we consider a model of two cities, and assume, as in Brueckner and Selod (2006), that transport systems are characterized by different time and money costs. We compare the outcomes reached when the transport system is decided by a central authority (a state or federal government) to the one decided by each jurisdiction in a decentralized way. In the latter case, city or local transportation authorities choose the system that maximizes residents' welfare, taking as given the decisions made elsewhere, essentially competing for residents (or workers). Our analysis shows that even though a shift toward a decentralized arrangement of the transportation system would generally lead to overinvestment (relative to the centralized case), the extent of this bias depends on the specific factors that drive transport authorities in deciding the transportation system, on the landownership structure, and on the financing arrangements in place. The paper also shows that, in a more general setup, when the two cities differ in their productivity levels, the more productive city will tend to overinvest in transportation systems that connect the two cities, and the less productive city will tend to underinvest in those systems.

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1 Introduction

In the U.S., investment in transportation infrastructure is decided through a complicated process that involves the participation of different levels of government, in addition to regional and local administrative units. This multilayer decision-making process is partly explained by the fact that the transportation network serves multiple purposes. First, within a region, the transportation network connects residential areas with employment centers or central business districts (CBD). Second, the transportation network connects cities and regions. And third, commuting patterns frequently entail residents crossing city and even state political boundaries. In such context, funding and other decisions concerning the design and organization of the transportation system becomes extremely challenging. The decision-making process, at least in U.S., has typically been structured from the "top" to the "bottom."

Fifty years ago, when the interstate highway program was developed, federal government involvement in transportation investment decisions was considered a priority. More recently, and partly due to the federal government's financial struggles, the entire organization of the transportation system has been under scrutiny.[1] All this has spurred a fruitful academic discussion about the role the federal government should play in such decisions. This paper aims at contributing to this discussion.[2]

Some people advocate for switching from a transportation system in which decisions are predominantly made by a central transport authority to one that grants local jurisdictions greater responsibilities.[3] Some other researchers, however, suggest that decentralization leads to higher transportation expenditures. Estache and Humplick (1994), for instance, examine the impact of decentralization on transportation infrastruc-

[1] The United States Highway Trust Fund (HTF) is a federal fund that finances different transportation programs. The HTF receives money from a tax on fuels collected by the federal government. Currently, the HTF is undergoing severe solvency problems and its future is uncertain. In general, federal funding has been declining as a percentage of total investment in transportation. To compensate for the federal government struggling, some cities and states have recently passed referendums that allow them to raise local taxes to fund improvements in their transportation networks.

[2] See the article by Jaffe (2013) for a summary of the different points of view.

[3] For instance, Glaeser (2012) calls for the "defederalization" of the transportation system. Glaeser suggests that if states are granted the responsibility of financing their own transportation infrastructure, they would internalize the costs of their decisions and spend less and more efficiently. He states:

> *"Most forms of transport infrastructure overwhelmingly serve the residents of a single state. Yet the federal government has played an outsized role in funding transportation for 50 years. Whenever the person paying isn't the person who benefits, there will always be a push for more largesse and little check on spending efficiency."*

ture spending on a number of developed countries. They conclude that decentralization increases, so does local infrastructure spending. They suggest that such outcome could be attributed to the fact that choices made by local jurisdictions tend to differ both in quality and quantity from the choices made by the central government. Decentralization also creates other opportunities such as the design of transportation systems tailored to local needs and the development of new and diverse transportation alternatives.

Those who support a leading role for the federal government in transport investment decisions claim that if the transport system is “defederalized," states would tend to underinvest in their segments of the national highway or rail systems. It has also been argued that states would need to resort to increasingly distortive taxes to fund their transportation networks, and the burden of such measures tend to disproportionately fall on low-income residents.

The present paper theoretically examines the economic implications of shifting from an institutional arrangement in which transportation decisions are made in a centralized way (by a national or a state agency), to another that gives a more preponderant role to local or regional agencies. The impact of such reorganization is analyzed in the context of an urban equilibrium model with multiple employment centers or CBDs in which individuals simultaneously decide their residential location and where to work. Commuting to work involves both a money cost and a time cost. We assume that CBDs can choose from a variety of transportation networks, each one offering residents the possibility of commuting at different speeds (or different time transportation costs) and money transportation costs. This characterization of the transport system is similar to the one developed by Brueckner and Selod (2006). The key trade-off faced by transportation authorities is that faster transportation systems that reduce commuting time costs would also require residents to pay higher money costs.

In the present paper, the choice of the transportation system is endogenous. We separate the analysis in two parts. In the first part of the paper, we develop a framework that characterizes in a very stylized way the transit and transportation decisions made by certain local or regional transport authorities. There are numerous examples of such local authorities in the U.S., including the Regional Transportation Authority (RTA) and the Chicago Transit Authority (CTA) in Illinois, the Metropolitan Transportation Authority

(MTA) in New York, and the Jacksonville Transportation Authority (JTA) in Florida. These agencies are responsible for making several decisions regarding the local transportation system, including the scope and density of the transportation network, buses or trains frequency, and they may also even be in charge of expanding or constructing new highways.

We begin by studying the outcomes of a decentralized system where regional transportation authorities make their decisions individually and determine conditions under which those outcomes depart from a central arrangement. We also examine how the solutions differ when a region is more productive than another one. A key element in our analysis is that decentralization induces local authorities to behave strategically. We compare the equilibria reached in the centralized and decentralized arrangements assuming that authorities choose their transportation systems following two alternative objectives. First, we assume that the corresponding authorities maximize the city surplus measured as the difference between total production and total transportation costs. Second, we assume they maximize total consumption. In this latter case, we compare the solutions when land rents accrue to an absentee landlord (absentee landlord model) and when residents own the land. Moreover, we evaluate the effects of relying on alternative mechanisms to finance the expansion of the transportation network.

The second part of the paper examines the implications of assuming that cities belong to exogenously delimited regions, so that the region's transport authorities can only choose the transport system in their respective region. We slightly modify the model developed in the first part of the paper in order to focus on the incentives of regional transportation authorities to invest in transportation within the region or increase connectivity across regions.

2 The Model

We consider a closed, linear urban area that has unit width, represented by the interval $[0, 1]$. There are two employment centers or cities: 0 and 1. The CBD of city 0 (CBD_0 hereafter) is located at 0, while the CBD of city 1 (CBD_1) is located at the other end 1. Distance from CBD_0 is denoted by x, and distance from the CBD_1 by $(1 - x)$. The space is populated by N identical residents, who consume land directly. We assume that land consumption is fixed at one unit, so the urban area is also fixed and $N = 1$. Individuals receive labor income from working at either CBD_0 or CBD_1 and are endowed with an identical share of total land rents. For simplicity, the rent earned by the nonurban land is set equal to zero.

Urban residents derive utility exclusively from the consumption of a composite nonland good, denoted z (in other words, the utility of an urban resident is simply z). Good z is produced at CBD_0 and CBD_1 using a constant-returns technology that only employs labor as an input.[4] The output produced in CBD_i is $y_i L_i$, where $y_i > 0$ and L_i denotes aggregate labor input. The labor market is competitive, so a consumer would earn the wage y_i in CBD_i in the absence of commuting. However, the time spent commuting reduces actual income from y_i. Assuming that leisure time is fixed, an additional minute of commute reduces the time available for work in the same amount.

We follow Brueckner and Selod (2006) in assuming that transport costs have two components: money cost and time cost. The money cost per mile of travel, denoted t, includes construction and operation costs of the transport system. Time cost, on the other hand, depends on the value of time spent commuting. Let ϕ denote the inverse of the transport system's speed. Then, the value of time spent in travel is ϕ multiplied by the wage rate. Transport systems are characterized by different combinations of money and time costs $\{t, \phi\}$, in addition to a fixed cost, which depends both on t and the size of the transportation system. We assume that ϕ is a decreasing function of t. Thus, in choosing the transport system, cities face a trade-off between time and money costs: faster transport systems (low ϕ) are associated with higher costs per mile (large t). Specifically, we assume that this trade-off is continuous and consider that $\phi' < 0$ and $\phi'' > 0$, i.e., time cost decreases with t at a decreasing rate.[5]

A commute of x miles to CBD_0 implies a time cost of $\phi_0 x$, where $\phi_i \equiv \phi(t_i)$. If the time available for work is normalized to 1, then work time for this commuter is $(1 - \phi_0 x)$, and income is reduced to $y_0(1 - \phi_0 x) = y_0 - y_0 \phi_0 x$. This last expression represents income net of time costs after commuting x miles. Specifically, it is the difference between "full

[4]Good z can be traded with the rest of the world at a price normalized to 1.

[5]It is assumed that the speed offered by the transportation system in place is constant across space. In particular, there is no congestion.

income" (y_0) and the value of time lost to commuting ($y_0\phi_0 x$). As a result, the total number of labor hours at CBD_0, L_0, is given by the integral of $(1-\phi_0 x)$ over those agents who commute to CBD_0. In addition, a commute of x miles also entails a money cost of tx. As a result, total transport costs are given by $(y_0\phi + t_0)x$, so disposable income net of transport costs is $y_0 - (y_0\phi_0 + t_0)x$. A similar argument applies for residents commuting to CBD_1.

Setting up a transportation network with speed s_i and length $\bar{x}$ also entails a fixed cost. We assume that fixed costs take the simplest form. Let $K(s_i)$ denote the fixed cost per mile of a network characterized by s_i, with $K'(s_i) > 0$ and $K''(s_i) \geqslant 0$. Since $s_i \equiv s(t_i) = 1/\phi(t_i)$, then $k(t_i) \equiv K[s(t_i)]$, with $k'(t_i) > 0$ and $k''(t_i) \geqslant 0$, and the total fixed cost becomes $F_i \equiv k(t_i)\bar{x}$.[6]

3 Optimal Transport System

Consider as a first step the socially optimal transport system for the two cities. The social planner chooses the values of t_0 and t_1 that maximize the aggregate social surplus $\mathcal{S} = \mathcal{S}_0 + \mathcal{S}_1$. The social surplus of city i, $\mathcal{S}_i$, is defined as total production in CBD_i, given by $y_i N_i$, where N_i denotes the total number of workers commuting to CBD_i, minus total transport costs TTC_i. Let x^* denote the border that separates residents commuting to CBD_0 from residents commuting to CBD_1. The values x^* and $(1-x^*)$ also represent the number of commuters to CBD_0 and CBD_1, respectively. Total transport costs for CBD_i, TTC_i, include total time transport costs, total money commuting costs C_i, and total fixed

[6]Fixed costs include different types of structures such as bridges, overpasses, intersections, drainage facilities, retaining walls, sound walls, etc., and other fixed expenses such as administration costs and the extent of demolition required to expand the network. Regulations may also have an impact on fixed costs. For example, shoulders and medians are generally required to satisfy a specific minimum size. Fixed costs may vary across cities due to physical geographic factors (flat or mountainous terrain, rivers, lakes, etc.). In this latter case, the fixed cost functions defined earlier would include the subindex i, i.e., $K_i(s)$ and $k_i(t_i)$.

costs F_i:

$$\begin{aligned} TTC_0 &= T_0 + C_0 + F_0 \\ &= \int_0^{x^*} y_0\phi(t_0)x dx + \int_0^{x^*} t_0 x dx + k(t_0)x^*, \text{ and} \end{aligned} \tag{1}$$

$$\begin{aligned} TTC_1 &= T_1 + C_1 + F_1 \\ &= \int_{x^*}^1 y_1\phi(t_1)(1-x)dx + \int_{x^*}^1 t_1(1-x)dx + k(t_1)(1-x^*). \end{aligned} \tag{2}$$

Alternatively, $\mathcal{S}_i$ can be written as $y_iL_i - C_i - F_i$, where L_i is defined as the effective amount of labor in CBD_i

$$L_0 = \int_0^{x^*}[1-\phi(t_0)x]dx, \text{ and } L_1 = \int_{x^*}^1[1-\phi(t_1)(1-x)]dx. \tag{3}$$

Substituting these expressions into $\mathcal{S}$ gives

$$\begin{aligned} \mathcal{S} &= \mathcal{S}_0 + \mathcal{S}_1 \\ &= x^*\left\{y_0 - k(t_0) - [y_0\phi(t_0)+t_0]\frac{x^*}{2}\right\} + (1-x^*)\left\{y_1 - k(t_1) - [y_1\phi(t_1)+t_1]\frac{(1-x^*)}{2}\right\} \end{aligned} \tag{4}$$

The following FOCs implicitly define the optimal solutions $\{x^{*O}, t_0^O, t_1^O\}$:[7]

$$\frac{\partial \mathcal{S}}{\partial t_0} \equiv -\left[y_0\phi'(t_0)+1\right]\frac{x^{*2}}{2} - k'(t_0)x^* = 0, \tag{5}$$

$$\frac{\partial \mathcal{S}}{\partial t_1} \equiv -\left[y_1\phi'(t_1)+1\right]\frac{(1-x^*)^2}{2} - k'(t_1)(1-x^*) = 0, \tag{6}$$

$$\begin{aligned} \frac{\partial \mathcal{S}}{\partial x^*} &\equiv [y_0 - k(t_0)] - [y_1 - k(t_1)] + [y_1\phi(t_1)+t_1] \\ &\quad -[y_0\phi(t_0)+t_0+y_1\phi(t_1)+t_1]x^* = 0. \end{aligned} \tag{7}$$

Isolating x^* from (7) gives

$$x^* = \frac{[y_0 - k(t_0)] - [y_1 - k(t_1)] + [y_1\phi(t_1)+t_1]}{[y_0\phi(t_0)+t_0) + (y_1\phi(t_1)+t_1]}. \tag{8}$$

Consider equation (5). Recalling that $\phi' < 0$, the expression $-y_0\phi'(t_0)$ reflects the increase in production (per mile) due to an increase in t_0 . Since individuals working at CBD_0

[7] We assume throughout the entire analysis that the SOCs are always satisfied.

commute $\int_0^{x^*} x dx = x^{*2}/2$ miles, then $-y_0\phi'(t_0)x^{*2}/2$ represents the increase in total production taking place at CBD_0 due to an increase in t_0. At the same time, a higher t_0 increases total transportation costs: a higher t_0 increases money transport cost in 1 per mile traveled, so it increases total money transportation cost in $x^{*2}/2$; and an increase in t_0 increases the fixed cost of a transport network of size x^* in $k'(t_0)x^*$. The value of t_0 chosen by the social planner is attained when the former and the latter expressions are equalized. A similar reasoning holds for the determination of t_1. For future reference, we denote the solutions $\{x^{*O}, t_0^O, t_1^O\}$.

Note that the condition (8) assumes an interior solution for x^*. In principle, if the productivity y_i becomes large enough (or the productivity in y_j becomes low enough, or both), it is clear from the comparative static results in expression (39) that CBD_i may eventually end up attracting all workers. Specifically, when production at CBD_0 net of transport costs for a worker residing at $x = 1$ is greater than production at CBD_1 for that same resident (transport costs would be zero in this case), or if $y_0 - k(t_0) - [y_0\phi(t_0) + t_0] > y_1 - k(t_1)$, then $x^* = 1$. In the rest of the paper, the analysis focuses on interior solutions, which means that y_0 and y_1 are such that $0 < x^* < 1$.

4 Equilibrium Analysis

Our goal is now to characterize and compare the values of t_0 and t_1 chosen by a central transport authority (or by the "federal government") to the same values chosen by the cities acting in a decentralized way. The timing of the decisions is the following. The transport authorities (either the central authority or the cities) decide the respective $\{t_0, t_1\}$. After observing these choices, individuals decide their residential location and whether to commute to CBD_0 or CBD_1.

Throughout most of the analysis, we assume that the fixed transportation cost F_i is equally shared among all residents commuting to CBD_i. Specifically, let τ_i denote the lump-sum tax imposed on an individual who commutes to location i to pay for the fixed transportation cost F_i. Then, each commuter to CBD_0 pays $\tau_0 = F_0/x^* = k(t_0)$, and each commuter to CBD_1 pays $\tau_1 = F_1/(1 - x^*) = k(t_1)$. We examine in section 6.1 the implications of relying on an alternative financing mechanism.

4.1 Land market equilibrium

We start by defining a land market equilibrium in the present framework.

Definition: A land market equilibrium in a duocentric, closed, and linear urban model is a vector $\{z, x^*\}$ such that:

1. $z_0 = z_1 = z$ for all $x \in [0, 1]$,

2. $r(x^*) = r(1 - x^*) = 0$,

3. Equilibrium land rent at $x \in [0, 1] : \bar{r}(x) = \max\{r(x), r(1 - x), 0\}$.

Condition 1 states that in equilibrium all individuals obtain the same utility at all locations x regardless of where they commute to work (CBD_0 and CBD_1). Condition 2 determines the border x^* between those who commute to CBD_0 and CBD_1. In other words, the bid-rent functions of CBD_0- and CBD_1-workers intersect at x^*. As a result, $\int_0^{x^*} dx = N_0$ individuals commute to CBD_0 and $\int_{x^*}^1 dx = N_1$ to CBD_1. At the border x^*, the opportunity cost of land is equal to agricultural rent, which is assumed equal to 0. Finally, condition 3 determines the equilibrium land rent at all locations $x \in [0, 1]$.

To compute the equilibrium, the first step is to derive the bid-rent curves. Let $r(x)$ denote land rent per unit of land at distance x from CBD_0, and a the share of land rents received by each individual (a is defined below). The budget constraint for an individual located at x who commutes to CBD_0 becomes

$$z_0 + r(x) = a + y_0 - \tau_0 - [y_0\phi(t_0) + t_0]x, \tag{9}$$

while the corresponding budget constraint if the resident commutes to CBD_1 is

$$z_1 + r(1 - x) = a + y_1 - \tau_1 - [y_1\phi(t_1) + t_1](1 - x). \tag{10}$$

Since in equilibrium residents are indifferent between all locations, consumption should be the same for all residents regardless of their place of residence. This means that land rent must vary with location to offset transportation costs. As a result, $z_0 = z_1 = z$. Residents at locations $x \in [0, x^*]$ commute to CBD_0, and residents at locations $x \in (x^*, 1]$

commute to CBD_1, where x^* is defined by $r(x^*) = r(1 - x^*)$, or

$$a + y_0 - \tau_0 - [y_0\phi(t_0) + t_0]x^* - z = a + y_1 - \tau_1 - [y_1\phi(t_1) + t_1](1 - x^*) - z, \tag{11}$$

which gives[8]

$$x^* = \frac{[(y_0 - \tau_0) - (y_1 - \tau_1)] + [y_1\phi(t_1) + t_1]}{[y_0\phi(t_0) + t_0) + (y_1\phi(t_1) + t_1]}. \tag{12}$$

Given that the relationship $r(x) - r(x^*) = (y_0\phi(t_0) + t_0)(x^* - x)$ must hold and that the opportunity cost of land is zero (so that $r(x^*) = 0$), then

$$r(x) = [y_0\phi(t_0) + t_0](x^* - x).$$

A similar argument for those who commute to CBD_1 establishes that

$$r(1 - x) = [y_1\phi(t_1) + t_1](x - x^*).$$

A graphical representation of the equilibrium is shown in figure 1. Substituting the previous two expressions respectively into (9) and (10) gives the equilibrium consumption level

$$\begin{aligned} z &= a + \tilde{z} \\ &= a + y_0 - \tau_0 - [y_0\phi(t_0) + t_0]x^* \\ &= a + y_1 - \tau_1 - [y_1\phi(t_1) + t_1](1 - x^*), \end{aligned}$$

where $\tilde{z} = y_0 - \tau_0 - [y_0\phi(t_0) + t_0]x^* = y_1 - \tau_1 - [y_1\phi(t_1) + t_1](1 - x^*)$. Thus, consumption is equal to disposable income at the edge of each city. Throughout the analysis we focus on equilibria in which $\tilde{z} > 0$.

[8]Note that in this case it is possible to explicitly solve for x^* because the τ_i's do not depend on x^*.

Finally, aggregate land rent $R = R_0 + R_1$ is defined as aggregate land rent in region 0 plus aggregate land rent in region 1, where

$$\begin{aligned} R_0 &= \int_0^{x^*} r(x)dx = [y_0\phi(t_0) + t_0]\frac{x^{*2}}{2} = T_0 + C_0 \\ R_1 &= \int_{x^*}^1 r(1-x)dx = [y_1\phi(t_1) + t_1]\frac{(1-x^*)^2}{2} = T_1 + C_1. \end{aligned}$$

These expressions show that R_i is in fact the sum of time and money transportation costs for region i. The land rent as capitalized transportation cost (excluding transport fixed costs) was first highlighted by Arnott and Stiglitz (1979) and is a general property inherent in urban models. This relationship is also highlighted by Brueckner and Selod (2006). Note that using R_i we can rewrite total surplus $\mathcal{S}$ as

$$\mathcal{S} = \underbrace{x^*[y_0 - k(t_0)] - R_0}_{\mathcal{S}_0} + \underbrace{(1-x^*)[y_1 - k(t_1)] - R_1}_{\mathcal{S}_1}.$$

Hence, choosing the transportation networks that maximize $\mathcal{S}$ also entails minimizing R.

Since the total population is normalized to 1 $(N = 1)$, R is also the average land rent (ALR). We assume that each individual in this economy receives a share $0 \leqslant \theta \leqslant 1$ of ALR, which means that $a \equiv \theta R$. The value of θ describes different cases of landownership: $\theta = 0$ would describe the absentee-landowner case, and $\theta = 1$ the case where land is entirely owned by residents.

4.2 Comparative Static Analysis

For future reference, we derive the following comparative static results:

$$\frac{\partial x^*}{\partial t_0} = -\{[y_0\phi'(t_0)+1]x^* + k'(t_0)\}\frac{(1-\alpha_0)}{[y_1\phi(t_1)+t_1]}, \tag{13}$$

$$\frac{\partial x^*}{\partial t_1} = \{[y_1\phi'(t_1)+1](1-x^*) + k'(t_1)\}\frac{(1-\alpha_0)}{[y_1\phi(t_1)+t_1]}, \tag{14}$$

$$\frac{\partial \tilde{z}_0}{\partial t_0} = -\{[y_0\phi'(t_0)+1]x^* + k'(t_0)\}(1-\alpha_0), \tag{15}$$

$$\frac{\partial \tilde{z}_1}{\partial t_1} = -\{[y_1\phi'(t_1)+1](1-x^*) + k'(t_1)\}\alpha_0, \tag{16}$$

$$\frac{\partial R}{\partial t_0} = \{[y_0\phi'(t_0)+1]x^* + k'(t_0)\}(1-\alpha_0) - \left\{[y_0\phi'(t_0)+1]\frac{x^{*2}}{2} + k'(t_0)x^*\right\}, \tag{17}$$

$$\begin{aligned}\frac{\partial R}{\partial t_1} = {} & \{[y_1\phi'(t_1)+1](1-x^*) + k'(t_1)\}\alpha_0 \\ & - \left\{[y_1\phi'(t_1)+1]\frac{(1-x^*)^2}{2} + k'(t_1)(1-x^*)\right\},\end{aligned} \tag{18}$$

where

$$0 \leqslant \alpha_0 = \frac{y_0\phi(t_0)+t_0}{y_0\phi(t_0)+t_0+y_1\phi(t_1)+t_1} \leqslant 1. \tag{19}$$

A few observations are worth noting from the previous expressions. First, $\partial\tilde{z}_i/\partial t_i = 0$ if and only if $\partial x^*/\partial t_i = 0$. In other words, both $\tilde{z}_i$ and x^*, as it will become clear later, reach a maximum at the same value of t_i.[9] This result will be particularly relevant in the decentralized case examined below.

Second, the utility of resident in i, represented by $\tilde{z}_i$, depends on x^*, and x^* ultimately depends on t_0 and t_1. Hence, a change in t_i will, in general, affect the utility of residents in both CBD_i and CBD_j. The effect on jurisdiction j will not be internalized by the transport authority in i when decisions are made in a decentralized way. However, if $\partial x^*/\partial t_i = 0$, then the strategic effect in the choice of t_i vanishes.

And third, consider expression (17). It follows that if the first term, which is equal to $-\partial\tilde{z}_0/\partial t_0 = -(\partial x^*/\partial t_0)[y_0\phi(t_1)+t_1]$, is zero, then the second term is negative, which

[9] It can be shown that $(\partial^2 x^*/\partial t_0^2)$ evaluated at the value of t_0 at which $\partial x^*/\partial t_0 = 0$ is negative, so the second order condition is satisfied locally. Similar results hold for $\tilde{z}_i$.

means that $\partial R/\partial t_0 < 0$. This result is relevant because it reflects the trade-offs faced by the transport authority when choosing the system that maximizes $z = \theta R + \tilde{z}$, since t_0 affects $\tilde{z}$ and R in conflicting ways. Similar reasoning applies to $\partial R/\partial t_1$ in (18).

5 Determination of the Transport System

We now examine the determination of t_0 and t_1 decided by the transportation authorities prior to the residents' localization and commuting choices. In principle, when transport authorities decide the characteristics of the transportation system, they may consider a variety of objectives. In the following sections, we study and compare the outcomes reached under two alternative objectives. First, we assume that the corresponding transportation authorities choose $\{t_0, t_1\}$ that maximize the city's total surplus defined as the difference between total production and total transportation costs. Second, we assume that authorities choose the values of $\{t_0, t_1\}$ that maximize total consumption. In this latter case, we also examine the implications of making different assumptions regarding landownership, i.e, the distribution of ALR. We compare the outcomes when $\theta = 0$ (absentee landlord model) to those reached when $0 < \theta \leqslant 1$ (residents receive at least part of the ALR).

As stated earlier, we assume for the moment that residents commuting to CBD_i equally pay for the fixed costs F_i. We examine later in section 6.1 how the choices change when aggregate fixed costs $(F_0 + F_1)$ are uniformly distributed across residents.

5.1 Total Surplus

5.1.1 Centralized Solution

Consider the following problem faced by a central (or federal) transport authority: choose $\{t_0, t_1\}$ that maximize aggregate surplus $S = S_1 + S_2$.[10] When deciding these values, the central transport authority anticipates that individuals behave in the way described in section 4. This means that after observing the transport systems characterized by t_0 and

[10] In this section, we use S_i instead of $\mathcal{S}_i$ to refer to city i's surplus. The difference between the two is explained by the fact that $S = S_1 + S_2$ depends on the specific financing mechanism chosen by the authorities $\mathcal{S} = \mathcal{S}_1 + \mathcal{S}_2$ does not. Since in this section we assume that $t_i = k(t_i)$, then the two expressions coincide. However, we will later evaluate the implications of financing the fixed costs using alternative mechanisms, so $\mathcal{S}_i$ and S_i will differ.

t_1 chosen by the central authority, individuals simultaneously decide where to live and where to commute. These decisions determine an equilibrium value of x^*, defined earlier by (12). We assume there is a specific institutional arrangement in place that determines the way the fixed costs are shared. In general, when residents commuting to CBD_i pay the lump-sum tax τ_i to cover the fixed costs, the total surplus S becomes

$$\begin{aligned} S &= S_0 + S_1 \qquad (20) \\ &= x^* \left\{ y_0 - \tau_0 - [y_0\phi(t_0) + t_0]\frac{x^*}{2} \right\} + (1 - x^*) \left\{ y_1 - \tau_1 - [y_1\phi(t_1) + t_1]\frac{(1 - x^*)}{2} \right\}, \end{aligned}$$

and x^* is defined by (12). This expression differs from the social surplus defined earlier in that each resident of city is now responsible for the share τ_i of the fixed transportation costs.

Recall that we assume in this section that the fixed cost F_i is equally shared among all residents commuting to CBD_i, so $\tau_0 = F_0/x^* = k(t_0)$ and $\tau_1 = F_1/(1 - x^*) = k(t_1)$. Then, note that (20) and (12) are identical to (4) and (8), respectively, so the problem faced by a central authority is exactly the same as the one faced by the social planner. This means that the centralized solution denoted by $\{x^{*CS}, t_0^{C,S}, t_1^{C,S}\}$ is also optimal.

Proposition 1. *Suppose that residents of city i equally share the fixed cost associated with the transportation system in city i, F_i. Then, a central transportation authority that maximizes total surplus chooses the optimal transportation systems, i.e.,* $\{t_0^O, t_1^O\} = \{t_0^{C,S}, t_1^{C,S}\}$.

5.1.2 Decentralized Equilibrium

We now characterize the equilibrium values of $\{t_0, t_1\}$ when cities make decisions in a decentralized way. The sequence of events is as follows. Each CBD_i simultaneously chooses the value of t_i that maximizes the city's total surplus $\mathcal{S}_i$. After observing the corresponding choices, individuals decide their residential locations and whether they commute to CBD_0 or CBD_1. When choosing the value of t_i that maximizes the city surplus S_i, the transport authority in CBD_i takes the value of t_j chosen by the other city parametrically.

From the FOCs of each city's maximization problem, we obtain

$$-\left[y_0\phi'(t_0)+1\right]\frac{x^{*2}}{2}=\gamma_0 k'(t_0)x^*, \tag{21}$$

$$-\left[y_1\phi'(t_1)+1\right]\frac{(1-x^*)^2}{2}=\gamma_1 k'(t_1)(1-x^*), \tag{22}$$

where

$$\gamma_0 \equiv \frac{y_0-k(t_0)+[y_1\phi(t_1)+t_1]x^*}{y_0-k(t_0)+[y_1\phi(t_1)+t_1]x^*+y_0-k(t_0)-[y_0\phi(t_0)+t_0]x^*}, \tag{23}$$

$$\gamma_1 \equiv \frac{y_1-k(t_1)+[y_0\phi(t_0)+t_0](1-x^*)}{y_1-k(t_1)+[y_0\phi(t_0)+t_0](1-x^*)+y_1-k(t_1)-[y_1\phi(t_1)+t_1](1-x^*)}. \tag{24}$$

Note that since we assume that $\tilde{z}>0$, it follows $1/2<\gamma_i<1$. Substituting (21) and (22) into (5) and (6), respectively, gives $\partial\mathcal{S}/\partial t_i<0, i=0,1$. This means that, relative to the centralized case, cities tend to choose higher values of t_i and, consequently, lower values of $\phi(t_i)$. In other words, when cities behave strategically, they tend to choose more expensive and faster transport systems.

Proposition 2. *Suppose that transportation authorities (central or local) maximize total surplus. Let $t_i^{C,S}$ denote the value of t_i chosen by a central transport authority (i.e., when it maximizes $S=S_1+S_2$), and $t_i^{D,S}$ the equilibrium values when cities act in a decentralized way (i.e., when each city maximizes its own surplus S_i) for $i=0,1$. Then, $t_i^{D,S}>t_i^{C,S}$ and $\phi(t_i^{D,S})<\phi(t_i^{C,S})$.*

This result can also be explained by focusing on the external effects generated by one city on the other one. Consider the choice of t_0 by the transport authorities in region 0. First, note that evaluated at the equilibrium (21), $\partial x^*/\partial t_0>0$.[11] Next, the external effect of t_0 on the surplus of CBD_1 is given by

$$\frac{\partial S_1}{\partial t_0}=-\{y_1-k(t_1)-[y_1\phi(t_1)+t_1](1-x^*)\}\frac{\partial x^*}{\partial t_0}<0. \tag{25}$$

The expression between brackets is the disposable income or consumption at the border x^* (or $\tilde{z}$), which is positive. Since $\partial x^*/\partial t_0>0$, then $\partial S_1/\partial t_0<0$. In other words, in equilibrium, the choice of t_0 by city 0 generates a negative effect on the surplus of city 1.

[11]Substituting (21) into the comparative static result (13) gives $(\partial x^*/\partial t_0)>0$

Since this negative effect is not internalized by local transport authorities in city 0, they will end up choosing an excessively large value of t_0 (relative to the optimal one).

Additionally, a closer inspection of the FOCs that determine the optimal and decentralized levels of t_0 (expressions (5) and (21), respectively) reveals that the marginal cost of expanding the network in region 0, $k'(t_0)$, is in fact multiplied by $1/2 < \gamma_0 < 1$ in the decentralized case. This means that in the decentralized case this marginal cost is underestimated, inducing region 0 to choose a larger transport system.

5.2 Total Consumption

We now assume the central authority or each region acting independently chooses the transport systems that maximize total consumption. One difference with respect to the maximization of total surplus is that in this case the distribution of landownership matters in deciding t_0 and t_1. We examine the implications of different landownership arrangements including the extreme cases of absentee landlord ($\theta = 0$) and full distribution of aggregate land rents across individuals ($\theta = 1$).

5.2.1 Centralized Solution

Suppose the central authority sets the levels of $\{t_0, t_1\}$ that maximize total consumption. The problem in this case becomes

$$\max_{\{t_0,t_1\}} W = x^* z_0 + (1 - x^*) z_1. \tag{26}$$

However, since $z_0 = z_1 = z = \tilde{z} + a$, this problem is equivalent to maximizing z with respect to t_0 and t_1. We assume as before that $\tau_i = k(t_i)$. The FOCs in this case are

$$\frac{\partial W}{\partial t_i} \;=\; \frac{\partial \tilde{z}_i}{\partial t_i} + \theta \frac{\partial R}{\partial t_i} = 0, \quad i = 0, 1. \tag{27}$$

To characterize the solution of this problem, suppose initially that $\theta = 0$. Then, maximizing W entails maximizing $\tilde{z}_i$, and the solution would satisfy $\partial \tilde{z}_i / \partial t_i = 0$, or

$$[y_0 \phi'(t_0) + 1] x^* + k'(t_0) = 0, \tag{28}$$

$$[y_1 \phi'(t_1) + 1](1 - x^*) + k'(t_1) = 0. \tag{29}$$

Now suppose that $0 < \theta \leqslant 1$, but the values of $\{t_0, t_1\}$ still satisfy (28) and (29). Then, substituting these expressions into comparative static results (17) and (18), it follows that $\partial R/\partial t_i < 0$, and, consequently, $\partial W/\partial t_i < 0$. This means that when $0 < \theta \leqslant 1$, the values of t_i that maximize z_i are lower than those that maximize $\tilde{z}_i$.

Proposition 3. *The values $\{t_0, t_1\}$ that maximize $z = a + \tilde{z}$ are higher when $\theta = 0$ (absentee landlord case) than when $0 < \theta \leqslant 1$ (residents receive at least part of the ALR).*

Finally, we compare the values of t_0 and t_1 that maximize total surplus to those that maximize total consumption in the centralized case. First, note that when $\theta = 1$, $\mathcal{S} = W$, which means that the centralized and optimal solutions coincide. Next, suppose that $\theta = 0$. Then, by substituting (28) and (29) into (5) and (6), it is straightforward to obtain $\partial \mathcal{S}/\partial t_i < 0$, which means that when $\theta = 0$, the centralized solutions $\{t_0, t_1\}$ are larger than the optimal ones. In fact, the latter holds for all values $0 < \theta < 1$.

Proposition 4. *When the central transport authority maximizes total consumption and $0 \leqslant \theta < 1$, it chooses higher values of t_0 and t_1 than the optimal values. The centralized solutions are optimal when $\theta = 1$.*

5.2.2 Decentralized Solution

Suppose that in the decentralized case cities maximize total consumption taking place within the region. In other words, suppose that region 0 chooses the value of t_0 that maximizes $W_0 = x^* z_0$ (taking t_1 as given), and region 1 chooses the value of t_1 that maximizes $W_1 = (1 - x^*) z_1$ (taking t_0 as given). In both cases, the city authorities anticipate that $z_0 = z_1 = z$. The FOCs are given by[12]

$$\frac{\partial W_0}{\partial t_0} = (\tilde{z}_0 + \theta R)\frac{\partial x^*}{\partial t_0} + x^* \left(\frac{\partial \tilde{z}_0}{\partial t_0} + \theta \frac{\partial R}{\partial t_0} \right) = 0, \tag{30}$$

$$\frac{\partial W_1}{\partial t_1} = -(\tilde{z}_1 + \theta R)\frac{\partial x^*}{\partial t_1} + (1 - x^*) \left(\frac{\partial \tilde{z}_1}{\partial t_1} + \theta \frac{\partial R}{\partial t_1} \right) = 0. \tag{31}$$

[12] We assume the second order conditions $\partial^2 W_i/\partial t_i^2 < 0, i = 0, 1$ are satisfied.

Consider expression (30) and suppose initially that $\theta = 0$. Hence,

$$\frac{\partial W_0}{\partial t_0} = \tilde{z}_0 \frac{\partial x^*}{\partial t_0} + x^* \frac{\partial \tilde{z}_0}{\partial t_0} = 0, \tag{32}$$

$$\frac{\partial W_1}{\partial t_1} = -\tilde{z}_1 \frac{\partial x^*}{\partial t_1} + (1 - x^*) \frac{\partial \tilde{z}_1}{\partial t_1} = 0. \tag{33}$$

Substituting the comparative static results derived earlier into (32) and (33), it can be shown that the equilibrium in this case is achieved when

$$[y_0 \phi'(t_0) + 1] x^* + k'(t_0) = 0, \tag{34}$$

$$[y_1 \phi'(t_1) + 1](1 - x^*) + k'(t_1) = 0. \tag{35}$$

Notice that these conditions are the same as (28) and (29) obtained in the centralized case. This result holds because both the city size (x^* or $(1 - x^*)$, respectively) and $\tilde{z}_i$ are maximized at the same values of t_i, as explained earlier.[13] When (34) and (35) hold, $\partial x^* / \partial t_0 = \partial x^* / \partial t_1 = \partial z_0 / \partial t_0 = \partial z_1 / \partial t_1 = 0$. As a result, the strategic competition effect that would arise in the decentralized case vanishes.

Now, suppose that $0 < \theta \leqslant 1$ and conditions (34) and (35) still hold. Then, it turns out that $\partial x^* / \partial t_i = \partial z_i / \partial t_i = 0$ and $\partial R / \partial t_i < 0$, which implies $\partial W_i / \partial t_i < 0$. The latter means that, as in the centralized case, the equilibrium values of t_0 and t_1 are lower in the absentee landlord case, $\theta = 0$, than the corresponding values achieved when residents receive at least some of the ALR, or $0 < \theta \leqslant 1$.

Proposition 5. *When the transport system is decided in a decentralized way, and regional transport authorities maximize total consumption within the limits of their respective regions, the equilibrium values of t_0 and t_1 are higher when $\theta = 0$ than when $0 < \theta \leqslant 1$.*

Next, we compare the values of t_0 and t_1 in the centralized and decentralized cases. Evaluating the centralized solution (27) at $\partial W_0 / \partial t_0 = 0$ and $\partial W_1 / \partial t_1 = 0$ gives

$$\frac{\partial W}{\partial t_0} = -\frac{1}{x^*} \frac{\partial x^*}{\partial t_0} (\tilde{z}_0 + \theta R), \tag{36}$$

$$\frac{\partial W}{\partial t_1} = \frac{1}{(1 - x^*)} \frac{\partial x^*}{\partial t_1} (\tilde{z}_1 + \theta R). \tag{37}$$

[13] In other words $\tilde{z}_0$ ($\tilde{z}_1$, respectively) and $x^* \tilde{z}_0$ ($(1 - x^*)\tilde{z}_1$, respectively) reach a maximum at the same value of t_0 (t_1, respectively).

When $\theta = 0$, the equilibrium is characterized by (34) and (35), so $\partial x^*/\partial t_i = 0$. As a result, $\partial W/\partial t_i = 0$, which means that the centralized and the decentralized solutions are identical. Now, assume that $0 < \theta \leqslant 1$. Since by Proposition 5 the values of t_i are lower in this case, then $-[y_0\phi'(t_0)x^* + k'(t_0)] > 0$ and $-[y_1\phi'(t_1)(1 - x^*) + k'(t_1)] > 0$. By substituting these expressions into $\partial x^*/\partial t_0$ and $\partial x^*/\partial t_1$ gives $\partial x^*/\partial t_0 > 0$ and $\partial x^*/\partial t_1 < 0$, which, in turn, implies, $\partial W/\partial t_i < 0, i = 0, 1$. Then, we conclude that relative to the centralized case, the values of t_i chosen by the regions are larger. The following proposition summarizes the results.

Proposition 6. *Suppose that the transport authorities both in the centralized and decentralized cases choose the values of t_i that maximize consumption (aggregate consumption or total consumption within the region, respectively). Let $\{t_0^{C,C}, t_1^{C,C}\}$ denote the centralized solution and $\{t_0^{D,C}, t_1^{D,C}\}$ the decentralized solution. Then,*

(i) If $\theta = 0$, then $t_i^{D,C} = t_i^{C,C}, i = 0, 1$.

(ii) If $0 < \theta \leqslant 1$, $t_i^{D,C} > t_i^{C,C}, i = 0, 1$.

A simple numerical example helps illustrate the results obtained thus far. The numerical example assumes that $\phi(t_i) = 1/t_i^2$ and $k(t_i) = \kappa_i\, t_i$, where κ_i is a positive constant. Also, $y_0 = y_1 = 50$. Figure 3 shows the optimal values of t_i and equilibrium values of t_i for different values of $\theta \in [0, 1]$, when the transport authorities maximize either the city's surplus or consumption.[14] When cities maximize their surplus, the solutions are independent of θ. The graph shows, however, that the decentralized solution $t_i(DS) = 2.14$ is larger than the optimal and centralized solution value $t_i(O) = t_i(CS) = 1.81$. When the cities maximize total consumption, the values t_i decline as θ rises. The centralized and decentralized solutions in this case ($t_i(CC)$ and $t_i(DC)$, respectively) are equal when $\theta = 0$, but $t_i(CC) < t_i(DC)$ when $0 < \theta \leqslant 1$. Note that the centralized solution is optimal when $\theta = 1$.

[14]This example assumes, among other things, that the productivity levels y_0 and y_1 and the costs κ_0 and κ_1 are identical. Given that cities are completely identical, we then focus on a symmetric equilibrium, with $t_0 = t_1 = t_i$. The next section examines how the transportation system changes when one city becomes more productive than the other.

6 Extensions

We consider two possible extensions of the previous analysis. In first place, we analyze the additional distortions generated by a financing mechanism that shares the cost of the transportation systems uniformly across the entire population, regardless of their residential location. And in second place, we compare the distortions in the transportation systems arising in urban settings where the cities differ in their productivity levels.

6.1 Alternative financing mechanism

Suppose now that the total fixed cost of setting up the transportation networks is financed by all individuals regardless of their residential location and commuting destination.[15] In other words, suppose that $\tau_0 = \tau_1 = \tau = k(t_0)x^* + k(t_1)(1 - x^*)$. In general, the equilibrium solutions are no longer optimal. One consequence of implementing a uniform lump-sum tax across cities is that x^* no longer depends on $k(t_0)$ and $k(t_1)$:

$$x^* = \frac{(y_0 - y_1) + [y_1\phi(t_1) + t_1]}{[y_0\phi(t_0) + t_0) + (y_1\phi(t_1) + t_1]}. \tag{38}$$

We use the previous numerical example to compare the values of t_i chosen under different objective functions when the transport fixed costs are funded through a uniform lump-sum tax or a city-specific tax. We assume as before that CBDs are identical ($y_0 = y_1 = 50$) and focus on symmetric equilibria. The results are reported in figure 4.

Consider the case of total surplus maximization. It was shown earlier that the centralized solution is optimal when $\tau_0 = k(t_0)$ and $\tau_1 = k(t_1)$. A uniform tax is only optimal when the cities are completely identical (shown in the figure). In this situation, it becomes irrelevant whether the fixed costs are financed by each city or through a uniform tax. In the decentralized case, cities are induced to choose even larger t_i's since they expect to shift part of the burden of financing the local transport system to the other city. In the figure, this is represented by the horizontal line at $t_i(DS) = 3.79$.

When transport authorities maximize consumption, the results are similar to those shown in figure 3. In other words, the level of $t_i(CC)$ chosen when the costs are uniformly

[15] To some extent, this could be considered the truly "centralized" case, since total transport fixed costs are financed through centrally collected taxes.

shared is the same as the one chosen if they are financed through a city- or region-specific tax. As before, $t_i(CC)$ is inefficiently high and it declines as θ increases. In the decentralized case, and when the cities are identical, the equilibrium values of $t_i(DC)$ do not depend on θ when the tax is uniform across cities, since in this case $R(\partial x^*/\partial t_0) + x^*(\partial R/\partial t_0) = 0$. In fact, the values of $t_i(DC)$ are exactly the same as the equilibrium values of $t_i(DS)$, observed when cities maximize their respective surplus.

6.2 Cities with different productivity levels

How do the optimal, centralized, and decentralized transportation networks change when one city is more productive than the other? The examples developed thus far focus on symmetric equilibria, where $y_0 = y_1$. Suppose now that y_0 and y_1 may differ. Consider first the social planner's problem. By differentiating the previous FOCs (5), (6), and (7) with respect to y_i, we obtain[16]

$$\frac{\partial x^*}{\partial y_0} > 0, \ \frac{\partial x^*}{\partial y_1} < 0, \ \frac{\partial t_i}{\partial y_i} > 0, \ \text{and} \ \frac{\partial t_j}{\partial y_i} < 0, \ i \neq j. \tag{39}$$

This means that the social planner chooses a higher value of t for city i when the city becomes relatively more productive and a lower t for the city that becomes less productive (in this case, city j). As a result, the border that determines the number of commuters to i also increases.

For the decentralized case, the comparative static analysis is substantially more complicated. As result, we rely on numerical example to illustrate what happens to the equilibrium values of t_i when cities differ in their productivity levels. We compare as well the solutions arising in those cases to the respective centralized solutions. In the exercise, we assume that $y_0 = y_1 + \Delta$, and calculate the equilibrium values of x^*, t_0, and t_1 for different Δs. Moreover, we consider all the different scenarios studied earlier, including the uniform financing alternative of section 6.1. The solutions are shown in figures 5 and 6. A few remarks are worth pointing out. First, the border x^* that determines the number of residents working at CBD_0, which in this case is the city that is more productive, is always larger in the decentralized case than in the centralized case. Second, when

[16] The derivations are shown in the Appendix.

uniform financing is added to the decentralized case, x^* becomes even larger (i.e., the distortion becomes even larger). Note, however, that the financing mechanism does not affect the decisions made in the case CS (in other words, $t_i(CS_{uniform}) = t_i(O) = t_i(CS)$). Third, in the decentralized case, t_0 increases and t_1 decreases, as in the optimal and centralized cases, but the levels of $t_i(DS)$ are always above the levels of $t_i(O)$, $t_i(CS)$, and $t_i(CS_{uniform})$. And fourth, uniform financing in the decentralized case gives the largest values of t_i.

7 Exogenous Political Boundaries

We now assume that each city belongs to a different region, where regions are delimited by an exogenously given border $\bar{x}$. We modify slightly our setup and assume that there is one residential location in each region, denoted by x_i. In other words, all residents of region 0 reside at a single location x_0 miles from CBD_0, such that $x_0 < \bar{x}$, and all residents of region 1 live at x_1, where $x_1 > \bar{x}$, or at $(1 - x_1)$ miles from CBD_1.[17] The objective in this section is once more to characterize the transportation system decided by each regional administrative unit in a decentralized way when the productivities differ across cities and compare the solutions to those decided by a central transport authority.

Households residing at x_i commute to work to either CBD_i or CBD_j. Utility is given by $u^{ij} = z_{ij}^{\alpha}\varepsilon_{ij}$, $0 < \alpha \leqslant 1$, where i denotes the place of residence and j the place or work, and ε_{ij} is an idiosyncratic preference shock that captures the idea that individuals may differ in terms of their preferences for living and working in different cities. The values of ε_{ij} are drawn from an independent Fréchet distribution, $F(\varepsilon_{ij}) = e^{-\varepsilon_{ij}^{-\sigma}}$, where $\sigma > 1$ determines the dispersion of the idiosyncratic utility.

We also assume, that ex-ante, it is possible to choose different transportation systems within each region i, discriminating between those who commute inwards to city i, represented by transportation system t_{ii}, and those who commute outwards, to city j,

[17] We use the same name for regions and CBDs.

given by t_{ij}. Under these conditions, z_{ij} becomes[18]

$$\begin{array}{llcl}
\text{Work in 0} & & & \\
x_0 < \bar{x}: & z_{00} & = & y_0 - [y_0\phi(t_{00}) + t_{00}]\, x_0 - \tau_{00} - r(x_0), \\
x_1 > \bar{x}: & z_{10} & = & y_0 - [y_0\phi(t_{10}) + t_{10}]\, (x_1 - \bar{x}) \\
 & & & - [y_0\phi(t_{01}) + t_{01}]\, (\bar{x} - x_0) \\
 & & & - [y_0\phi(t_{00}) + t_{00}]\, x_0 - \tau_{10} - r(x_1), \\
\text{Work in 1} & & & \\
x_1 > \bar{x}: & z_{11} & = & y_1 - [y_1\phi(t_{11}) + t_{11}]\, (1 - x_1) - \tau_{11} - r(x_1), \\
x_0 < \bar{x}: & z_{01} & = & y_1 - [y_1\phi(t_{00}) + t_{00}]\, (\bar{x} - x_0) \\
 & & & - [y_1\phi(t_{10}) + t_{10}]\, (\bar{x} - x_1) \\
 & & & - [y_1\phi(t_{11}) + t_{11}]\, (1 - \bar{x}) - \tau_{01} - r(x_0),
\end{array}$$

We consider a closed-city model in which the total number of residents is given by N, which is also equal to the total labor supply. Housing supply at location i is exogenously given and equal to H_i^S. The two regions can host the total number of residents, so that $N = H_0^S + H_1^S$. Given the assumption on the distribution of ε_{ij}, the probability of living in i and commuting to j is

$$\lambda_{ij} = \frac{(z_{ij}^{\alpha})^{\sigma}}{\sum_r \sum_s (z_{rs}^{\alpha})^{\sigma}}, \quad r, s = 1, 2. \tag{40}$$

As a result, the total number of individuals residing in i is $\sum_s \lambda_{is} N$, and the total number of individuals working in j is $L_j = \sum_r \lambda_{rj} N$. Since each household demands one unit of housing and local housing markets clear, so that $\sum_s \lambda_{is} N = H_i^S$. This last equality determines $\{r(x_0), r(x_1)\}$.

When deciding the transportation system, we assume that the authority in i decided the transportation system that maximizes the city surplus S_i defined, in the present case,

[18] We also assume that in principle residents can be taxed differently depending on both where they reside and where they work. Additionally, we assume that land rents accrue to absentee landowners.

by

$$
\begin{aligned}
S_0 &= y_0 L_0 \left\{1 - [\phi(t_{00}) y_0 + t_{00}] x_0\right\} \\
&\quad -\lambda_{10} N \left\{[\phi(t_{01}) y_0 + t_{01}](\bar{x} - x_0) + [\phi(t_{10}) y_0 + t_{10}](x_1 - \bar{x})\right\}, \\
S_1 &= y_1 L_1 \left\{1 - [\phi(t_{11}) y_1 + t_{11}](1 - x_1)\right\} \\
&\quad -\lambda_{01} N \left\{[\phi(t_{01}) y_1 + t_{01}](\bar{x} - x_0) + [\phi(t_{10}) y_1 + t_{10}](x_1 - \bar{x})\right\}.
\end{aligned}
$$

The central transport authority, on the other hand, chooses the values of $\{t_{ij}\}_{i,j=0,1}$ that maximize total surplus $S = S_0 + S_1$.

We develop a numerical example that illustrates how the outcomes differ when one city becomes more productive than the other. Specifically, we assume that $y_0 = y + \Delta$ and $y_1 = y$ and evaluate how the policies t_{ij} change when Δ rises. We assume in the numerical example that $\alpha\sigma = 1$.[19] In this case, housing demand is homogeneous of degree 0 in prices, and we choose the normalization $\{r(x_0), 1\}$. We also consider two cases concerning fixed costs of setting up the transportation network. In first place, we assume that fixed costs are zero, which means that $\tau_{ij} = 0$. In second place, we assume that fixed costs are uniformly shared across the entire population, regardless of where they live and work, i.e., $\tau_{ij} = (F_0 + F_1)/N$. The results are summarized in figures 8, 9, and 10.

A few interesting conclusions emerge from this exercise. Consider the case in which $\tau_{ij} = 0$. First, the levels of t_{00} and t_{11} in both the centralized and decentralized cases coincide. In all these cases, t_{ii} satisfies $[y_i \phi'(t_{ii}) + 1] = 0$. In other words, t_{ii} is chosen to minimize the transportation costs $y_i \phi(t_{ii}) + t_{ii}$. Moreover, as Δ increases, t_{00} also increases.[20]

Second, the central transport authority always chooses $t_{01} = t_{10}$. This means that the central authority does not discriminate between residents who commute to work outward to a different city. Also, as Δ increases, t_{ij} increases as well. So when one city becomes more productive than the other, a central authority would invest in faster transportation networks connecting the cities.

[19]For instance, this relationship holds if the systematic part of the utility function is $\sqrt{z}$ and $\sigma = 2$.
[20]Since y_1 is held constant throughout this exercises, t_{11} does not change.

Third, the centralized and decentralized solutions are equal when $\Delta = 0$. When $\Delta > 0$, t_{01} and t_{10} differ in the decentralized case. Moreover, when Δ increases, t_{01} tends to rise, and t_{10} tends to decrease for low values of Δ, and tends to increase when Δ becomes sufficiently large.

Fourth, when Δ increases, more households would be willing not only to work in CBD_0, but also to live in region 0. Since housing supply is inelastically given at location x_0, $r(x_0)$ would tend to rise. Note, however, that $r(x_0)$ rises more in the decentralized case than in the centralized case.

From this exercise, it is possible to calculate total surplus arising in both the centralized and decentralized cases. It follows that $S^D < S^C$.[21] The previous analysis also sheds some light on an alternative institutional arrangement that combines both regional and central efforts, which may reinstate the outcomes observed in the centralized case. Specifically, this arrangement would grant cities the responsibility of deciding the transportation system that best connects the region's residential area with the city, while the central government would be fully responsible for ensuring the appropriate level of transportation connectivity across regions.[22]

Figure 10 shows the solutions t_{ij} when $\tau_{ij} = (F_0 + F_1)/N$ for both the centralized and decentralized cases. When costs are equally shared across all residents regardless of where they live and work, an additional external effect is generated across cities: when city i raises t_{ii} or t_{ij}, it does not fully internalize the full cost of such a decision. As a result, note that the levels of t_{00} and t_{11} are now higher in the decentralized case. Similar results are observed concerning the choices of t_{01} and t_{10} as those obtained in the previous case with no fixed costs: in the centralized case, $t_{01} = t_{10}$ and t_{ij} increases as Δ increases; $t_{01} > t_{10}$ in the decentralized with t_{01} rising and t_{10} initially declining and then rising as Δ gets sufficiently large.[23]

[21] The numbers are not shown here.

[22] The solution of the following program gives precisely this solution: city i chooses the levels of t_{ii} that maximize S_i, and the central authority chooses the levels of t_{01} and t_{10} that maximize $S = S_0 + S_1$, where each authority takes the decisions of the others as given.

[23] In this situation, a program as the one described in the previous footnote does not fully restore the centralized equilibrium, but it definitely improves upon the fully decentralized case.

8 Conclusions

Shifting toward a decentralized transportation system could be beneficial for several reasons. For instance, it would allow local transport authorities to tailor their transportation systems to satisfy local needs. Also, since local officials would be responsible for funding their own projects, they would have incentives to act more efficiently. And finally, the defederalization process could generate a variety of transportation systems benefiting consumers.

Defederalization also presents several challenges, though. This paper focuses on one of them: when local transportation authorities make their decisions in a decentralized way, they would not internalize the impact that their choices have on other jurisdictions. The paper establishes certain conditions under which the decentralized case would lead to overinvestment in transportation relative to the centralized arrangement. Specifically, it shows that when transport authorities choose transportation systems that maximize total surplus, the outcome in the decentralized case would be larger than the outcome in the decentralized case. A similar result would hold when the objective is to maximize total consumption and residents receive part of the aggregate land rents. However, in the absentee landlord case, i.e., land rents accrue to an absentee landlord, the centralized and decentralized solutions coincide. The distortion is even larger if the transport systems are funded through a uniform tax on all residents regardless of their residential location and commuting destinations. Finally, other distortions arise when cities belong to exogenously delimited regions, and transport authorities can only choose the transport system in their own regions. In the decentralized case, city transport authorities tend to overinvest in transport systems that connect their own residential areas with the city. Moreover, when the productivity of cities differ, more productive cities tend to overinvest in transport systems connecting their residential areas with surrounding regions, while low productive cities tend to underinvest. A central transport authority, however, connects regions by choosing the same transport system in every region, and this transport system is faster when the productivity of at least one city increases.

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Figure 1: Land Market Equilibrium

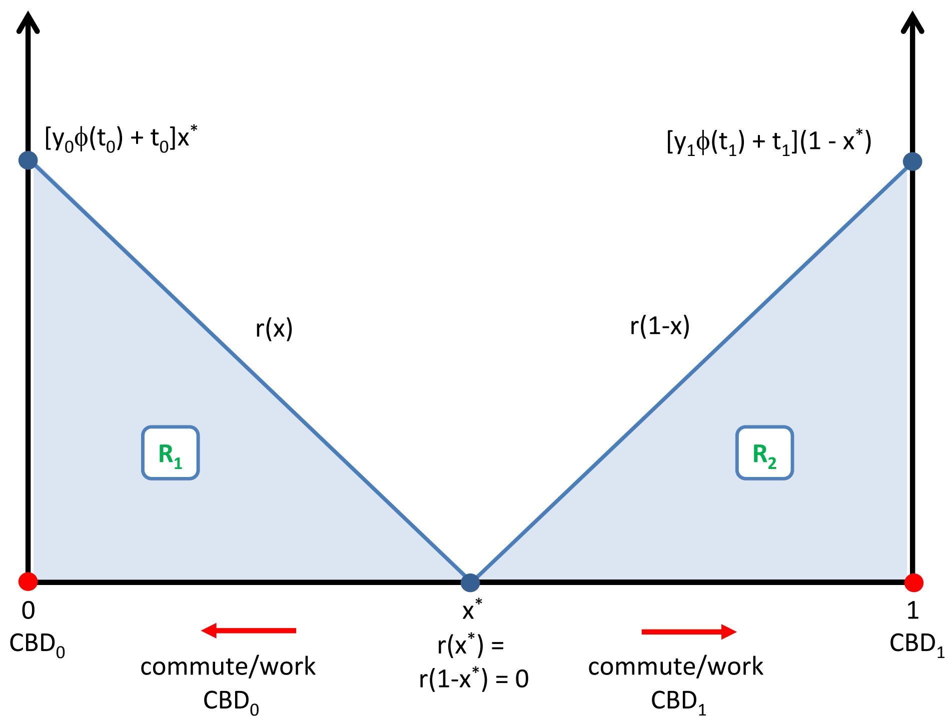


Figure 2: Transportation Systems Under Different Scenarios

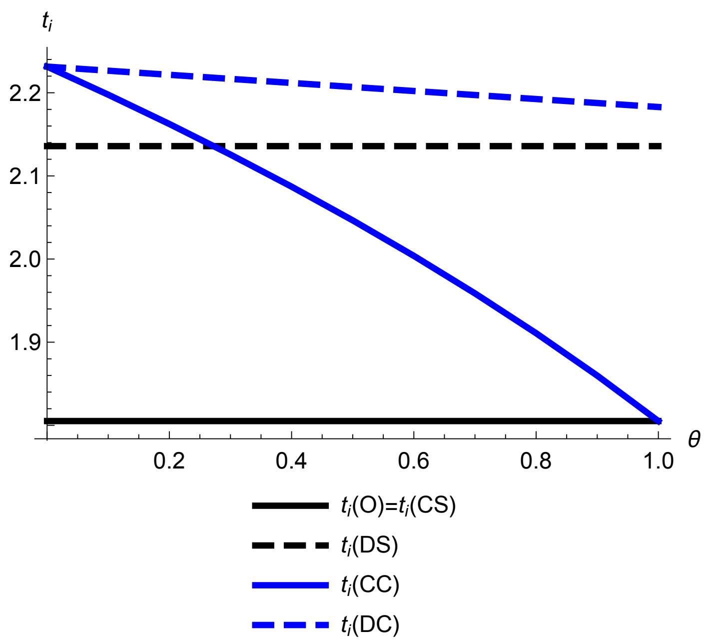


Figure 3: Transportation Systems Under Different Scenarios

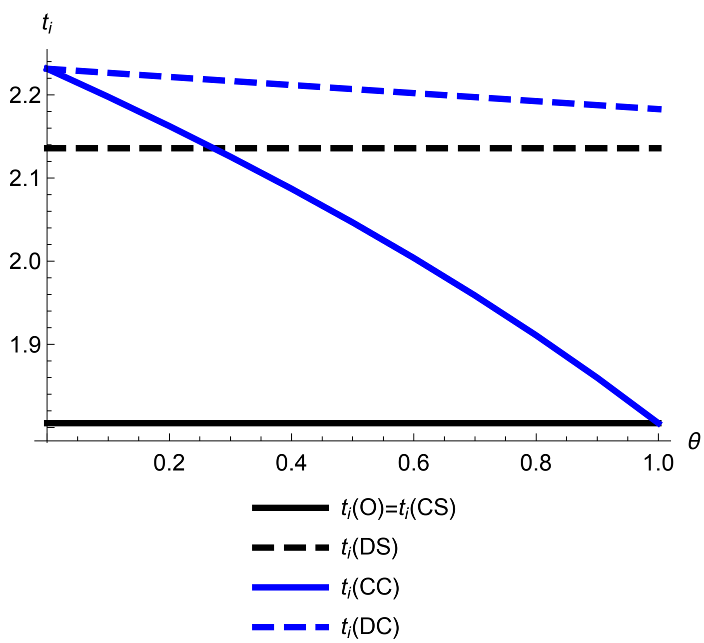


Figure 4: Transportation Systems: City Specific vs. Uniform Tax

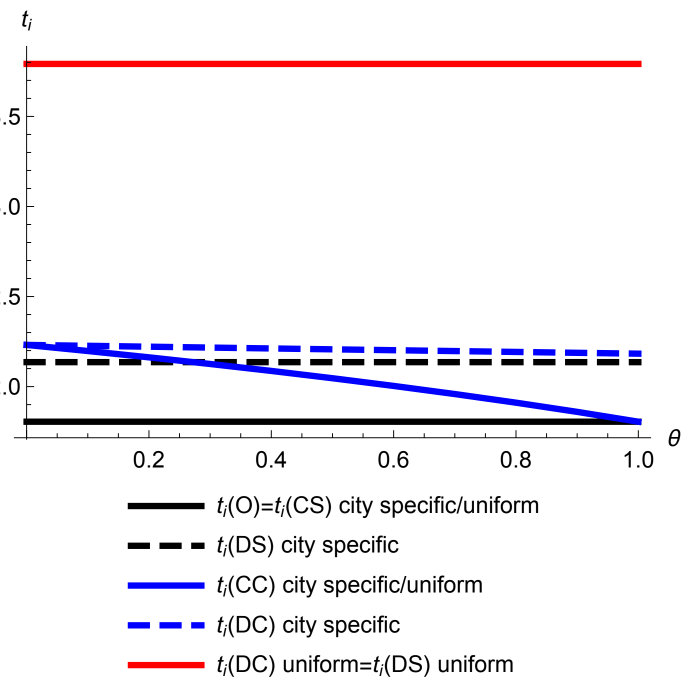


Figure 5: Cities with different productivity levels: $y_0 = y_1 + \Delta$

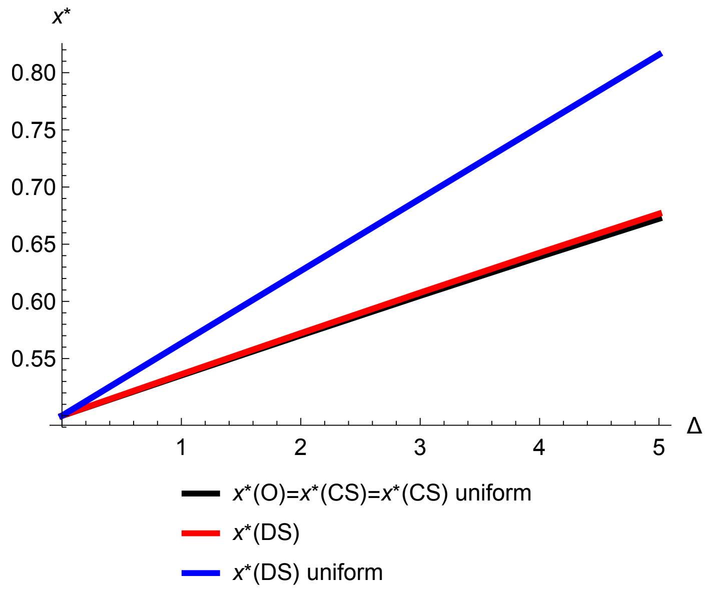


Figure 6: Cities with different productivity levels

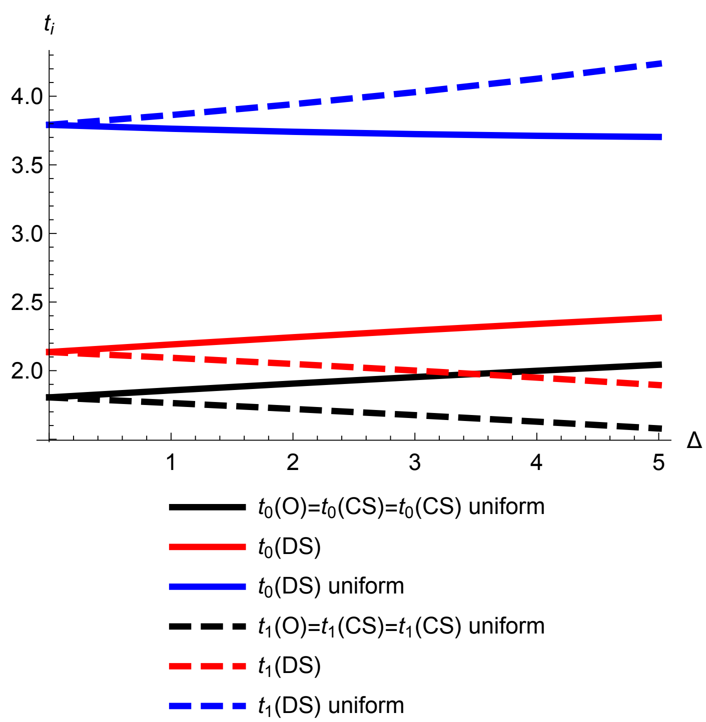


Figure 7: Exogenously given border

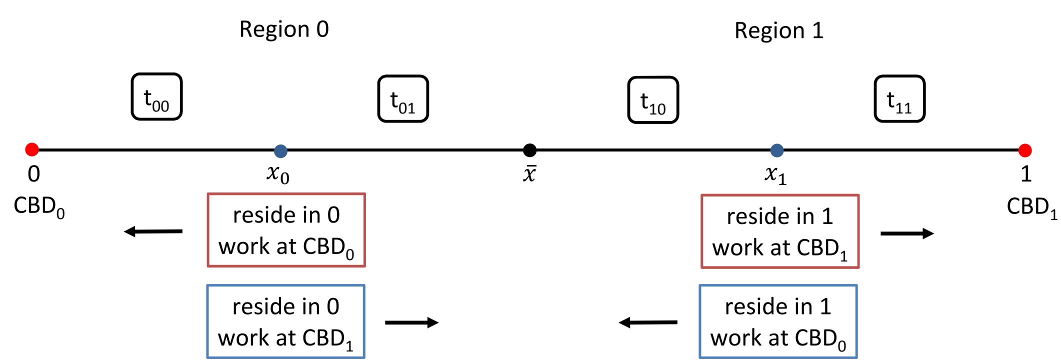


Figure 8: Exogenously given border: $\tau_{ij} = 0$

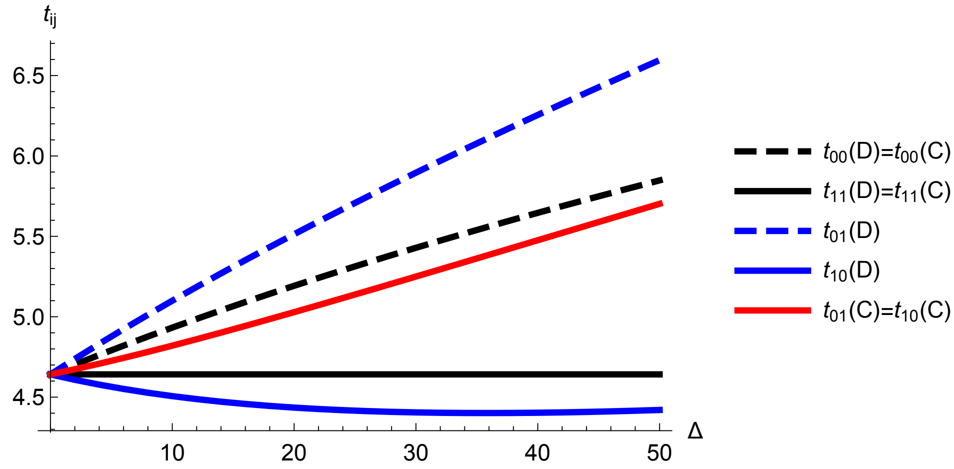


Figure 9: Exogenously given border: $\tau_{ij} = 0$

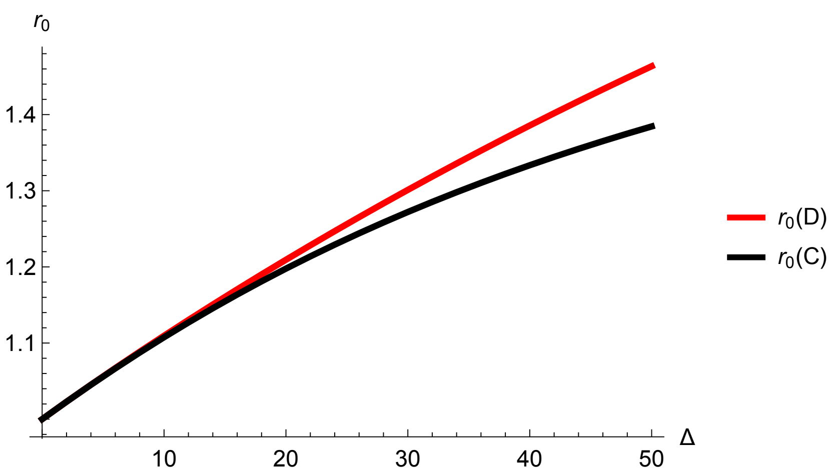
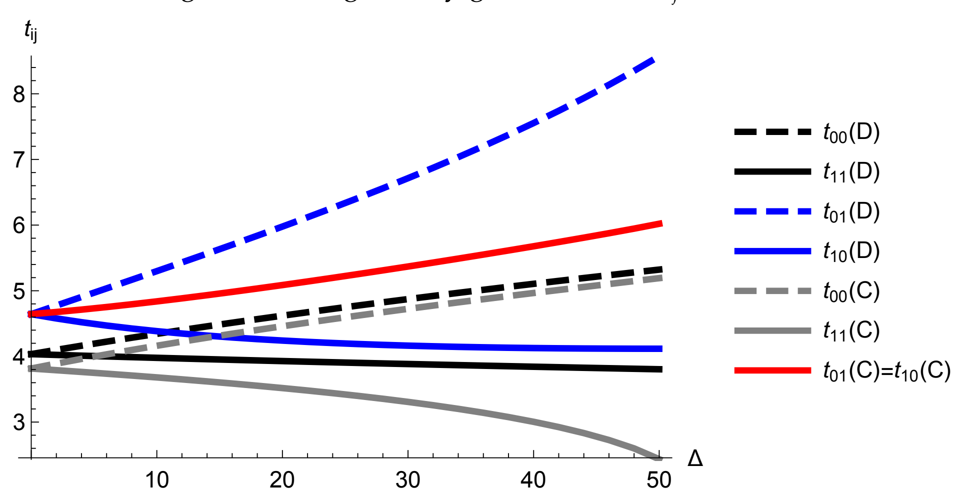


Figure 10: Exogenously given border: $\tau_{ij} = TTC/N$



Appendix

A Section 3: Comparative Statics Results

By denoting $\mathcal{S}_m \equiv \partial \mathcal{S}/\partial m$ and $\mathcal{S}_{mn} \equiv \partial^2 \mathcal{S}/\partial m \partial n$, we can express the Hessian of the optimal transport system program as

$$\begin{aligned} H &= \begin{bmatrix} \mathcal{S}_{t_0t_0} & \mathcal{S}_{t_0t_1} & \mathcal{S}_{t_0x^*} \\ \mathcal{S}_{t_1t_0} & \mathcal{S}_{t_1t_1} & \mathcal{S}_{t_1x^*} \\ \mathcal{S}_{x^*t_0} & \mathcal{S}_{x^*t_1} & \mathcal{S}_{x^*x^*} \end{bmatrix} \\ &= \begin{bmatrix} -\frac{1}{2}x^*(2k_0'' + x^*y_0\phi_0'') & 0 & -(k_0' + x^*y_0\phi_0') \\ 0 & -\frac{1}{2}(1-x^*)[2k_1'' + (1-x^*)y_1\phi_1''] & k_1' + (1-x^*)y_1\phi_1' \\ -(k_0' + x^*y_0\phi_0') & k_1' + (1-x^*)y_1\phi_1' & -(t_0 + y_0\phi_0 + t_1 + y_1\phi_1) \end{bmatrix}. \end{aligned}$$

Moreover, differentiating the system of equations 5, 6, and 7 with respect to y_0, we obtain

$$\begin{bmatrix} \mathcal{S}_{t_0y_0} \\ \mathcal{S}_{t_1y_0} \\ \mathcal{S}_{x^*y_0} \end{bmatrix} = \begin{bmatrix} -\frac{1}{2}x^{*2}\phi_0' \\ 0 \\ -(1-\phi_0x^*) \end{bmatrix}.$$

This means that

$$\frac{\partial t_0}{\partial y_0} = \frac{1}{|H|}\left[-\mathcal{S}_{t_0y_0}(\mathcal{S}_{t_1t_1}\mathcal{S}_{x^*x^*} - \mathcal{S}_{t_1x^*}^2) + \mathcal{S}_{x^*y_0}\mathcal{S}_{t_1t_1}\mathcal{S}_{t_0x^*}\right] > 0, \tag{41}$$

$$\frac{\partial t_1}{\partial y_0} = \frac{1}{|H|}\left[\mathcal{S}_{t_0y_0}\mathcal{S}_{t_1t_1}\mathcal{S}_{x^*t_0} + \mathcal{S}_{x^*y_0}\mathcal{S}_{t_0t_0}\mathcal{S}_{t_1x^*})\right] < 0, \tag{42}$$

$$\frac{\partial x^*}{\partial y_0} = \frac{1}{|H|}\left[\mathcal{S}_{t_0y_0}\mathcal{S}_{t_1t_1}\mathcal{S}_{x^*t_0} - \mathcal{S}_{x^*y_0}\mathcal{S}_{t_0t_0}\mathcal{S}_{t_1t_1})\right] > 0. \tag{43}$$

The results are obtained using the second order conditions for a maximum, specifically, $\mathcal{S}_{mm} < 0$, $\mathcal{S}_{mm}\mathcal{S}_{nn} - \mathcal{S}_{mn}^2 > 0$, for $m \neq n$, and $|H| < 0$, in addition to the fact that from the FOCs, $(k_0' + x^*\phi_0') < 0$ and $(k_1' + (1-x^*)\phi_1')$. Similar results hold for changes in y_1.