Chapter 6

Toll competition in General Equilibrium Land Use and Transport models: explorations with a North-South setting for Randstad

6.1. Introduction

So far we have assumed the existence of a (federal) government capable of imposing a different level of a road tax on each part of the network and returning the revenue either lump-sum or in the form of a labor tax cut. Although the above setting can potentially lead to an (economically) efficient allocation (i.e. when the correct level of a tax is combined with the correct revenue-recycling program), the implementation of tax reforms introducing urban road charges has met strong resistance. One of the drivers behind the low acceptability may be the spatial profile of such reforms: decisions over the details of the pricing scheme (type, charges) and the use of the generated revenue are usually centralized, leaving the impression that local welfare is decreased after the introduction of these policies.

There are at least two reasons why a centralized reform may give rise to substantial local discomfort. The first is that the pricing scheme may create, or intensify spatial inequality, despite being (on average) welfare improving. For instance, a cordon toll favors certain population groups in a monocentric setting, such as those that own land inside the cordon area (see Verhoef, 2005). The hypothesis that road pricing may induce local discomfort is matched by the results of the referendum succeeding the Stockholm congestion charge trial period, from January 2006 to July 2006 (Stockholmsförsöket, 2006). During this period, authorities charged a road fee to the users of a set of links which, together, form a virtual cordon encircling a large part, but not the entire area, of Stockholm municipality. As the middle and right panel of Figure 6.1 suggest, the cordon excludes part of Stockholm municipality and the spatial dominion of all the other municipalities in Stockholm county. In the referendum that succeeded the trial period, all fourteen municipalities surrounding the municipality of Stockholm voted against the permanency of the measure, with negative rates ranging from 54.1% to 70.4% (while inside the cordon a majority of 53% voted yes).

The second driver behind the low acceptability of urban tolls is likely to be the use of collected revenue. Local discomfort may be fueled by a revenue recycling scheme that is perceived to be unfair, or (even worse) that is not known to the public. Here, the argument is that the tax lacks, at least locally, the element of reciprocity. For instance, while the citizens of a certain geographic area may contribute a large portion of the collected revenue, the benefits they receive in return (e.g. in the form of public goods) are disproportionally low.
Local fiscal autonomy, defined here as the granted authorization of local governments to spatially differentiate taxes and handle collected revenue their own way, has been proposed by stakeholders and public policy makers as a possible way to restore the political acceptability of road pricing and spatially-related environmental tax reforms in general. However, the higher acceptability comes at a cost, as local tax setting and redistribution mechanisms are known to generate tax exporting behavior through policy competition. That is, local governments are given the incentive to overtax the use of local facilities (i.e. those facilities provided in their jurisdiction) from outsiders in order to collect more revenue that can be redistributed locally, i.e. to favor their citizens. The incentive is stronger when the demand of the local facility by external users (i.e. citizens that reside in dominions of other local governments) is relatively inelastic.

Figure 6.1. Stockholm congestion trial. Left panel: percentage vote in favor (YES) and against (NO) the permanency of the pricing scheme in fourteen municipalities of Stockholm county where a referendum was held. Middle panel: Yes- versus No-majority. Right panel: the cordon of the toll scheme (dashed polygon) encircling a significant portion of Stockholm municipality (i.e. middle panel’s green/Yes area).


The literature on transport policy competition is voluminous. An excellent survey of it is offered by De Borger and Proost (2012). Multiple classifications of transport policy competition are possible. With respect to the nature of competition, a distinction between horizontal and vertical competition can be made. In the former case, competition concerns authorities acting on the same level of governance, such as municipalities, private operators, or local governments. Typically, these authorities attempt to satisfy similar objectives and control the user price of similar facilities. For instance, different revenue-maximizing authorities may be granted control over different parts of a network. On the other hand, vertical competition involves authorities at different levels competing in order to satisfy different objectives. For instance, rail-road competition may involve a local government controlling road prices (aiming to maximize local
welfare) and a rail operator that functions under the -partial- control of a federal government. In this type of competition, the spatial domains of governments at different levels may overlap. For example, Proost and Sen (2006) investigate the interactions between an urban government controlling parking fees and a regional government in charge of a peak period cordon toll.

A second classification regards the nature of the network in which competition takes place. The distinction here regards parallel, serial and mixed networks. De Borger et al. (2008) show that the type of network plays a key role in the determination of pricing and capacity decisions in settings with horizontal fiscal externalities. De Borger et al. (2005) investigate toll competition between public operators (national governments), each controlling a different link of a parallel network that is used by local and transit users. Tax exporting behavior is examined from two different perspectives: uniform and differentiated tolls for local and transit users. Both regimes encapsulate the incentive to obtain revenue at the detriment of transit road users. Differentiation between local and transit tolls as compared to uniform tolls is not found to generate large welfare differences, although tolls on transit are shown to differ substantially. Competition in a serial network can be more harmful in terms of social welfare, due to double marginalization. Because an alternative route is absent, the operators controlling intermediate links in a serial network form a series of local monopolies that result in higher charges and lower revenue (compared to a centralized setting in which a sole monopolist controls the entire network), as it would be the case with intermediate suppliers holding monopoly power in a vertical supply chain (Spengler, 1950; Tirole, 1988).

This is the first attempt to numerically compute the social cost of a decentralized, i.e. locally-autonomous, toll system in a polycentric general equilibrium setting upon an existing network. The model we propose is a direct extension of the general equilibrium land use and transport model (hereafter, GELUT) described thoroughly in Chapters 4 and 5. The extension pertains the introduction of local governments that are assigned specific, non-overlapping dominions. These authorities are granted the permission to i) set toll levels in their dominions and ii) redistribute toll revenues according to their objectives. The general equilibrium setting is highly desirable in this context because it facilitates the computation of welfare effects by accounting explicitly for residence and job location choices. These adjustments are important to control, since they can mitigate or fuel further the fiscal externalities of horizontal tax competition.

To simplify things while we simultaneously keep the context in line with the setting of Chapter 5, we focus exclusively on games resulting from a dichotomy of Randstad area in two large fiscal dominions (Figure 6.2). This partition is in line with the OECD functional urban area delimitations (Figure 6.3). We reduce the complexity of strategic interactions by restricting the number of instruments controlled by each local government to just one: a flat

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135 A functional urban area (FUA) is a unit of spatial delimitation developed by the OECD (2012). Every FUA is a cluster of core and peripheral municipalities. Core municipalities are identified using grid population data and municipal population data and are characterized by increased population density. Commuting data are used to identify peripheral municipalities. Peripheral municipalities belong to the same functional urban area if their population exceeds 50000 inhabitants and at least 15% of their labor is supplied to the municipal urban core(s).
kilometer tax for all roads that fall into its dominion. At the same time, route choice decisions are considered through allowing for the same mixed (general) representation of network as the one used in Chapter 5. We consider two different local government objectives: local utility maximization and local revenue maximization. In each case, the welfare of the resulting unique Nash equilibrium is compared to the social planner solution, which maximizes the average utility in the two regions.

We find that toll competition in terms of local welfare reduces overall utility, but favors the large area whose links are widely used by residents of the smaller region. On the other hand, when the objective shifts to revenue maximization, both regions end up with much higher toll levels and are worse-off compared to the no-toll equilibrium. These decentralized settings are juxtaposed against two centralized cases, in which the kilometer tax is set by a social planner who aims to maximize the average utility of the two regions. In these social planner settings, the kilometer tax can (in the latter case) or cannot (in the former) be differentiated across the two regions. In both cases, the resulting allocation is found to be Pareto-preferred to the no-congestion toll equilibrium by both regions. Finally, we investigate a scheme that combines centrally-set toll levels aiming to maximize average utility combined with local revenue recycling.

The chapter has the following structure: Section 6.2 briefly recaps the model specification used in Chapter 5. It also presents the main modifications, as well as the methodological hurdles that need to be circumvented in order to introduce policy competition in the model described in Chapter 5. Section 6.3 briefly recaps the calibration of the model. Section 6.4 provides the policy analysis and Section 6.5 summarizes the main findings.

6.2. Model

6.2.1. Main structure

The model proposed in this section is a direct extension of the model proposed in Tikoudis (2015), as described in detail in Chapter 5. That is in turn a network-based, polycentric extension of the general equilibrium monocentric city models by Verhoef (2005), Tikoudis et al. (2015a, 2015b) and fully in line with the preexisting contributions in the field (Anas and Kim, 1996; Anas and Xu, 1999; Anas and Liu, 2007; Anas and Hiramatsu, 2012).

The behavior of households and firms is identical to the behavior described in Chapter 5. *Households* maximize utility through discrete-continuous choices resulting in i) a *choice probability* for each alternative \( a = \{i,j,q\} \) (i.e. combination of a residential zone \( i \), an employment zone \( j \) and a commuting route \( q \)) and ii) conditional (to the choice of an arbitrary alternative) *Marshalian demands* for a composite good, residential space and leisure. *Firms* and

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156 The exposition in Section 6.2 draws, to some extent, from Tikoudis (2015). Literal citations from that source are not marked as such for legibility; a duplication of equations will be provided in future versions of this chapter in order to keep a forthcoming working paper self-contained.
developers are cost minimizers and operate under constant returns. Therefore, perfect competition implies that prices equal marginal costs in all relevant markets.

6.2.2. Extensions and modifications

Chapter 5 assumed a federal government that is capable of imposing a different level of a road tax on each link of the network. The road tax revenue was returned either lump-sum or in the form of a labor tax cut. In this chapter we disregard distortions in the labor market (therefore, the uniform-in-space labor tax is set to zero, \( \tau_L = 0 \)). We focus entirely on the efficiency of policies that grant some degree of fiscal autonomy to a small number of local governments. We juxtapose these decentralized policies against the centralized setting of Chapter 5.

The decentralized setting of this chapter partitions the set of eighteen zones considered in Chapter 5 (i.e. the set \( J \)) into two subsets, that is the dominions \( J^A \) and \( J^B \), each containing zones that fall into the jurisdiction of local governments \( A \) and \( B \) respectively. Because dominions do not overlap, it holds that \( J^A \cap J^B = \emptyset \). The allocation of zones in the dominions \( J^A \) and \( J^B \) determines who controls each link of the road network. The level of control local governments exert upon an arbitrary road link \( l^{(se)}_R \) is given by the authorization functions \( 0 \leq I(A, s, e) \leq 1 \) and \( 0 \leq I(B, s, e) \leq 1 \) (for local government \( A \) and \( B \) respectively). These functions indicate the proportion of the link’s length, \( \ell^{se}_R \), that lies into their dominion. Because parts of some links do not fall into the dominion of any local government, it must hold that \( I(A, s, e) + I(B, s, e) \leq 1 \).

For games that involve flat kilometer charges imposed by local governments (denoted by \( \tilde{\tau}_A \) and \( \tilde{\tau}_B \) respectively), the total charge to the commuter/user of road link \( l^{(se)}_R \) that leads from node (zone) \( s \) to node (zone) \( e \) is:

\[
\tau^{se}_R = \ell^{se}_R \left( \frac{(I(A, s, e) \tilde{\tau}_A) + (I(B, s, e) \tilde{\tau}_B)}{\text{weighted kilometer charge}} \right)
\]

There are two types of households. One residing in fiscal dominion \( A \), facing the choice set \( C^A \) and one residing in fiscal dominion \( B \), facing the choice set \( C^B \). The arbitrary alternative \( a = \{i, j, q\} \) in \( C^A \) is such that \( i \in J^A \); similarly, for each \( a = \{i, j, q\} \) in \( C^B \) it holds that \( i \in J^B \). Therefore, residential mobility is restricted: the exogenous populations, \( N_A \) and \( N_B \) respectively, are required to reside in fiscal dominions \( A \) and \( B \), but are free to relocate inside their dominion and supply their labor to the other dominion. Because of the above restriction, in the general-stochastic user equilibrium the expected maximum utility is not equalized across household types (i.e. across dominions), thus \( E_{\text{max}}^A \neq E_{\text{max}}^B \) can occur in equilibria.

There is one budget constraint for each local government. The total revenue that accrues from road taxes for government \( A \) is:
\[ R_R^a = N_A \sum_{a \in C_A} \left\{ P_a \left( \sum_{\ell_R^s \in q(a)} (I(A, s, e) \bar{\tau}_A \ell_R^{se}) D_{Wa}^* \right) \right\} \]
\[ + N_B \sum_{a' \in C_B} \left\{ P_a \left( \sum_{\ell_R^s \in q(a')} (I(B, s, e) \bar{\tau}_B \ell_R^{se}) D_{Wa}^* \right) \right\}. \]

A similar revenue accrues for local government B:

\[ R_R^b = N_A \sum_{a \in C_A} \left\{ P_a \left( \sum_{\ell_R^s \in q(a)} (I(B, s, e) \bar{\tau}_B \ell_R^{se}) D_{Wa}^* \right) \right\} \]
\[ + N_B \sum_{a' \in C_B} \left\{ P_a \left( \sum_{\ell_R^s \in q(a')} (I(B, s, e) \bar{\tau}_B \ell_R^{se}) D_{Wa}^* \right) \right\}. \]

Both local public budgets are balanced, therefore:

\[ B_A = \frac{R_R^a}{N_A}, \]

and

\[ B_B = \frac{R_R^b}{N_B}. \]

Equations (6.2)-(6.5) show why local governments are equipped with an incentive to overcharge traffic on local roads. The parts of (6.2) and (6.3) that refer to cross-commuting constitute a source of revenue that is collected from non-local populations and can be distributed in favor of the local population. That is, part of the local kilometer tax is exported to cross commuters in favor of the local residents (through the redistribution of revenues).

Since the implementation of road pricing has been transferred from the jurisdiction of the federal government to local authorities and the labor tax has been eliminated \((\tau_L = 0 \iff R_L = 0)\), the budget of the federal government (equation 42 in chapter 5) collapses to:

\[ B = -\frac{D_T}{(N_A + N_B)}, \]

with the deficit of public transport in the entire region, \(D_T\), now being determined via:
\[ D_T = F + \sum_{a \in C^A} \left\{ P_a D^*_W (\hat{p}_P - p_P) L_{Pq} \right\} + N_B \sum_{a' \in C^B} \left\{ P_{a'} D^*_W (\hat{p}_P - p_P) L_{Pq} \right\} \]

[public transport deficit]

\[ + \sum_{a \in C^A} \left\{ P_a D^*_g (\hat{p}_g - p_g) L_{Pq} \right\} + N_B \sum_{a' \in C^B} \left\{ P_{a'} D^*_g (\hat{p}_g - p_g) L_{Pq} \right\}. \]

[private transport subsidies]

From equations (6.4) and (6.5) it is apparent that households located in dominion \( J^A \) will receive a different lump-sum transfer than households located in \( J^B \). The rest of the model specification is similar to that in Chapter 5. However, the resulting equilibrium conditions are modified to take into account the two types of households that the model of this chapter considers.

For each of the \( J \) labor markets, the clearing condition now is:

\[
N_A \sum_{a \in C^A} \left\{ I(j|a) P_a D^*_W \right\} + N_B \sum_{a' \in C^B} \left\{ I(j|a') P_{a'} D^*_W \right\} - L^D_j = 0. \tag{6.8}
\]

Similarly, for each housing market in zone \( i \in J^A \), the clearing condition is:

\[
N_A \sum_{a \in C^A} \left\{ I(i|a) P_a s^*_a \right\} - H^S_i = 0, \tag{6.9}
\]

and for each housing market in zone \( i \in J^B \):

\[
N_B \sum_{a' \in C^B} \left\{ I(i|a') P_{a'} s^*_{a'} \right\} - H^S_i = 0. \tag{6.10}
\]

The aggregate demand for the composite good in the entire region is given by:

\[
Y^D = N_A \sum_{a \in C^A} \left\{ P_a y^*_a \right\} + N_B \sum_{a' \in C^B} \left\{ P_{a'} y^*_{a'} \right\}. \tag{6.11}
\]

6.3. Calibration

The spatial resolution is the same as the one used in Chapter 5 (18 zones and 52 links). Each of these zones represents a group of municipalities, which share either similar commuting patterns
or a common strategic position in the road network. The model is recalibrated in order to (roughly) reproduce most of the stylized facts proposed in Chapter 5: the benchmark consumption, housing and transport expenditure shares, the average equilibrium-to-free flow travel time ratio, the modal split and the commute-to-work time ratio.

Figure 6.2. Aggregation of Randstad zones (municipal clusters) into local fiscal dominions.

6.4. Discussion

6.4.1. Results

We now examine four different equilibria vis-à-vis the benchmark equilibrium described above. The first (Nash-local welfare row in Table 6.5) is the unique Nash equilibrium resulting from a Bertrand game in which local governments set the flat kilometer tax in order to maximize local utility. We hereafter refer to this as the Nash-U equilibrium. A sample of best response kilometer taxes is displayed in Table 6.1 (Government B) and Table 6.2 (Government A). The associated computations indicate that both best response curves are monotonically decreasing in the flat

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An initial selection excluded municipalities with population below 20000 inhabitants. A first grouping of municipalities into clusters (zones) was made in order to merge neighboring municipalities with populations between 20000 and 180000 inhabitants that share similar labor supply patterns to the larger zones, i.e. those municipalities with a population over 180000 inhabitants. Further refinements rived some of these groupings into smaller parts, to account for the fact that some municipalities had access to more than one major highway link and would therefore hold larger monopoly power (ceteris paribus) had they granted fiscal autonomy to perform road pricing on their own.
kilometer tax of the other region. The left panel of Figure 6.4 displays these curves and their intersection, *i.e.* the (unique) Nash-U equilibrium. The most important result is that this equilibrium is preferred (to the base equilibrium) only by the average citizen in dominion A, who is found to be better-off by 0.26% of the income; both the average citizens of dominion B and of the entire region are worse-off, by 1.90% and 0.69% of their income respectively.

*Figure 6.3. OECD Functional Urban Areas of Randstad.*

<table>
<thead>
<tr>
<th>Flat km charge at dominion A</th>
<th>0.0000</th>
<th>0.0350</th>
<th>0.0650</th>
<th>0.0800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best response by B</td>
<td>0.0862</td>
<td>0.0727</td>
<td>0.0671</td>
<td>0.0618</td>
</tr>
</tbody>
</table>

Notes: pecuniary cost of car and public transport per unit of distance are set to 0.03 and 0.008 respectively.

The second setting we examine is the unique Nash equilibrium generated by a game in which local governments aim to maximize toll revenue (hereafter, the Nash-R equilibrium). This is displayed on the fourth row of Table 6.5 (a sample of best responses is given in Tables 6.3 and 6.4 and best response curves are displayed in the right panel of Figure 6.4). Contrary to the Nash-U, in this equilibrium all parties are worse-off, even though revenue is redistributed lump-sum to
local populations. Compared to the Nash-U setting, revenue competition results in much higher (more than double) kilometer charges, despite the total road tax revenue is higher by 15% only. Therefore, horizontal competition for a mobile tax base can provide qualitatively different results under benevolent (i.e. local welfare maximizing) and revenue-maximizing authorities. These findings raise concerns regarding the desirability of urban toll decentralization, which (in many cases) has been proposed as a remedy to low public acceptability of centralized toll schemes.

Table 6.2. Government A’s best responses to various levels of flat kilometre charges imposed by local government B under local welfare maximization.

<table>
<thead>
<tr>
<th>Flat km charge at dominion B</th>
<th>0.0000</th>
<th>0.0350</th>
<th>0.0650</th>
<th>0.0800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best response by A</td>
<td>0.0740</td>
<td>0.0676</td>
<td>0.0643</td>
<td>0.0621</td>
</tr>
</tbody>
</table>

Notes: pecuniary cost of car and public transport per unit of distance are set to 0.03 and 0.008 respectively.

Table 6.3. Government B’s best responses to various levels of flat kilometre charges imposed by local government A under revenue maximization.

<table>
<thead>
<tr>
<th>Flat km charge at dominion A</th>
<th>0.0000</th>
<th>0.0600</th>
<th>0.1250</th>
<th>0.1800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best response by B</td>
<td>0.1879</td>
<td>0.1667</td>
<td>0.1576</td>
<td>0.1515</td>
</tr>
</tbody>
</table>

Notes: pecuniary cost of car and public transport per unit of distance are set to 0.03 and 0.008 respectively.

Table 6.4. Government A’s best responses to various levels of flat kilometre charges imposed by local government B under revenue maximization.

<table>
<thead>
<tr>
<th>Flat km charge at dominion B</th>
<th>0.0000</th>
<th>0.0600</th>
<th>0.1250</th>
<th>0.1800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best response by A</td>
<td>0.1545</td>
<td>0.1445</td>
<td>0.1333</td>
<td>0.1273</td>
</tr>
</tbody>
</table>

Notes: pecuniary cost of car and public transport per unit of distance are set to 0.030 and 0.008 respectively.

Next, we juxtapose the two decentralized equilibria (Nash-U, Nash-R) with two equilibria in which a central social planner imposes flat kilometer charges aiming to maximize the weighted expected maximum utility. Thus the objective in this case is:

\[ W = N_A E_{max_A} + N_B E_{max_B}. \]  \quad (6.12)

We assume that the planner redistributes toll revenue uniformly to the two populations. Therefore the lump-sum transfers in equations (6.4) and (6.5) become:

\[ B_A = B_B = \frac{R^a_A + R^b_B}{N_A + N_B}. \]  \quad (6.13)
We explore two settings: In the first case (hereafter, the Planner-\(U\) equilibrium), the planner is restricted to use a uniform charge rate, \(\bar{\tau}_P^U\), across the two dominions. Then, equation (6.1) becomes:

\[
\tau^s_R = \bar{\tau}_P^U \ell^s_R \left( I(A,s,e) + I(B,s,e) \right),
\]

(6.14)

where \(I(A,s,e) + I(B,s,e)\) is kept fixed to maximize comparability to the decentralized scenarios. This results in a considerably lower optimal kilometer charge: the optimal \(\bar{\tau}_P^U\) is roughly one third of the charges obtained in the Nash-\(U\) equilibrium and one sixth of the charges obtained in the Nash-\(R\) equilibrium. Table 6.5 indicates that the scheme generates moderate welfare gains for both populations. The magnitude of these gains is roughly consistent with previous literature that has shown a high relative efficiency of archetype pricing schemes such as a flat kilometer tax (Verhoef, 2005) which however tends to fade out as the setting becomes less monocentric (Mun et al., 2005). Therefore, it is not possible to provide an improvised estimate of the maximum welfare gains that can be realized through a set of link-specific charges, \textit{i.e.} through a kilometer tax that varies optimally across links.

The second setting (hereafter, the Planner-\(D\) equilibrium) allows the planner to differentiate the flat kilometer charges (\(\bar{\tau}_P^A\) and \(\bar{\tau}_P^B\)) across the two regions so that \(\tau^s_R\) is determined by:

\[
\tau^s_R = \ell^s_R \left[ \left( I(A,s,e) \bar{\tau}_P^A \right) + \left( I(B,s,e) \bar{\tau}_P^B \right) \right],
\]

(6.15)

with revenue returned as in (6.13). As Table 6.5 shows, this setting results in a marginal modification of the undifferentiated kilometer charge: downwards for the region with the largest population and upwards for the smaller region. This differentiation is accompanied by a transfer of utility from the smaller to the larger region, which is partially driven by the constant marginal utility of money assumed in the model. Despite this equilibrium is not Pareto preferred to Planner-\(U\) equilibrium in dominion B, it is still preferred to the base equilibrium.

Can some hybrid arrangement in which levels of kilometer charges are federally-set and revenue is collected and distributed locally provide welfare gains for both populations? A positive answer would provide an argument in favor of local revenue management settings that could act as a remedy to local discomfort caused by the pricing scheme. At the same time, toll levels would be federally-set, preventing tax exporting behavior. To answer whether such a setting could generate a Pareto-preferred allocation for both regions, we compute a hybrid equilibrium with differentiated levels of a kilometer tax (\(\bar{\tau}_P^A\) and \(\bar{\tau}_P^B\)) that maximize (6.12) under the freedom of local authorities to redistribute local revenue in favor of their dominion, \textit{i.e.} under conditions (6.4) and (6.5). We refer to this equilibrium as Hybrid-\(D\); results are displayed in the final row of Table 6.5. To interpret them in conjunction with those of Planner-\(D\) setting, recall that the marginal utility of income is constant across alternatives and regions. The first
order effect of this setting is a zero-sum redistribution from region B to region A: splitting revenue $R_R = 0.0029$ into its local parts (i.e. $R^A_R = 0.0018$ and $R^B_R = 0.0011$) and redistributing accordingly transfers utility from the smaller to the larger region. However, the Planner-D charges are now suboptimal since the above redistribution alters the traffic composition in the network, calling for new optimal levels of $\bar{\tau}_A$ and $\bar{\tau}_B$, i.e. those shown in Table 6.5.

*Figure 6.4. Best response curves of government A (dashed) and B (solid) and resulting Nash equilibria under local utility (left) and revenue maximization (right).*

<table>
<thead>
<tr>
<th>Equilibrium</th>
<th>$E_{\text{max}}$ A</th>
<th>$E_{\text{max}}$ B</th>
<th>Weighted Utility</th>
<th>$R^A_R$</th>
<th>$R^B_R$</th>
<th>$R_R$</th>
<th>$\bar{\tau}_A$</th>
<th>$\bar{\tau}_B$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>26.867357</td>
<td>26.450955</td>
<td>26.684139</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Nash-U</td>
<td>26.875396</td>
<td>26.393341</td>
<td>26.663291</td>
<td>0.0042</td>
<td>0.0024</td>
<td>0.0066</td>
<td>0.0643</td>
<td>0.0671</td>
</tr>
<tr>
<td>Nash-R</td>
<td>26.755032</td>
<td>26.215527</td>
<td>26.517650</td>
<td>0.0047</td>
<td>0.0029</td>
<td>0.0076</td>
<td>0.129</td>
<td>0.156</td>
</tr>
<tr>
<td>Planner-U</td>
<td>26.869106</td>
<td>26.460993</td>
<td>26.689536</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0029</td>
<td>0.0225</td>
<td>0.0225</td>
</tr>
<tr>
<td>Planner-D</td>
<td>26.872261</td>
<td>26.457017</td>
<td>26.689554</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0029</td>
<td>0.0211</td>
<td>0.0250</td>
</tr>
<tr>
<td>Hybrid-D</td>
<td>26.879712</td>
<td>26.447541</td>
<td>26.689557</td>
<td>0.0018</td>
<td>0.0011</td>
<td>0.0000</td>
<td>0.0212</td>
<td>0.0248</td>
</tr>
</tbody>
</table>

Notes: marginal utility of income is 35.6. Total population normalized to one. Exogenous local populations: 0.56 for dominion A and 0.44 for dominion B. Relative efficiency gains ($\omega$) are computed using the welfare gain of each dominion in the Planner-D (against the base) case as reference.
The reason *Hybrid-D* equilibrium fails to provide a Pareto-preferred allocation to region B is that it involves a local redistribution of revenue that does not guarantee any reciprocity to residents of region B using network links of region A. Since commuting flows are by calibration (see also Chapter 5) asymmetric, the volume of these users exceeds the respective volume of users from region A using network links of region B. Therefore, there is a net welfare loss of region B in favor of region A, which in *Planner-D* setting was offset by the lump-sum revenue recycling across the two regions.

6.5. Summary

This chapter provided a first provisional exploration of the welfare effects of local fiscal autonomy when pricing a mixed, polycentric road network with significant cross-commuting flows; future versions will refine the preliminary results through elaborate sensitivity analyses. We used a direct extension of the model developed in Chapter 5 for the area of Randstad, modified in order to abstract from pre-existing distortionary taxation. To simplify the analysis, we focused on a “North-South” setting by partitioning the area of Randstad into two large municipal clusters. The transportation network representation considered in the previous chapter was left intact, allowing for mode and route choice.

We found that toll competition in terms of local welfare reduces overall utility, but favors the large area whose links are widely used by residents of the smaller region. On the other hand, when the objective shifts to maximizing revenue, both regions end up with much higher toll levels and are worse-off. These decentralized settings were juxtaposed against two centralized cases, in which the kilometer tax is set by a social planner who aims to maximize the average utility of the two regions. This kilometer tax can (in the latter) and cannot (in the former) be differentiated in the two regions. In both cases, the resulting allocation is found to be Pareto-preferred to the no-toll equilibrium, in both regions. Finally, we investigated a scheme that combines centrally-set toll levels aiming to maximize average utility combined with local revenue recycling. At first sight, this hybrid scheme may appear equally efficient and more fair than the pure social planner scheme (with or without cross-region toll differentiation). However, the results reveal that the reciprocity of the hybrid scheme in the smaller region (region B), *i.e.* the part of the revenue generated by commuters originating from region B that is redistributed back to region B, is low enough to render this region worse-off. This result suggests that local discomfort to urban tolls may not be mitigated with local redistribution measures, especially when household relocation is subject to significant frictions as it is the case in the short run. Instead, this discomfort may be rooted in the existence of local redistribution mechanisms that intensify spatial inequality in the first place, *e.g.* spatially concentrated public good provision.
Appendix 6.A: Replicability of simulation experiments

The following tables provide the calibrated values of parameters used in the simulation experiments, as well as the values of the exogenous variables in the model. A vector of satisfactory initial values of the endogenous variables is available upon request.

Table 6.C.1. Values of parameters and exogenous variables

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
<th>Value 4</th>
<th>Value 5</th>
<th>Value 6</th>
<th>Value 7</th>
<th>Value 8</th>
<th>Value 9</th>
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<th>Value 15</th>
<th>Value 16</th>
<th>Value 17</th>
<th>Value 18</th>
<th>Value 19</th>
<th>Value 20</th>
</tr>
</thead>
</table>
| \( \alpha \) | 0.65 | \( z_p \) | -5.0 | \( \zeta_{11} \) | 0.140 | \( z_{15} \) | -1.47 | \( z_{17} \) | 0.00 | \( z_{11} \) | 2.60 | \( p_g \) | 0.05 | \( \hat{p}_g \) | 0.05 | \( \gamma \) | 0.40 | \( \zeta_{13} \) | 0.055 | \( z_{17} \) | 4.0 | \( z_{13} \) | 2.90 | \( p_P \) | 0.015 | \( \pi_0 \) | 35.6 | \( \zeta_{14} \) | 0.110 | \( z_{18} \) | -1.55 | \( z_{18} \) | 2.00 | \( \hat{p}_P \) | 0.015 | \( \pi_1 \) | 3.1 | \( \zeta_{15} \) | 0.040 | \( z_{18} \) | -1.82 | \( z_{18} \) | -4.0 | \( \beta \) | 0.35 | \( \zeta_{16} \) | 0.060 | \( z_{17} \) | 0.70 | \( z_{18} \) | -0.70 | R | 0.001 | \( \lambda \) | 3.0 | \( \zeta_{17} \) | 0.035 | \( z_{18} \) | 0.30 | \( z_{18} \) | 0.40 | Notes: Capital shares are assumed to be constant across zones for both firms (= 0.3) and developers (\( \theta = 0.3 \)). Volume delay function parameters are constant across all (road and rail) links; this is a weak assumption because all links represent large parts of a highway system which, at this level of aggregation, is relatively homogenous. Total factor productivity is uniform over space: differences in factor employment (including job concentration) and output level are generated through non-uniform cost shares (\( \zeta \)) of the assembly industry. This prevents wages from displaying a spatial variation that would be incompatible with data.