discussion paper

FLEMOSI
Tools for ex ante evaluation of socio-economic policies in Flanders

DISCUSSION PAPER 13

INEFFICIENCIES IN REGIONAL COMMUTING POLICY

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FLEMOSI DISCUSSION PAPER DP13

INEFFICIENCIES IN REGIONAL COMMUTING POLICY

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Abstract: This paper develops a small theoretical model to study commuting between a more productive and a less productive region. Both regions can tax or subsidize commuters and facilitate the commuting flow through transport investments. We show how strategic behaviour by regional governments may arise and lead to underinvestment in interregional transport infrastructure. This result can be reproduced in a setting with agglomeration or congestion externalities. A numerical example applies the theoretical insights to commuting in Belgium.

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1 Introduction

Commuting is a pervasive phenomenon in urbanized areas nowadays. Many people travel to work by car or by means of public transport. Agglomeration forces result in a higher concentration of economic activity. Together with residential structures, these spatial patterns create employment centers that attract workers from surrounding cities, regions or countries. In Belgium, for instance, the capital Brussels, with a population of 1 million, attracts nearly 400000 commuters on a daily basis from surrounding regions Flanders and Wallonia. Numerous countries stimulate commuting by providing commuting subsidies, for instance by making commuting costs income tax deductible or by heavily subsidizing public transport. In many countries, political decisions on transportation issues are made by different levels of government. For instance, a city can decide on parking fees, the regional authorities decide on investments in roads and the federal government holds responsibility for rail transport. This paper discusses some aspects of transport policy in a federal state. In particular, we study the commuting flows between a productive and a less productive region. Workers are immobile but can work in another region. Both the region sending the commuters and the region receiving the commuters can influence the commuting flow using different types of policy instruments. We study the incentives for the two regions to encourage or discourage commuting via commuting subsidies, taxes or transport investments and how these incentives depend on the ownership structure of firms, the number of regions, the tax sharing rules and agglomeration and congestion externalities.

We relate our paper to two strands of literature: urban economics literature and intergovernmental tax competition literature. Recent literature in urban economics discusses commuting in the context of agglomeration and congestion externalities. It distinguishes potential reasons and disadvantages of subsidizing commuting. The typical arguments in favor of commuting subsidies build upon agglomeration externalities, market imperfections and pre-existing distortions.

Wrede (2009) shows that commuting subsidies that countervail a distortive wage tax are efficiency enhancing if and only if labor supply is shifted from a less to a more productive area. This is closely related to our setting, since we show how a labor tax distorts job location decisions between two regions that differ in productivity.

Arnott (2007) studies the trade-off between congestion and agglomeration effects: unpriced congestion leads to too high commuting flows while agglomeration effects call for an encouragement of commuting. He concludes that if, for some reason, it is impossible to internalize agglomeration externalities, the optimal road toll should be set lower than the congestion externality costs. Both agglomeration and congestion externalities are considered specifically in separate sections of our paper, in which we illustrate how these effects might influence our results. Verhoef and Nijkamp (2003) also discuss the interaction between agglomeration externalities and externalities from commuting (pollution, in this case). They emphasize that the first best policy includes both a road toll, to account for pollution caused by traffic, and a labor subsidy, to stimulate agglomeration economies. In particular, changes in residential locations will lead to shorter commutes, which positively impacts both labor supply and environmental quality. Our paper neglects residential mobility, so that commuting subsidies and road tolls affect behavior (i.e. commuting decisions) in the same manner.

Borck and Wrede (2009) present a model in which workers, choosing place of residence and place of work simultaneously, generate urbanization externalities in production. If agglomeration rents are captured locally, commuters do not get their share of these rents. In this setting, commuting subsidies serve to internalize the agglomeration externalities and may lead to a first-best solution. Furthermore, they claim that a differing treatment between short- and long-distance commuting might be justified in terms of distributional concerns because the commuting subsidy would imply a transfer from the core to the periphery. As the authors acknowledge, their focus is on efficiency aspects, therefore neglecting competition between governments. In our paper, we neglect relocation of workers, focus on transport infrastructure investments and, most importantly, have regional governments as independent agents.

Commuting subsidies or taxes are not decided by one region in isolation. Different regions interact strategically and instruments of transport policy are allocated to different levels of government. Therefore, the second branch of literature on which we stand is intergovernmental tax literature. Tax competition arises when different government levels or regions affect each other's budget by choosing taxes and expenditures. The fact that a region does not take the effects on other regions into account when deciding on its optimal tax schedule can introduce allocative distortions and may result in overall efficiency losses (Oates 1999). The same holds when congestion, environmental or agglomeration externalities are not fully accounted for.

Horizontal tax and capacity competition - between governments at the same level, e.g. regional or state governments - in the transport sector is studied by De Borger et al. (2007). The paper relates to this one, since it discusses a non-cooperative game in both transport pricing and capacity investments. A specific feature of the model presented there is the distinction between local and transit traffic. In this setting, tax exporting behavior might lead to inefficiently high tolls. Our paper is different in that it looks into transport motives (commuting) and also integrates the effects on the labor markets and local profits.

The next section introduces the model and the underlying assumptions. Section 3 derives the first best allocation of workers and the optimal investments in transport. Subsequently, in sections 4 and 5, we analyze decisions on transport policy made at the regional level and discuss how government competition can give rise to undesirable outcomes. Section 6 introduces Nash competition between regional governments with transport investments as a strategic variable. Section 7 checks the robustness of our conclusions when we introduce additional features like more than two regions, revenue sharing mechanisms, changes in ownership structure of profits, agglomeration effects and congestion externalities. Before summarizing the findings in the conclusion, a numerical example illustrates the model for two Belgian regions.

2 The model

The economic model has three main actors. First, individuals, whose residence is fixed, choose where to work, i.e. whether to commute or not. Second, firms demand labor in a perfectly competitive environment. Third, regional governments influence commuting flows via their commuting policy. Initially, a model with only two regions is considered. This simplifies the analysis yet captures the basic intuition. In many areas, commuting flows come from only a limited number of areas, especially when labor mobility is limited. We return to this assumption in section 7.

First consider individuals. Let N_1 (N_i with $i = 1$) denote the number of homogeneous[1] individuals that live and work in region 1 (N_2 for region 2; $i = 2$). The number of people that reside in region 1 and work in region 2, i.e. the commuters, is labeled N_{12}. Empirical studies show the existence of an urban wage premium. Glaeser and Maré (1994), for instance, show that the urban wage gap is not only due to the fact that workers with higher ability live in the city, but that cities make workers more productive. In our model, region 2 attracts commuters because of its higher productivity and wages. Region 2 can be an urban area or a city, surrounded by a rural area or the periphery, region 1. Equivalently, region 2 is the central business district (CBD) to which a daily commuting flow is observed. The fixed total number of residents in region 1 equals $N = N_1 + N_{12}$.

The number of individuals is sufficiently large, such that any individual takes prices and wages as given. The economy is closed and there is no migration into the two regions, so that the total number of residents of both regions is fixed. Labor supply is perfectly inelastic. An individual of region 1 has the choice to work in his region of residence or to commute to the other region. No distinction is made between transport modes and leisure trips are ignored. If a worker decides to commute, he faces a fixed commuting cost c. This can include both time and monetary costs[2]. In the remainder of the paper, the commuting costs are thought of as using up physical resources. Note that by assuming that the commuting cost c is independent of the number of commuters, congestion externalities are not incorporated. In section 7.5 and the numerical example we include congestion and show that our main results carry through.

Furthermore, assume an individual's utility $U_i(x_i)$ depends only on the consumption of a homogeneous good x_i. Freight costs are ignored and as the good is homogeneous and there are many producers, the price of the homogeneous good can be normalized to 1 in both

[1] An analysis of commuting policy in a setting with heterogeneous workers, including redistributive impact of commuting subsidies, can be found in Borck and Wrede (2008).

[2] In fact, any disutility of commuting can be included in this commuting cost. Stutzer and Frey (2008), for instance, report a lower subjective well-being of commuters.

regions.

Next, consider the production side of the economy. Firms use homogeneous labor as the only input and produce a single homogeneous product. The stock of capital is fixed. A higher stock of capital in the urban area could then account for the higher productivity in this region. In addition, a firm pays its workers a uniform wage equal to their marginal product.

Different technologies are at firms' disposal in the different regions: $F_1(N_1)$ represents the production function in region 1 and $F_2(N_{12} + N_2)$ reflects the technology in region 2. We assume that region 2 is the more productive one, resulting in higher wages in region 2 ($w_2 > w_1$). This is the reason why commuting in only one direction is discussed. The higher productivity may be caused by some natural advantage or by agglomeration economies. There is extensive evidence on the nature and sources of agglomeration economies, as discussed by Rosenthal and Strange (2004). They claim that labor market pooling, input sharing and knowledge spillovers - the sources already suggested by Marshall (1920) - are important factors in explaining higher productivities in cities. In this paper, however, firms will not move towards more productive regions, as firm location is assumed to be fixed. We focus on worker mobility. Firms face decreasing returns to scale in both regions. Profits are paid out to regional shareholders, so they are a benefit to the region in which the firm is located. Only section 7.3 deviates from this assumption and discusses cross-border firm ownership. Later in the paper, specific functional forms for the production functions in both regions will be used to illustrate and clarify the impact of the commuting flow on profits and wages. Linearly decreasing marginal products offer a simple, albeit restrictive framework to discuss the model implications. The major drawback of this modeling approach is the absence of endogenous agglomeration externalities that point to marginal productivities that increase with the number of workers. In section 7.4 we analyze what results are robust when we allow for agglomeration effects. Figure 1 gives a graphical summary for the case with constantly decreasing marginal productivities in both regions.

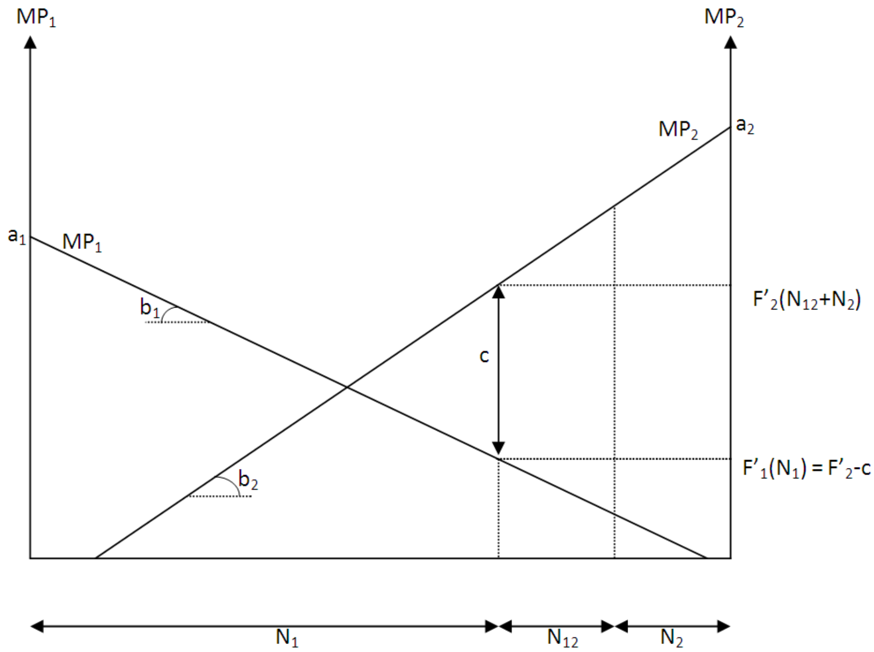

Figure 1: Model representation with constantly decreasing marginal productivities.

In figure 1, marginal products are shown on the vertical axes; there is a productivity advantage in the urban region as $a_2 > a_1$. The figure shows that marginal product in region 2, MP_2 (or F_2' or $\frac{\partial F_2}{\partial N_{12}}$), is higher for the initial distribution of residents ($N_1 + N_{12}$ people living in region 1) than the marginal product in region 1, MP_1. In perfect competition, the marginal product curves can be interpreted as wage curves ($MP_1 = w_1$ and $MP_2 = w_2$). With free commuting of workers, the wage gap would be eliminated by commuting and the equilibrium would occur at the intersection of the marginal product curves (N_{12} would increase and N_1 would decrease, as the total number of residents in region 1 is assumed to be fixed). However, a commuting cost c restricts mobility and allows a wage gap to exist in the spatial equilibrium. This equilibrium, and deviations from it, will be discussed in more detail in the remainder of the paper.

The average commuting cost c from region 1 to region 2 is constant. This commuting cost can be decreased by public transport investments ψ (in region 1) and ϕ (in region 2) that reduce the average commuting cost to $c - \psi - \phi$. Transport investments come at an increasing convex cost $K(\psi)$ (or $K(\phi)$). Our formulation is strongly simplified as we want to focus on commuting policy rather than on transport policy.

Note that we neglect many other aspects of wage formation, such as institutional settings or collective bargaining[3]. Regional growth and location decisions of firms are not discussed in this paper either. For a broader analysis of regional transport investment based on location theories, see Puga (2002) for a discussion of improvements in transport infrastructure in the context of the European regional policy.

Table 1 summarizes the main variables used in the rest of this paper. They will be clarified in following sections.

Variable	Explanation
i	Region $i = 1, 2$
N	Total number of people living in region 1
N_i	Number of people working and living in region i
N_{12}	Number of commuters from region 1 to region 2
c	Commuting cost
F_i	Production in region i
F_i'	Marginal product in region i
w_i	Wage in region i
ψ, ϕ	Investments in transport infrastructure
K	Transport infrastructure investment cost function
π_i	Profits in region i
$t_{(i)}$	(Regional) Labor tax rate
$s_{(i)}$	(Regional) Commuting costs subsidy rate
$W_{(i)}$	(Regional) welfare

Table 1: Model variables

[3]For a discussion of road pricing under alternative labor market structures and union preferences, we refer to De Borger (2009).

3 Federal government in control

Before we move on to regionalized policies, we discuss the efficient outcome for the federation as a whole. The results obtained here will serve as a benchmark. First, we assume that the government can simply choose the number of commuters. Next, we investigate optimal transport policy decisions when individuals are free to choose their job location.

3.1 Social optimum

This section derives the labor allocation and investment in transport infrastructure in a first best framework. The welfare maximizing social planner can decide on the optimal allocation of workers over the two regions and the level of transport investments. Since the utility of individuals only depends on consumption, the social planner maximizes the total production, which comprises profits and incomes, and takes commuting and infrastructure investment costs into account:

$$\underset{N_{12},\psi,\phi}{Max}\ W = F_1(.) + F_2(.) - (c - \psi - \phi)N_{12} - K(\psi) - K(\phi) \tag{1}$$

Note that the level of production in both regions depends on the number of commuters. The investment costs are assumed to depend only on the level of investments. The first order conditions with respect to the number of commuters N_{12} and the level of investment ψ (similar[4] for ϕ) display a clear intuition:

$$\frac{\partial F_1}{\partial N_1} = \frac{\partial F_2}{\partial N_{12}} - (c - \psi - \phi) \tag{2}$$

$$N_{12} = \frac{\partial K}{\partial \psi} \tag{3}$$

Condition (2) states that an efficient labor allocation implies that the gap between marginal products in both regions equals the commuting cost (which can be decreased through investment). Note that we have used $\frac{\partial F_1}{\partial N_1} = -\frac{\partial F_1}{\partial N_{12}}$ here (remember that $N - N_1 = N_{12}$ and that N is fixed). Expression (3) simply states that the marginal benefit of lowering transport costs should equal marginal costs of investing. It implies that the marginal benefit of investing in transport infrastructure is proportional to the number of commuters. This assumption is derived here from a non congestible transport technology. We include a linear congestion function in section 7.5 and in the numerical example. We assume increasing marginal cost

[4] Since ψ and ϕ work in an identical way, we show the expressions for ψ only.

of infrastructure investment (similar for ϕ)

$$K(\psi) = k\psi + \frac{1}{2}l\psi^2 \tag{4}$$

with $k, l > 0$. If one assumes linearly decreasing marginal products in both regions,

$$\begin{aligned} \frac{\partial F_1}{\partial N_1} &= a_1 - b_1 N_1 & (5) \\ \frac{\partial F_2}{\partial N_{12}} &= a_2 - b_2(N_2 + N_{12}), & (6) \end{aligned}$$

$a_1, a_2, b_1, b_2 > 0$, then we obtain an explicit expression for the optimal number of commuters. The first order conditions become

$$\begin{aligned} N_{12} &= \frac{1}{b_1 + b_2}(a_2 - a_1 - c + \psi + \phi + Nb_1 - N_2 b_2) & (7) \\ N_{12} &= k + l\psi & (8) \end{aligned}$$

From expression (7) we see that the optimal number of commuters is increasing in the difference of marginal products and decreasing in transport costs. The number of commuters increases with transport investments. Solving this system of equations, we find[5] explicit expressions for the optimal number of commuters and for the optimal transport investment level:

$$\begin{aligned} N_{12}^* &= \frac{l}{l(b_1 + b_2) - 1}(a_2 - a_1 - c + Nb_1 - N_2 b_2 - \frac{k}{l}) & (9) \\ \psi^* &= \frac{1}{l(b_1 + b_2) - 2}(a_2 - a_1 - c + Nb_1 - N_2 b_2 - k(b_1 + b_2)) & (10) \\ \phi^* &= \frac{1}{l(b_1 + b_2) - 2}(a_2 - a_1 - c + Nb_1 - N_2 b_2 - k(b_1 + b_2)) & (11) \end{aligned}$$

Unsurprisingly, expressions (10) and (11) show that the optimal transport investment level will be higher if the cost parameters k and l are lower[6]. We make two important assumptions. First, we assume that the optimal number of commuters is positive, even without transport investments: $a_2 - a_1 - c + Nb_1 - N_2 b_2 > 0$. Secondly, the parameters of the investment cost function are such that ψ^* and ϕ^* are positive. The functional forms (4), (5) and (6) will be used throughout the paper.

[5] See details in appendix A.

[6] We assume here that the cost parameters are the same in both regions.

3.2 Attaining first best under free movement of workers

Instead of the social planner deciding directly on the number of commuters, we now let indiviuals choose their location of work. Assume there is an exogenous labor tax t to finance government operation. The government has two policy instruments at its disposal: infrastructure investments ψ and ϕ and commuting subsidies s. The inclusion of the (flat) labor tax rate is crucial in that it provides the rationale for commuting subsidies, as will be shown here. Furthermore, there is a perfectly competitive labor market, such that workers are paid their marginal product ($w_1 = \frac{\partial F_1}{\partial N_1}$ and $w_2 = \frac{\partial F_2}{\partial N_2} = \frac{\partial F_2}{\partial N_{12}}$, where w_i is the gross wage in region i). In this section, the government does not allocate workers to regions, but individuals decide where to work. We then have a spatial equilibrium condition (12) that equalizes net wages for all workers:

$$(1-t)\mathbf{w}_1(.) = (1-t)\mathbf{w}_2(.) - (1-s)(c-\psi-\phi) \tag{12}$$

The fraction of commuting costs that is subsidized is represented by s. Hence, an individual that crosses jurisdictional borders to work, will be compensated through a higher wage. We ignore compensation in the form of lower housing prices, since the assumption of fixed residence location cancels out land rent aspects[7]. Rewriting the spatial equilibrium condition (12) gives

$$\frac{\partial F_1}{\partial N_1} = \frac{\partial F_2}{\partial N_{12}} - \frac{1-s}{1-t}(c-\psi-\phi) \tag{13}$$

This shows that the combination of commuting costs and labor taxation distorts labor location decisions: the labor tax decreases the incentive for the commuters so that social marginal products of labor are not equalized. The federal government can make commuting expenses tax deductible, i.e. $s = t$, to correct the distortion in the labor market. This allows to achieve the efficient, first best outcome. Expression (13) then simply reduces to equation (2), such that an efficient spatial distribution of labor is guaranteed. Decisions on infrastructure investments remain unchanged. In this case, the optimal number of commuters and the optimal investment level is again given by expressions (9), (10) and (11). Non-distortionary lump sum taxes instead of labor taxation would result in an optimal commuting subsidy of $s = 0$. In conclusion, the federal government makes commuting expenses tax deductible in order to correct the distortion created by the combination of labor taxes and commuting costs.

[7] Van Ommeren and Rietveld (2007), for instance, obtain only partial (how much depends on the wage bargaining power between worker and employer) compensation for commuting costs through wages in a setting with imperfections in housing and labour markets.

Note that we have not specified that the labor tax revenue should cover the expenses on subsidies and infrastructure investment. More specifically, we assume that the government uses a linear income tax where the fixed term can be varied, or uses another non-distortionary tax T_0 to balance the budget. With the exogenous revenue requirement R_0, the government budget constraint is

$$T_0 + \underbrace{t\left(N_1 w_1 + N_{12} w_2 + N_2 w_2\right)}_{\text{labor tax revenue}} = R_0 + \underbrace{K}_{\text{inv. cost}} + \underbrace{N_{12} s(c - \psi - \phi)}_{\text{subsidy expenditures}}$$

where exogenous public expenditures R_0 enter the utility function as a separable argument.

4 Strategic behavior of regional government

We now shift the responsibility of transport decisions to the government of the peripheral region. First we discuss strategic incentives in transportation policy in depth. Afterwards, we include a second policy instrument and we include also labor tax distortions.

4.1 Strategic behavior in transport investments

This section analyzes in detail, in a simplified setting, whether the regional government has incentives for strategic behavior that would lead to over- or underinvestment in commuting transport infrastructure. In order to do so, we regionalize the decisions on transport infrastructure investment in region 1, ψ. Assume that the region has the same investment cost function as the social planner and that the federal government makes commuting costs tax deductible, $s = t$. We abandon the latter assumption in the next section. The full deductibility of commuting expenses cancels out the labor tax distortion, as shown in the previous section. Here we also assume that the region does not have the opportunity to influence commuting flows through commuting subsidies or taxes. This allows us to demonstrate the idea of the strategic behavior in a minimal setting. The objective function of the government of region 1, when maximizing welfare of its residents, takes local profits, incomes of its residents and investment costs into account:

$$\underset{\psi}{Max} W_1(\psi) = \underbrace{\pi_1(N_{12}(\psi))}_{\text{Profits}} + \underbrace{N_1(\psi)\frac{\partial F_1(N_{12}(\psi))}{\partial N_{12}(\psi)} + N_{12}(\psi)(\frac{\partial F_2(N_{12}(\psi))}{\partial N_{12}(\psi)} - c + \psi)}_{\text{Real labor incomes}} - \underbrace{K(\psi)}_{\text{Inv. cost}} \tag{14}$$

Tax revenue is not included in the objective function, as we assume that the region is mainly financed via non-labor taxes[8]. Using $\frac{\partial F_1(N_{12}(\psi))}{\partial N_{12}(\psi)} = \frac{\partial F_2(N_{12}(\psi))}{\partial N_{12}(\psi)} - (c - \psi - \phi)$ (see equation 13), the first order condition for the optimal transport investment by the region becomes:

$$\underbrace{\frac{\partial N_{12}(\psi)}{\partial \psi}[\frac{\partial \pi_1(N_{12}(\psi))}{\partial N_{12}(\psi)} + N_1(\psi)\frac{\partial^2 F_1(N_{12}(\psi))}{\partial N_{12}(\psi)^2} + N_{12}(\psi)\frac{\partial^2 F_2(N_{12}(\psi))}{\partial N_{12}(\psi)^2}]}_{\text{Strategic effect}} + N_{12}(\psi) = \frac{\partial K(\psi)}{\partial \psi} \tag{15}$$

If region 1, the peripheral region, perceives its position on the labor market in urban region 2 as dominant, a strategic effect appears. To see where the strategic concerns of the regional government stem from, one can disentangle the strategic effect into three components. Firstly, the number of commuters has an impact on profits in region 1. This is reflected by the term

[8] or receives a fixed grant from the federal government.

$\frac{\partial \pi_1(N_{12}(\psi))}{\partial N_{12}(\psi)}$. Secondly, there will be an effect on wages in region 1, which is captured by $\frac{\partial^2 F_1(N_{12}(\psi))}{\partial N_{12}(\psi)^2}$. Thirdly, the urban wages will be affected by the number of commuters. These wages are relevant for the regional government since they are also paid to individuals that reside in region 1 but work in the city. This effect shows up in $\frac{\partial^2 F_2(N_{12}(\psi))}{\partial N_{12}(\psi)^2}$.

If one assumes linearly decreasing marginal products in both regions, as in (5) and (6), the first two terms in the strategic effect cancel each other out, which implies a redistribution of income between workers and firm-owners in region 1. Therefore, using the functional forms (5) and (6) for marginal products, the first order condition (15) becomes

$$N_{12}(\psi)\underbrace{(1 - \frac{b_2}{b_1 + b_2})}_{<1} = \frac{\partial K(\psi)}{\partial \psi}. \tag{16}$$

This shows that the regional investment level will now be lower than in the social optimum[9]. The marginal benefits of investing, on the left-hand side of (16), are reduced (compare with expression (8)). Region 1 invests less in transport infrastructure as this allows to restrict the number of commuters and increase their wage. This can be seen as a terms-of-trade effect: region 1 "exports" commuters to region 2 and can influence its terms of trade by restricting the number of commuters. One disguised way of doing this is to restrict transport investments. The decreased commuting flow is welfare-reducing for region 2 and for the federation as a whole.

The distinct effects are shown in detail in figure 2 and table 2. The strategic effect is illustrated in figure 2 by a reduction of the number of commuters from N_{12}^*, the social planner optimum, to N_{12}^{strat}, the restricted commuting flow under strategic behavior of region 1. A lower number of commuters implies more people working in region 1, which will decrease local marginal products and therefore wages in the rural region. The wage decrease combined with an increase of production results in a profit increase in region 1 of the area $EBDF$. However, all individuals that now work in region 1 will face a decrease of net wages, which amounts to the area $EODF$. The net effect is negative and is represented by the triangle BOD. This loss has to be traded off with the increase of net wages of commuters, shown by the area $KLMO$ (or $CGPH$ in gross wages in figure 2).

[9] See appendix B for the complete derivation.

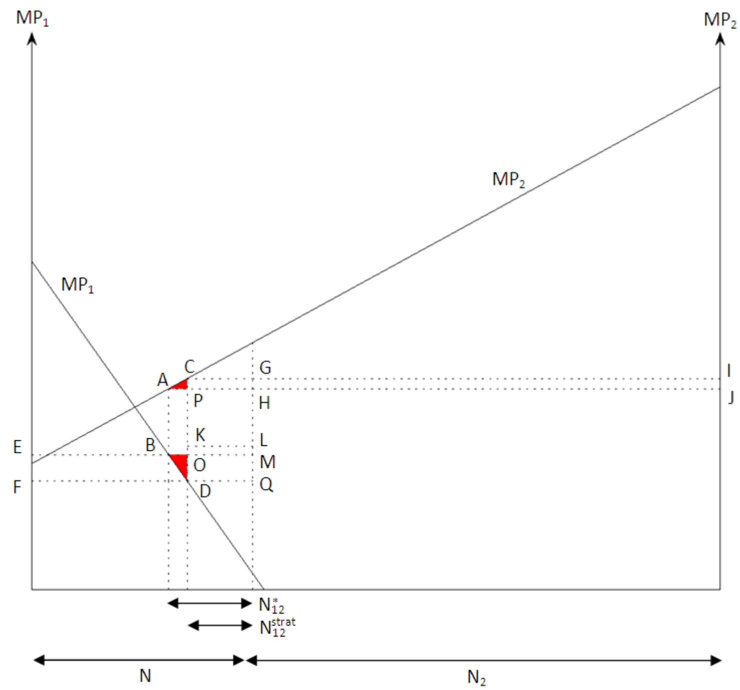

Figure 2: Welfare effects of a restricted number of commuters.

The impact on welfare in the urban region 2 is unambiguously negative. The loss in profits (area $ACIJ$), caused by a lowered production level and a higher wage, can be decomposed in three parts: area $GIJH$ is shifted towards city residents in terms of higher wages, area $CGPH$ goes to commuters for the same reason, and triangle ACP is lost due to the lower production level. The net effect for region 2 will therefore be negative and equal to the area $ACGH$, since commuters' wages are not part of urban region welfare. Total welfare in the economy is decreased by the triangles ACP and BOD. Table 2 summarizes.

	Region 1	Region 2	Total
Profits	+EBDF	-ACIJ	+EBDF - ACIJ
Real income	-EODF +KLMO	+GHIJ	-EODF + KLMO + GHIJ
Total	-BOD +KLMO	-ACGH	-ACP - BOD

Table 2: Welfare effects of limiting the number of commuters

4.2 Regional transport investment and commuting subsidies when labor is taxed

We now derive optimal decisions of the regional government in a wider policy framework, including a regional commuting subsidy rate s_1, regional infrastructure investments ψ and regional labor taxes t_1. First we derive general analytical results for a combination of regional subsidies and transport investments. The next subsections discuss different effects separately and add a regional labor tax. Take the regional labor tax $t_1 < 1$ as given. The government of region 1 then faces the following maximization problem:

$$\underset{s_1,\psi}{Max}\ W_1 = \underbrace{\pi_1(.)}_{\text{local profits}} + \underbrace{N_1(.)w_1(.) + N_{12}(.)(w_2(.) - c + \psi)}_{\text{local real income}} - \underbrace{K(.)}_{\text{inv. cost}} \tag{17}$$

$$s.t. \qquad \pi_1 = \frac{1}{2}N_1(.)(a_1 - w_1(.)) \tag{18}$$

$$N_{12} = \frac{1}{b_1 + b_2}(a_2 - a_1 - \frac{1 - s_1}{1 - t_1}(c - \psi) + b_1 N - b_2 N_2) \tag{19}$$

where w_1 and w_2 are given by expression (5) and (6) respectively. The specification of profits π_1 can be easily understood by looking at figure 1. Equivalently, we can write profits π_1 as the difference between total revenue and total costs: $\pi_1 = F_1(.) - N_1(.)w_1(.)$, with production $F_1(.) = a_1 N_1(.) - \frac{1}{2}b_1 N_1^2(.)$. The number of commuters is given by equation (19), which can be obtained (in a similar fashion as (7)) from the spatial equilibrium condition (similar to (13)). Commuting subsidies influence the number of commuters, but are no net cost for region 1 as they go to inhabitants. Policy instruments influence the allocation of workers, which in turn affects wages and profits. The regional government can now subsidize commuting at a rate s_1. Setting the first order condition with respect to s_1 equal to 0 gives an expression for the regional commuting subsidies:

$$s_1 = -\frac{b_2}{(c - \psi)(b_1 + 2b_2)}\left(a_2 - a_1 - c + \psi + Nb_1 - N_2 b_2\right)(1 - t_1) + t_1 \tag{20}$$

To make a clear case, the effects embodied in this expression will be analyzed step by step. First we ignore labor taxes and transport investments, because if the government can influence the number of commuters in a direct way by subsidies and taxes, the optimal investment rule will boil down to equating marginal costs and benefits. Next, the additional interactions with pre-existing labor market distortions are included when we replace lump sum taxation by a tax on labor. This set-up is interesting because it makes the trade-off between the strategic effect (derived in section 4.2.1) and the incentive to give commuting subsidies (caused by the distortive labor tax) explicit. Finally, transport investments are added to the analysis to have the full picture and the interaction between all regional commuting policy instruments.

4.2.1 A regional tax on commuters

In this section, we set ψ equal to 0 and clarify the strategic behavior by analyzing commuting subsidies that are a more direct way to influence commuting flows. Focusing on subsidies instead of investments implies that no assumptions on the cost of infrastructure investment have to be made. If we assume there are no labor taxes (set $t_1 = 0$ in equation (20) to cancel out the labor tax distortion), we can isolate the strategic effect. The expression for the optimal commuting subsidy boils down to

$$s_1^{strat} = -\frac{b_2}{cb_1 + 2cb_2}\left(a_2 - a_1 - c + Nb_1 - N_2 b_2\right). \tag{21}$$

Under the assumptions made in section 3.1, $s_1^{strat} < 0$ and the government taxes commuters instead of subsidizing. Therefore, the resulting number of commuters,

$$N_{12}^{strat} = \frac{1}{b_1 + \mathbf{2}b_2}\left(a_2 - a_1 - c + Nb_1 - N_2 b_2\right),$$

will be restricted compared to the federal optimum. We can compare with expression (7) (with $\psi = \phi = 0$) to see that this is indeed the case. Whereas an efficiency-preserving social planner would set commuting subsidies equal to 0, the regional government limits the number of commuters by levying a tax on commuting. The reason is the increase in the commuters' wages obtained via the terms-of-trade effect.

4.2.2 Labor taxation and commuting subsidies

We keep $\psi = 0$, but consider the interaction with a regional labor tax t_1. This section shows that whether the regional government sets a commuting tax or a subsidy depends on two countervailing forces. Correcting the labor tax distortion asks for a commuting subsidy, whereas strategic reasons provide an incentive for a commuting tax. The trade-off can be shown more explicitly. In particular, the regional government taxes commuters if s_1 is negative, so if[10]

$$-\frac{b_2}{cb_1 + 2cb_2}\left(a_2 - a_1 - c + Nb_1 - N_2 b_2\right)(1 - t_1) + t_1 < 0$$

$$\Longleftrightarrow$$

[10] See appendix C for more details.

$$\underbrace{|s_1^{strat}|}_{Strategic\ effect} \quad > \quad \underbrace{|\frac{t_1}{t_1 - 1}|}_{Distortive\ effect}$$

The left-hand side captures the strategic effect (as in expression (21)). The right-hand side shows the distortion caused by the taxation of labor. With $t_1 < 1$, the commuting subsidy will not be equal to the labor tax rate ($s_1 < t_1$). Whereas efficiency concerns ask for a complete deductibility of commuting expenses, as discussed in section 3.2, strategic motives will prevent the regional government from setting $s_1 = t_1$. Again, this reduces the number of commuters compared to the social planner outcome and raises the commuter wage.

4.2.3 Labor taxation, transport investments and commuting subsidies

Now add transport investments as a second instrument of transport policy. We then obtain the full expression given by (20). The marginal benefit of investing in infrastructure depends on the number of commuters. Since the trade-off in the previous subsection results in a restricted number of commuters, the marginal benefit of infrastructure investments will be reduced. Therefore, the level of these investments will be lower than socially optimal. Note that the optimal subsidy s_1 is decreasing in ψ. This means that a higher transport investment will bring about a higher tax on commuters. This makes sense: as transport costs are reduced, more people choose to commute. But to keep wages of commuters high, the commuting should be restricted. In short, the government invests to reduce the commuting costs and limits the commuting flow by setting a tax on commuting. In fact, the regional government has contradictory objectives when transportation investments are added as a policy instrument. Reducing transport costs, on the one hand, and thereby increasing the number of commuters, is beneficial because transport costs are considered to be a loss for its commuters. On the other hand, strategic arguments would restrict the number of commuters. These two arguments influence the commuting flow in opposite directions.

5 Strategic behavior of urban area government

The previous section assumed that region 1 was a dominant supplier of labor to the urban region 2. However, this is not necessarily the case in reality. In this section we analyze the situation in which the urban area or city is a dominant player on the demand side of the labor market. For region 2 the incentives are different. In our model, the urban region would prefer as much commuters as possible, since this causes an increase in local profits that overcompensates the income loss for local workers (recall figure 2 and table 2: the wage decrease of commuters is not taken into account by region 2). Therefore, the commuting inflow has unambiguously positive effects for the urban region. However, taxing commuters gives an extra government income. This reasoning suggests that the city may have an incentive to invest in transport infrastructure in order to keep the number of commuters high, in combination with a tax on commuters to increase government revenue. We show in this section that the urban region's government may have an incentive for tax exporting and study the interaction between commuting policy instruments.

5.1 Transport investments and commuting taxes set by the urban area

Consider transport investments ϕ and commuting subsidies s_2 ($s_2 < 0$ if it is a tax) by the urban region. Assume there is no labor tax and that the urban area has the following costs associated with investments in commuting transport on its own territory:

$$K(\phi) = m\phi + \frac{1}{2}n\phi^2,$$

$m, n > 0$. The government of the urban region then has an incentive to set high taxes on commuters and high investments in transport. The city government faces the objective function

$$\begin{aligned} \underset{s_2,\phi}{Max} W_2 &= \underbrace{\pi_2(.)}_{\text{local profits}} + \underbrace{N_2 w_2(.)}_{\text{local real income}} - \underbrace{N_{12}(.) s_2 (c-\phi)}_{\text{tax revenue on commuters}} - \underbrace{K_c(.)}_{\text{inv. cost}} \\ s.t. \qquad \pi_2 &= \frac{1}{2}(N_{12}(.) + N_2)(a_2 - w_2) \end{aligned}$$

where gross wages again equal marginal products and profits π_2 are expressed as producer surplus on figure 1. Again, profits could be written as $\pi_2 = F_2(.) - (N_{12}(.) + N_2)w_2(.)$. Note that, in contrast to the objective function of region 1, the tax revenue is now a net benefit because it is paid by non-residents. The first order condition with respect to s_2 gives

$$s_2 = -\frac{1}{c-\phi}\frac{b_1}{2b_1+b_2}(a_2 - a_1 - c + \phi + Nb_1 - N_2 b_2)$$

For now, note two effects. First, note that this is indeed a tax ($s_2 < 0$) for $\phi = 0$. Second, the expression above shows that the city region will set a higher tax on commuters when the level of transport investments is higher. This is because high investments leads to a high number of commuters. When there are many commuters, taxing them generates a substantial revenue for the government. The first order condition with respect to ϕ gives

$$\underbrace{1 - s_2}_{(1)} \left(\underbrace{\frac{b_2}{b_1+b_2} N_{12}}_{(2)} - \underbrace{\frac{s_2(c-\phi)}{b_1+b_2}}_{(3)} \right) + \underbrace{N_{12} s_2}_{(4)} = m + n\phi \tag{22}$$

Marginal benefit of investing in infrastructure, on the left-hand side of expression (22), now depends on four factors. We discuss these in turn.

Term (1) shows that commuters respond to the net wage gap. Consider for instance commuting subsidies of 20%. If transport costs are reduced by one unit, commuters then only react to a transport cost decrease of 0.8 (see expression 13). Therefore, the commuting subsidy reduces the impact of transport investments on commuting flow.

Term (2) is the marginal benefit of investing in transport infrastructure if the city does not have the possibility to tax or subsidize commuters, $s_2 = 0$. The reason for the city to invest in infrastructure is not to reduce transport costs (these are incurred by commuters), but merely to increase commuting, which drives down local wages and raises the level of production and profits in the city. This increase in profits overcompensates the reduction in wages of residents as part of the income shift is from commuters to local firms (as can be seen from figure 2). The investments in the urban area will be lower than socially optimal. This can be seen by comparing term (2) to expression (8) (assuming the same cost structure of investments, $k = m$ and $l = n$). The reason is that the commuting costs are borne by non-residents. A reduction in commuting costs therefore only has an indirect positive effect on welfare of region 2 via higher profits.

Term (3) enters the first order condition because a higher level of investments causes more workers to commute, thereby also increasing the commuting tax revenues. Therefore, this term is specific for the urban area and represents the tax exporting behavior. It depends on the size of the subsidy (numerator) and how the number of commuters is affected by an investment in transport (denominator, together with term (1)). Note that $s_2 < 0$, so that the tax revenues are included as an additional marginal benefit of infrastructure investment.

Term (4) indicates that an investment in transport lowers the tax income per commuter, since this is $s_2(c-\phi)$.

In conclusion, we see that both regions have an incentive to tax commuting. For region 1, the rural area, this incentive is driven by the attempt to reduce the number of commuters in order to increase their wage. Region 2, on the other hand, benefits from an increase in commuters, but nevertheless has an incentive to tax non-residential workers as a means of tax exporting. To attract an inflow of workers, the urban region will still invest in transport infrastructure. A higher number of commuters also means higher commuting tax revenues. The rural region will invest to reduce the transport costs borne by commuters. In many federal countries, regional commuting taxes or subsidies are not allowed and this could be justified when the federal government wants to avoid tax exporting or terms-of-trade effects. Therefore, it is interesting to look in the next section at the case where regions only have transport infrastructure investments as a policy instrument.

6 Nash equilibrium in transport investments

This section looks into the Nash equilibrium between the governments of the rural and the urban region when both can invest in transport infrastructure. Commuting subsidies or taxes are no longer possible and we assume there is no labor tax. The number of commuters is then given by

$$N_{12}(\psi,\phi)=\frac{1}{b_1+b_2}(a_2-a_1-c+\psi+\phi+Nb_1-N_2b_2)$$

From expressions (16) and (22) (with $s_2=0$) we obtain the optimal investment rules, where each region takes the investment of the other region as given:

$$\begin{aligned}\frac{b_1}{b_1+b_2}N_{12}(\psi,\phi) &= k+l\psi\\ \frac{b_2}{b_1+b_2}N_{12}(\psi,\phi) &= m+n\phi\end{aligned}$$

Both these reaction curves are increasing in the level of infrastructure investment from the other region. The intuition is the following; when the city region invests more in transport infrastructure, more workers will commute. More commuters implies more individuals will benefit from a reduction in transport costs. Therefore, the marginal benefit of investment will be higher for region 1 when investments of region 2 are higher. The reverse also holds: if rural region 1 invests in commuting infrastructure, more people will commute. This will increase profits in the urban region by reducing the wages. If there are many commuters, a wage decrease will be more interesting for region 2, because it implies a larger shift from commuter incomes to urban profits. Therefore the marginal benefit of an investment in the urban region will be increasing in the level of transport infrastructure investment in the rural region.

To compare the total level of investments to the social planner outcome of section 3.1, we assume that both the rural region and the city region have the same cost function for transport infrastructure. Solving for ψ and ϕ, with $k = m$ and $l = n$, and summing to obtain the total level of investments, we get[11]

$$\psi + \phi = \frac{\mathbf{1}}{l(b_1 + b_2) - \mathbf{1}} \left(a_2 - a_1 - c + Nb_1 - N_2 b_2 - \mathbf{2}k(b_1 + b_2)\right)$$

The total investment in transport is lower than in the social planner case. This can be seen by comparing with the sum of expressions (10) and (11). This should not come as a surprise. Previous sections showed that region 1 has an incentive to underinvest to keep commuter wages high. Region 2 underinvests in transport infrastructure because non-residents bear the commuting cost. In conclusion, the outcome of the Nash competition in transport investments results in a level of investments that, from a social point of view, is too low.

[11] See appendix D.

7 Alternative scenarios

In this section, we check the robustness of our results by relaxing some of the assumptions. First, we include a third region. Next, we discuss the impact of revenue sharing of federal taxes. Third, we change the assumption that profits are captured locally. Fourth, we include agglomeration externalities. The fifth and last extension looks at congestion costs.

7.1 Three regions

Consider a third region that, like region 1, sends commuters to the more productive region 2. We can now study the effects of Nash competition (Bertrand-Nash, with regions deciding on the subsidy rather than on the number of commuters directly) among governments 1 and 3 on the labor market in the urban region 2. Region 3 has M inhabitants of which N_3 live and work in this region. Productivity and wages in this region are lower than in region 2. Therefore, N_{32} workers commute. If region 3 is also a dominant supplier of labor in region 2, its government will have an incentive to set a tax on commuting, as discussed for region 1. Assume no labor taxation and no investments in transport. We now derive the Bertrand equilibrium (N_{12}, N_{32}) where regions 1 and 3 determine in a Nash way their preferred commuting subsidy (tax). The corresponding commuting taxes, set by region 1, are now[12]

$$s_1^{Nash} = \underbrace{-\frac{b_2}{cb_1 + 2cb_2}\left(a_2 - a_1 - c + Nb_1 - N_2 b_2\right)}_{s_1^{strat}} \underbrace{\frac{(b_1^2 + 3b_1 b_2 + b_2^2)}{(b_1^2 + 4b_1 b_2 + 3b_2^2)}}_{<1}$$

The inclusion of a third region, that also supplies labor to the city, reduces the scope for strategic behavior of region 1. Because region 1 is no longer the only supplier of labor in the city, its position is now less dominant. If the government of region 1 decides to reduce the number of commuters to keep wages in the city high, then an increased commuting flow from region 2 will (partially) offset the desired effect (higher wages). Therefore, region 1 has a weaker incentive to set commuting taxes. This result can be easily seen by comparing with expression (21) for the commuting tax s_1^{strat}.

This result makes us question whether the effects in this paper would hold for cities in the real world, where several regions can supply labor to the city region. With an infinite number of regions, perfect competition would render strategic behavior impossible. However, the geographic reality is that the number of regions supplying labor to an urban region are

[12] The derivation can be found in appendix E.

often limited to a few.

7.2 Revenue sharing mechanisms

Many federal countries have revenue sharing mechanisms for the labor tax (Boadway and Shah 2009). Assume there is a federal labor tax and consider a framework with only two regions. Define θ_1 as the share of federal tax revenue that goes to region 1 ($0 < \theta_1 < 1$). Consider the case where the lower level government decides on the commuting tax and the investments in transport infrastructure. The regional government now maximizes the following objective function:

$$\begin{aligned} \underset{N_{12},\psi}{Max}\ W_1 \ &= \ \pi_1 + N_1(.)w_1(.) + N_{12}(.)(w_2(.) - c + \psi)) - K(.) \\ &\quad +\theta_1 t(N_1(.)w_1(.) + (N_{12}(.) + N_2)w_2(.)) \\ &\quad -t(N_1 w_1(.) + N_{12} w_2(.)) \end{aligned} \tag{23}$$

where the last two lines represent region 1's share of federal tax revenues and its taxes paid, respectively. These no longer cancel each other out as is the case with a regional labor (or lump sum) tax. Rewriting the problem brings out the necessary intuition to analyze the problem:

$$\underset{N_{12},\psi}{Max}\ W_1 = \underbrace{\pi_1}_{(1)} + \underbrace{(1 - t + \theta_1 t)(N_1(.)w_1(.) + N_{12}(.)w_2(.))}_{(2)} + \underbrace{\theta_1 t N_2 w_2(.)}_{(3)} \underbrace{- N_{12}(.)(c - \psi) - K(.)}_{(4)},$$

An analysis of this objective function is enough to understand the nature of the outcome. We distinguish four terms.

(1): Regional profits enter the objective function as before;

(2): A lower weight is given to real income of residents of region 1, since $1 - t + \theta_1 t < 1$;

(3): Income of residents of region 2 enters the objective function with a weight of $\theta_1 t > 0$;

(4): Commuting and investment cost are subtracted, as before.

Because higher income in region 2 increases the value of tax revenue redistributed to region 1, this region will now attach a weight to income in region 2. Furthermore, a lower weight is attached to income of its own residents. We might therefore be inclined to state that this situation will drive the outcome towards the social optimum. However, consider the welfare effects displayed in table 2. The impact of restricting the number of commuters on real income of region 1 is given by area $-EODF + KLMO$. This area, which is possibly negative for welfare in region 1, is now given a lower weight. A higher weight is now given to the income effect in region 2, which is positive ($+GHIJ$). Therefore, the sharing rule for the federal labor tax revenues might even intensify the strategic behavior of region 1.

One could also distinguish here between distribution of federal tax revenues according to place-of-residence and place-of-work. If the collected labor taxes are redistributed on the basis of the number of residents in a region, we get (for region 1)

$$\theta_1 = \frac{N_1 w_1 + N_{12} w_2}{N_1 w_1 + (N_{12} + N_2) w_2} \tag{24}$$

In this case, tax revenue obtained from residents of region 1 is completely redistributed to that region. The last two lines of (23) would cancel each other out and we return to the case without revenue sharing. However, if federal labor tax revenues are allocated to the regions in relation to the number of people that are employed in that region, i.e. on a place-of-work basis, the share θ_1 becomes

$$\theta_1 = \frac{N_1 w_1}{N_1 w_1 + (N_{12} + N_2) w_2} \tag{25}$$

Then region 1 would no longer receive funds from labor taxes levied on commuters, which boils down to a decrease of θ_1. Following the same line of reasoning as in the previous paragraph, we conclude that labor tax redistribution according to the place-of-work principle might attenuate the strategic incentives of region 1, compared to tax revenue sharing on the basis of place-of-residence.

7.3 Ownership structure or profit taxes

A similar reasoning can be made for different ownership structures. Until now, firm ownership was assumed to be local, i.e. local firms were owned by local residents. This section assumes that profit shares are spread across jurisdictional borders. The assumption that each individual owns only a negligible share of profits can still be made. Residents of region 1 now get part of the profit made in region 2, and vice versa. Denote using δ_1 the share of profits of firms in region 1 owned by residents of region 1 ($0 < \delta_1 < 1$). Similarly, let γ_1 be the profit share of region 1 inhabitants in profits of firms in region 2 ($0 < \gamma_1 < 1$). The objective function of the government of region 1 becomes:

$$\underset{N_{12},\psi}{Max}\ W_1 = N_1(.)w_1(.) + N_{12}(.)(w_2(.) - c + \psi) - K(.) + \underbrace{\delta_1 \pi_1(.)}_{\text{share in profits region 1}} + \underbrace{\gamma_1 \pi_2}_{\text{share in profits region 2}}$$

An analysis of this expression reveals that local profits get a lower weight in the regional welfare function ($\delta_1 < 1$) and profits made in the city now enter the objective function with a positive weight ($\gamma_1 > 0$). Restricting the number of commuters affects profits in region 1 positively and profits in region 2 negatively (see table 2). A clear conclusion can be drawn: since a local government now cares less about profits on its own territory and more about profits made in the other region, the outcome will be closer to the social optimum.

7.4 Agglomeration economies in the urban region

The analyses in previous (and subsequent) sections builds upon the framework in which we assumed that every additional worker in a region marginally decreases wages in that region. This setting can represent a situation with a fixed capital stock or with a given level of public infrastructure. Productivity differed in the two regions and we had decreasing returns in both regions. However, the opposite is not unlikely: although the size of agglomeration externalities is still widely debated, the idea of increasing returns can not be ruled out. Venables (2007) and Graham (2007), for instance, emphasize the importance of including agglomeration economies in the analysis of transport investments. This section explores regional government competition in a simplified set-up with agglomeration economies in the urban area. We first lay out the simple analytical treatment, after which we use a graphical analysis to illustrate the incentives that regions face in this setting.

First of all, we assume that only the urban area provides the right framework for agglomeration externalities to occur. Therefore, the assumptions for the production in the rural area, region 1, remain unchanged (linearly downward sloping marginal product curves). However, on the production side of the urban region 2, we assume the presence of agglomeration externalities. The total amount of labor employed in region 2 increases productivity of all firms located in that region. In other words, adding a worker to the urban area increases wages in that region. As suggested by Henderson (1974) and applied by Borck and Wrede (2009) and Arnott (2007), we model the production of firm j in region 2 with labor input h_j as

$$y_j = E(N_{12} + N_2)F_2(h_j) \tag{26}$$

where $E(N_{12} + N_2)$ is the externality function that depends on the total labor employed in region 2, $N_{12} + N_2$. The externality function reflects that productivity increases in the presence of an agglomeration effect, $\frac{\partial E(N_{12}+N_2)}{\partial N_{12}} > 0$. The effect is 'external' to the firm in that each individual firm takes $E(N_{12} + N_2)$ as fixed. To keep the analysis as simple as possible, we assume that the externality function is linear[13]:

$$E(N_{12} + N_2) = \beta(N_{12} + N_2) \tag{27}$$

where $\beta > 0$ is a parameter for the strength of the agglomeration externality. The 'internal' production function of the firm could be modelled as displaying decreasing, constant or increasing returns. As in Arnott (2007), we assume constant returns to scale since this keeps

[13] It might be more realistic to model this as $(N_{12} + N_2)^\beta$, with $0 < \beta < 1$, but we use this assumption in order to keep the model tractable.

the model straightforward and insightful:

$$F_2(N_2 + N_{12}) = r(N_2 + N_{12}) \tag{28}$$

where $r > 0$ is the marginal return to an additional worker in the urban region. We assume perfect competition (so profits are 0 in region 2) and workers are paid their marginal product,

$$\begin{aligned} w_2 &= E(N_{12} + N_2)\frac{\partial F_2(N_{12} + N_2)}{\partial N_{12}} \\ &= r\beta(N_{12} + N_2) \end{aligned} \tag{29}$$

This wage does not reflect the fact that an additional worker in region 2 makes all workers in region 2 more productive. To see this more clearly, we can compare the wage to the full marginal product for society, which is the social marginal product in the urban area

$$\begin{aligned} SMP_2 &= E(N_{12} + N_2)\frac{\partial F_2(N_{12} + N_2)}{\partial N_{12}} + \underbrace{\frac{\partial E(N_{12} + N_2)}{\partial N_{12}} F_2(N_{12} + N_2)}_{externality} \\ &= \mathbf{2} r\beta(N_{12} + N_2) \end{aligned} \tag{30}$$

Because workers are not paid their full marginal product, the social optimum differs from the spatial equilibrium when workers are free to choose their job location. This provides an incentive for the social planner to provide a commuting subsidy, internalizing the agglomeration externality in the net wage, such that the social optimum can be attained. With an additional assumption on the relative slopes of the productivity curves, figure 3 visualizes the situation we have now. Note that we assume $b_1 > r\beta$. To keep this section compact, we will discuss this setting graphically, which enables us to set out the basic insights. For the formal analysis, which follows the same logic as before, we refer to appendix F.

Figure 3 shows the effects of an increase in the number of commuters over the commuting flow that would exist in spatial equilibrium ($w_1 = w_2 - c$), indicated on the horizontal axis by E. The point on the horizontal axis denoted by O represents the social optimum, in which full marginal products[14] are equal ($MP_1 = SMP_2 - c$). As illustrated in appendix F.1, region 1 would set the number of commuters between E and O, indicated by R. The reason is that region 1 takes into account some, but not all of the benefits of an increase in the number of commuters. More specifically, the rural area neglects the positive externality on wages of residents of region 2 (area $KNPL$). So the profit loss in region 1 (area $DFIH$),

[14] Remember that we have assumed the absence of agglomeration externalities in region 1, such that $MP_1 = SMP_1 = w_1$.

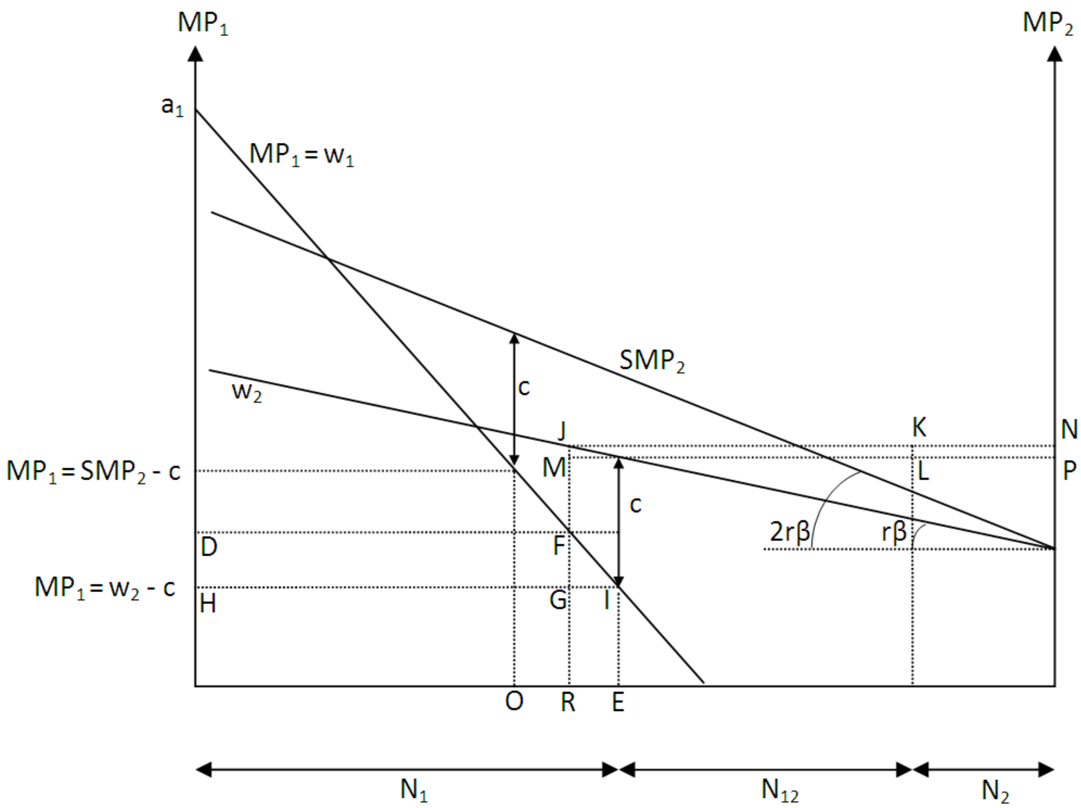

Figure 3: Welfare effects with agglomeration economies.

induced by an increased commuting flow and a higher wage in region 1, is relatively more important for the regional government than for a social planner. Region 2, however, would like to see everybody working in the city. Profits are 0, and an increase in the number of commuters is translated into higher wages in region 2, due to agglomeration economies. Table 3 summarizes the effects.

	Region 1	Region 2	Total
Profits	-DFIH	/	-DFIH
Real income	+DFGH + JKLM	+KNPL	+DFGH + JNPM
Total	-FGI + JKLM	+KNPL	-FGI+JNPM

Table 3: Welfare effects of increasing the number of commuters over the spatial equilibrium number of commuters

So what happens if both regions can invest in transport infrastructure? For equivalent assumptions to those in section 3.1, it can be shown (see appendix F.2 for details) that there will be underinvestment in transport infrastructure (as in section 6) when region 1 takes the investment level of region 2 as given. Region 1 does not take the wage increase for inhabitants of region 2 into account. Region 2 has no (direct) incentive to reduce transport costs because these are borne by commuters. Both regions therefore underinvest in transport infrastructure and the total level of commuting infrastructure investment will be too low. This can be seen from the optimality conditions in table 4.

Social planner ψ^{soc}	$(N_{12}$	$+N_2)$	$\frac{\partial N_{12}}{\partial \psi} r\beta + N_{12} = \frac{\partial K}{\partial \psi}$
Region 1 ψ	N_{12}		$\frac{\partial N_{12}}{\partial \psi} r\beta + N_{12} = \frac{\partial K}{\partial \psi}$
Social planner ϕ^{soc}	$(N_{12}$	$+N_2)$	$\frac{\partial N_{12}}{\partial \phi} r\beta + N_{12} = \frac{\partial K}{\partial \phi}$
Region 2 ϕ		N_2	$\frac{\partial N_{12}}{\partial \phi} r\beta + N_{12} = \frac{\partial K}{\partial \phi}$

Table 4: Optimality conditions for investments

7.5 Congestion externalities

In this section, we extend the basic model by including congestion externalities. More specifically, instead of assuming that the commuting cost c is fixed, we now express the commuting cost as a function of the commuting flow[15]: $c = c_0 + f\frac{N_{12}}{CAP}$. In this expression, c_0 is a fixed commuting cost, for instance representing the minimum time needed to travel to work. The second component is increasing with commuting density $\frac{N_{12}}{CAP}$, where N_{12} is the number of commuters and CAP is road capacity. The extent to which commuting cost increases with commuting density is measured by parameter f. Assume there is no labor tax. Contrary to the previous section, in which we discuss agglomeration externalities, there will now be too much commuting in the equilibrium without government intervention. The reason is the negative congestion externality. If a worker decides to commute, he will increase the cost c for every commuter because of congestion (the second term, $f\frac{N_{12}}{CAP}$, will increase). This effect will not be taken into account by an individual that decides whether or not to commute. We discuss three situations in table 5. First, the case without government intervention. Second, the social planner outcome that includes a correction for the congestion externality. Finally, we see the strategic behavior of region 1, where we see that region 1 adds the strategic restriction on the commuters on top of the congestion externality.

[15] This is the simplest formulation of congestion that can be seen as either an average time cost function derived from the speed-flow relation of a congested link or as the reduced form of a bottleneck model (Arnott, De Palma, and Lindsey 1993).

No government intervention	$w_2 - (c_0 + \frac{f}{CAP}N_{12}) = w_1$
Social planner	$w_2 - (c_0 + \frac{f}{CAP}N_{12}) - \frac{f}{CAP}N_{12} = w_1$
Region 1	$w_2 - (c_0 + \frac{f}{CAP}N_{12}) - \frac{f}{CAP}N_{12} - N_{12}b_2 = w_1$

Table 5: Optimality conditions with congestion

The corresponding number of commuters is given in table 6.

No government intervention	$N_{12} = \frac{1}{\frac{f}{CAP}+b_1+b_2}(a_2 - a_1 - c_0 + Nb_1 - N_2b_2)$
Social planner	$N_{12}^{soc} = \frac{1}{2\frac{f}{CAP}+b_1+b_2}(a_2 - a_1 - c_0 + Nb_1 - N_2b_2)$
Region 1	$N_{12}^{strat} = \frac{1}{2\frac{f}{CAP}+b_1+2b_2}(a_2 - a_1 - c_0 + Nb_1 - N_2b_2)$

Table 6: Number of commuters with congestion

The number of commuters in spatial equilibrium is higher than socially optimal because of the negative externality. The number of commuters when region 1 has market power and behaves strategically is lower than socially optimal in order to increase the commuter wage. In summary,

$$N_{12}^{strat} < N_{12}^{soc} < N_{12}$$

So a federal government is interested in a congestion tax that in our model boils down to a commuting tax. Region 1 will use a commuting tax that is too large[16]. In summary, our main results continue to hold in the presence of congestible transport infrastructure.

[16] See appendix G.

8 Numerical example for Belgium

This section presents a numerical example for Belgium, in particular the regions of Brussels and Flanders. We use the model with congestion of the previous paragraph to illustrate the basic insights. Brussels is the urban region 2 and Flanders is region 1. Residents of Flanders can commute to Brussels (N_{12}) or work in the region of Flanders (N_1). In the model equilibrium, net wages of all Flemish workers are equalized, but there is a gap between wages in Flanders and wages in Brussels. This gap is indeed what is observed in reality: the average gross wage disparity was approximately 17% in 2007. Note that this is partially due to differences in skill composition of the labor force. The data presented in table 7 will be used for the calibration[17].

Table 7: Data used for calibration

Average Gross monthly wage in Flanders	2796€
Average Gross monthly wage in Brussels	3263€
Paid Workers N_1*	1942
Commuters N_{12}*	239
Paid Workers N_2*	217

* Number of people in thousands.

The data on gross average regional wages, provided by Statistics Belgium[18], is dated October 2007. These wages concern full-time workers only. The number of workers in each region and number of commuters are based on estimates for the year 2007 of the Department of Work and Social Economics Flanders[19]. These numbers are for paid workers (excluding self-employed workers).

Currently, there is no congestion pricing in Belgium, so the situation we observe in reality corresponds with the equilibrium without government intervention of the previous section. The commuting cost c is defined as the gap between gross wages in both regions. Half of this cost is assumed to be fixed (c_0), the other half is due to congestion ($f\frac{N_{12}}{CAP}$). We normalize the capacity CAP to 1. Table 8 shows the results of the numerical exercise for the three situations discussed in previous paragraph. The first column shows the labor demand elasticity ϵ^{LD}. We assume ϵ^{LD} is the same in both regions. Highly negative values of ϵ^{LD}

[17] Some details on the calibration procedure can be found in the appendix.
[18] http://statbel.fgov.be/nl/statistieken/cijfers/arbeid_leven/lonen/maandloon/index.jsp
[19] Steunpunt WSE, http://www.werk.be/ (Vlaamse arbeidsrekening)

coincide with low values for b_1 and b_2 (marginal product curves less steep). The welfare changes (Δ) are expressed in % and are relative to the social planner outcome. The social planner restricts commuting because of the congestion externality (see column 2). Region 1 restricts the number of commuters to increase the commuters' wage.

Table 8: Numerical example

Situation	ε^{LD}	N_{12}	ΔW_1 Flanders	ΔW_2 Brussels	ΔW in total
No government intervention	-0,2	239*	-0,23	+1,00	-0,00
	-0,4	239	-0,33	+1,65	-0,01
	-0,5	239	-0,36	+1,89	-0,01
	-0,6	239	-0,39	+2,08	-0,01
	-0,8	239	-0,42	+2,36	-0,02
Social planner	-0,2	234			
	-0,4	229			
	-0,5	227	-	-	-
	-0,6	225			
	-0,8	221			
Region 1	-0,2	130	+2,20	-15,39	-1,00
	-0,4	130	+1,57	-12,60	-0,75
	-0,5	130	+1,36	-11,49	-0,66
	-0,6	130	+1,19	-10,52	-0,58
	-0,8	129	+0,94	-8,92	-0,47

* The number of commuters in the case without government intervention follows from the calibration and is equal to the observed number of commuters.

It is important to remark that the numerical example is presented for illustrative purposes. It shows the effects derived theoretically. An increase in the number of commuters has a negative welfare effect for region 1 (ΔW_1 in column 3). Region 2 benefits from an increase of commuters through higher profits (ΔW_2 in column 4). Both unpriced congestion and strategic behavior of region 1 reduce overall welfare (column 5). It is interesting to find that the urban region is better off without congestion charging as this would lead to a lower number of commuters. One should be cautious when interpreting the results in terms of ϵ^{LD}, because welfare levels in the social planner outcome change as well in accordance with changes in ϵ^{LD}. We simply use the variations in ϵ^{LD} as sensitivity analysis. The fact that a small negative welfare effect for Flanders and a larger (%) increase in welfare in Brussels still results in a negative overall welfare effect (in the case without government intervention) stems from the relative sizes of the regions. Proost and Sen (2006) adopt a transport model to estimate the potential welfare losses when pricing instruments are controlled by different levels of government. Their application on Brussels yields only limited overall efficiency losses compared to the situation where there is only one government level.

9 Conclusions

The main contribution of this paper is the introduction of a strategic aspect in commuting policy in a federation with a limited number of regions. Whereas traditional arguments for road pricing rest upon externalities, e.g. congestion or pollution, this paper presents strategic arguments in regional government competition as a motive for a level of infrastructure investments that is suboptimal from the federal point of view.

In the framework presented in this paper, a region that 'exports labor' behaves strategically by restricting the number of people that work in the other region, either by taxing commuters or by investing less in infrastructure. If less people commute because of a commuting tax, the marginal benefit of investing in transport infrastructure will be lower. Therefore, taxing commuters also results in lower transport investments. When the urban area or city region can tax commuters, its government will also decide to do this. The relevant trade-off, in this case, is between tax revenue and profit losses. If regions can decide on the level of transport infrastructure investments, there will be underinvestment. The labor-exporting rural region underinvests to keep wages of commuters high. The labor-importing urban region underinvests because commuting costs are borne by non-residents.

However, there may be circumstances where the strategic effect is attenuated. Five factors are considered. First, a third region can be introduced. When this region also supplies labor to the same city or central business district, the market power of the dominant labor-supplying region diminishes. This will result in a lower commuting tax and a higher investment level of the region that was previously the dominant supplier of labor. Second, an exogenous sharing rule for the redistribution of federal labor tax proceeds introduces interdependencies between regions' government revenues. Third, when firm ownership is spread across the federation, the incentive for restricting the number of commuters is reduced. Fourth, the result of underinvestment remains robust when there are agglomeration externalities in the city. Finally, the strategic behavior of the rural region and the underinvestment by regions is also found when congestion externalities are taken into account.

We leave for future research the analysis of how the federal government can correct incentive structures through mechanism design. Furthermore, it seems important to study the impact of firm mobility and migration of residents in this setting, since this might reduce the scope for strategic behavior of regional governments.

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Appendix

A Social optimum investments

From the first order conditions

$$\begin{aligned} N_{12} &= k + l\psi \\ N_{12} &= k + l\phi \end{aligned}$$

with $N_{12} = \frac{1}{b_1+b_2}(a_2 - a_1 - c + \psi + \phi + Nb_1 - N_2b_2)$, we get

$$\begin{aligned} \psi &= \frac{a_2 - a_1 - c + \phi + Nb_1 - N_2b_2 - k(b_1 + b_2)}{l(b_1 + b_2) - 1} \\ \phi &= \frac{a_2 - a_1 - c + \psi + Nb_1 - N_2b_2 - k(b_1 + b_2)}{l(b_1 + b_2) - 1} \end{aligned}$$

Solving this system of equations gives

$$\begin{aligned} \psi &= \phi = \frac{1}{l(b_1 + b_2) - 2}\,(a_2 - a_1 - c + Nb_1 - N_2b_2 - k(b_1 + b_2)) \\ \psi + \phi &= \frac{2}{l(b_1 + b_2) - 2}\,(a_2 - a_1 - c + Nb_1 - N_2b_2 - k(b_1 + b_2)) \end{aligned}$$

B Regional transport investments

From the optimal investment rule

$$N_{12}(\frac{b_1}{b_1 + b_2}) = k + l\psi$$

we can get an expression for the investment level

$$\psi = \frac{1}{l\,(b_1 + b_2) - \frac{b_1}{b_1+b_2}}(\frac{b_1}{b_1 + b_2}\,(a_2 - a_1 - c + Nb_1 - N_2b_2) - k\,(b_1 + b_2)),$$

which is smaller than the investment level ψ^*, expressed by equation (10). The resulting number of commuters is lower than optimal:

$$N_{12} = \frac{l}{l(b_1 + b_2) - \frac{b_1}{b_1+b_2}}(a_2 - a_1 - c + Nb_1 - N_2b_2 - \frac{k}{l})$$

C Trade-off

$$\begin{aligned} s_1 &= -\frac{b_2}{cb_1 + 2cb_2}(a_2 - a_1 - c + Nb_1 - N_2 b_2)(1 - t_1) + t_1 \\ &= (1 - t_1)s_1^{strat} + t_1 = s_1^{strat} + t_1(1 - s_1^{strat}), \end{aligned} \tag{31}$$

where s_1^{strat} is given by expression (21). Given that $s_1^{strat} < 0$, s_1 is now less negative than s_1^{strat}. Another relevant comparison can be made, namely with the social planner outcome of section 3.1. There the outcome was $s = t$. Region 1 now behaves strategically and sets a lower subsidy than the labor tax rate:

$$\begin{aligned} & s_1^{strat} + t_1(1 - s_1^{strat}) < t_1 \\ \iff & s_1^{strat} < t_1 s_1^{strat} \\ \iff & t_1 < 1, \end{aligned}$$

which is the case under the assumptions made (labor cannot be taxed at more than 100%). We therefore know that the regional government sets the commuting tax lower than in the case with lump sum taxes, and provides a lower commuting subsidy than in the federal social planner parallel. This situation can result in a lower tax or even a subsidy. The following proposition sheds some light on this issue:

Proposition 1 *In a setting with a regional labor tax and commuting policy (commuting tax or subsidy; no transport investments), the regional government provides a commuting subsidy if and only if* $s_1^{strat} > \frac{t_1}{t_1 - 1}$.

Proof. Region 1 installs a subsidy if:

$$\begin{aligned} s_1 &> 0 \\ &\iff s_1^{strat} + t_1(1 - s_1^{strat}) > 0 \\ &\iff 1 - s_1^{strat} > -\frac{s_1^{strat}}{t_1} \\ &\iff t_1 > (t_1 - 1)s_1^{strat} \\ &\iff s_1^{strat} > \frac{t_1}{t_1 - 1} \end{aligned} \tag{32}$$

■

D Nash competition in investments

The spatial equilibrium condition is now given by

$$N_{12}(\psi,\phi) = \frac{1}{b_1+b_2}(a_2 - a_1 - c + \boldsymbol{\psi} + \boldsymbol{\phi} + Nb_1 - N_2 b_2)$$

From the optimal investment condition for region 1

$$\frac{b_1}{b_1+b_2} N_{12}(\psi,\phi) = k + l\psi$$

we can get the reaction function for the rural region 1:

$$\psi(\phi) = \frac{b_1}{l(b_1+b_2)^2 - b_1}(a_2 - a_1 - c + \boldsymbol{\phi} + Nb_1 - N_2 b_2) - \frac{k(b_1+b_2)^2}{l(b_1+b_2)^2 - b_1}$$

And similarly for region 2: from investment condition

$$\frac{b_2}{b_1+b_2} N_{12}(\psi,\phi) = m + n\phi$$

we get the reaction function for the investments of the urban area:

$$\phi(\psi) = \frac{b_2}{n(b_1+b_2)^2 - b_2}(a_2 - a_1 - c + \psi + Nb_1 - N_2 b_2) - \frac{m(b_1+b_2)^2}{n(b_1+b_2)^2 - b_2}$$

Now impose $m = k$ and $n = l$. Solving the system of equations and summing ψ and ϕ then gives:

$$\psi + \phi = \frac{1}{l(b_1+b_2) - 1}\left(a_2 - a_1 - c + Nb_1 - N_2 b_2 - 2k(b_1+b_2)\right)$$

E Three regions

$$N_{12} = \frac{1}{b_1+b_2}\left(a_2 - a_1 - c\,(1-s_1) + Nb_1 - b_2\,(N_2 + N_{32})\right) \quad (33)$$

$$N_{32} = \frac{1}{b_2+b_3}\left(a_2 - a_3 - c\,(1-s_3) + Nb_3 - b_2\,(N_2 + N_{12})\right) \quad (34)$$

The steps taken to get an expression for the optimal commuting tax are as follows. Firstly, expression (33) and (34) are substituted in W_1. The government of region 1 then optimizes with s_1 as choice variable, taking N_{32} as given. The outcome is the optimal commuting tax s_1 as a function of N_{32}. Next, replacing this tax in the expression above results in the reaction function (35) (and (36) for region 3). Now impose symmetry, i.e. region 1 and 3 are identical. Finally, substituting the solution N_{32}^{Nash} in the expression for s_1, the Bertrand-Nash outcome for the commuting tax is obtained.

The numbers of commuters are now given by

$$N_{12} = \frac{1}{b_1 + b_2}\left(a_2 - a_1 + Nb_1 - b_2\left(N_2 + \mathbf{N}_{32}\right) - c\left(1 - s_1\right)\right) \tag{35}$$

$$N_{32} = \frac{1}{b_2 + b_3}\left(a_2 - a_3 + Nb_3 - b_2\left(N_2 + \mathbf{N}_{12}\right) - c\left(1 - s_3\right)\right) \tag{36}$$

Welfare in region 1 is given by

$$W_1 = \frac{1}{2}b_1 N_1^2 + N_1(a_1 - b_1 N_1) + N_{12}(a_2 - b_2(N_2 + N_{12} + \mathbf{N}_{32}) - c)$$

First order condition with respect to the commuting subsidy s_1:

$$\frac{\partial W_1}{\partial s_1} = \frac{b_2 c}{\left(b_1 + b_2\right)^2}\left(N_2 b_2 + b_2 N_{32} + c + a_1 - a_2 - Nb_1 - \frac{cb_1 s_1}{b_2} - 2cs_1\right) = 0$$

From this we obtain optimal taxes as functions of the number of commuters of the other region:

$$s_1 = \frac{b_2}{cb_1 + 2cb_2}\left(c + a_1 - a_2 - Nb_1 + N_2 b_2 + b_2 \mathbf{N}_{32}\right)$$

$$s_3 = \frac{b_2}{cb_3 + 2cb_2}\left(c + a_3 - a_2 - Nb_3 + N_2 b_2 + b_2 \mathbf{N}_{12}\right)$$

Solving and imposing symmetry gives

$$s_1^{Nash} = -\frac{b_2}{\left(cb_1 + 2cb_2\right)\left(b_1^2 + 4b_1 b_2 + 3b_2^2\right)}\left(b_1^2 + 3b_1 b_2 + b_2^2\right)\left(a_2 - a_1 - c + Nb_1 - N_2 b_2\right)$$

$$N_{12}^{Nash} = \underbrace{\frac{(b_1 + 2b_2)^2}{\left(b_1 + 2b_2\right)^2 - b_2^2}}\underbrace{(\frac{1}{b_1 + 2b_2}\left(a_2 - a_1 - c + Nb_1 - N_2 b_2\right)}$$

F Agglomeration externalities

F.1 The incentive for commuting subsidies

The social optimality condition equalizes full marginal products, taking into account the loss of resources due to commuting, whereas the spatial equilibrium condition, when workers can choose whether or not to commute, is based on equal net wages. Rewriting the welfare maximization problem for region 1 we get the following optimality conditions

Social optimum	$2w_2 - c$		$= w_1$
Spatial eq.	$w_2 - c$		$= w_1$
Region 1	$2w_2 - c$	$-r\beta N_2$	$= w_1$

Table 9: Optimality conditions with agglomeration externalities

These conditions allow us to derive the optimal number of commuters:

Social optimum	$N_{12}^{soc} =$	$\frac{(2r\beta N_2 - c - a_1 + Nb_1)}{b_1 - 2r\beta}$
Spatial eq.	$N_{12} =$	$\frac{(r\beta N_2 - c - a_1 + Nb_1)}{b_1 - r\beta}$
Region 1	$N_{12}^{strat} =$	$\frac{(r\beta N_2 - c - a_1 + Nb_1)}{b_1 - 2r\beta}$

Table 10: Number of commuters with agglomeration externalities

So we get too few commuters when region 1 decides on the commuting flow, and an even lower level of commuters in spatial equilibrium

$$N_{12} < N_{12}^{strat} < N_{12}^{soc}$$

$N_{12} < N_{12}^{soc}$ because each individual does not take into account the increase in wages in the city for all other people working in the city, when he decides to commute. A worker is not paid its full marginal product, but only $r\beta(N_2 + N_{12})$. To obtain the social optimum, commuters should receive a commuting subsidy equal to $s = \frac{r\beta}{c(b_1 - 2r\beta)}(b_1 N_2 - c - (a_1 - Nb_1))$. $N_{12}^{strat} < N_{12}^{soc}$ because the government of region 1 does not take into account the positive external effect of its commuters on the incomes gained by residents of region 2. Region 1 takes into account only part of the positive externality. Comparing with the setting of decreasing returns, we now see that the region no longer has an incentive to restrict the number of commuters in order to increase their wage.

F.2 Nash competition in infrastructure investments

From table 4 we can get the optimal level of investments:

Social optimum	ψ^{soc}	$=$	$\frac{A+b_1\phi+r\beta N_2(b_1-r\beta)}{l(b_1-r\beta)^2-b_1}$
Region 1	ψ	$=$	$\frac{A+b_1\phi}{l(b_1-r\beta)^2-b_1}$
Social optimum	ϕ^{soc}	$=$	$\frac{A+b_1\psi+r\beta N_2(b_1-r\beta)}{l(b_1-r\beta)^2-b_1}$
Region 2	ϕ	$=$	$\frac{r\beta N_2}{l(b_1-r\beta)} - \frac{k}{l}$

Table 11: Investments in transport infrastructure with agglomeration externalities

where $A = b_1(r\beta N_2 - c - a_1 + Nb_1) - k(b_1 - r\beta)^2$ and $N_{12} = \frac{1}{b_1 - r\beta}(r\beta N_2 - c + \psi + \phi - a_1 + Nb_1)$. Here we make the important assumption that l is large enough and k is not too large such that ψ is positive. This means we assume that the cost of investing in infrastructure is such that at least some investment is beneficial for region 1. Since $b_1 > r\beta$, we clearly see that region 1 underinvests. From the optimality conditions in table 4 we know that region 2 also underinvests. The reaction functions show that higher investment in region 2 leads to a higher investment level in region 1. Region 2 sets its level of investments in transport infrastructure independent of the investments in region 1. In Nash equilibrium, the level of investments in transport infrastructure is lower than socially optimal.

G Congestion

Here we derive the optimal road pricing from the social planner's point of view. This means the planner taxes commuters to account for the congestion externality. In particular, we look for a value of the tax t that equalizes N_{12}^{soc} and N_{12} from table 6. The optimal congestion tax is then

$$t^{soc} = \frac{2f(-a_1 + a_2 + Nb_1 - N_2 b_2) + (b_1 + b_2)c_0}{f(-a_1 + a_2 + c_0 + Nb_1 - N_2 b_2) + (b_1 + b_2)c_0} > 1$$

Region 1 will set t to end up with N_{12}^{strat} commuters, as in table 6. This can be done setting t equal to

$$t^{strat} = \frac{(2f + b_2)(-a_1 + a_2 + Nb_1 - N_2b_2) + (b_1 + b_2)c_0}{f\,(-a_1 + a_2 + c_0 + Nb_1 - N_2b_2) + (b_1 + 2b_2)c_0} > t^{soc}$$

H Calibration for numerical example

This section provides details on the calibration procedure. We need values for the parameters of the production functions (a_1, b_1, a_2, b_2), for the number of individuals of each type (N_1, N_{12}, N_2) and for the commuting cost c. With the data presented in table 7 and the assumption of linearly decreasing marginal products, we only need the slopes b_1 and b_2 to calibrate the model. We derive these for a range of labor demand elasticities. Assuming a competitive labor market, workers are paid their marginal product. Denoting by w_1 and w_2 the gross wages in Flanders and Brussels respectively, we get:

$$\begin{aligned} w_1 &= F_1^{'} = a_1 - b_1N_1 \\ w_2 &= F_2^{'} = a_2 - b_2(N_{12} + N_2) \end{aligned}$$

Note that gross average wages are used in the calibration. Using gross wages means we implicitly assume that the labor tax revenue is redistributed to the regions. The use of average wages means we neglect the differences in skill composition of the labor force in the two regions. Taking these into account might reduce the wage gap. From these expressions we can write the number of workers in a region as a function of the wage: this is the labor demand function. For instance, for region 1 we obtain the labor demand $LD_1 = -\frac{w_1 - a_1}{b_1}$, with partial derivative $\frac{\partial LD_1}{\partial w_1} = -\frac{1}{b_1}$. This means labor demand elasticity can be stated as $\varepsilon_1^{LD} = \frac{\partial LD_1}{\partial w_1}\frac{w_1}{N_1} = -\frac{1}{b_1}\frac{w_1}{N_1}$. For different values of labor demand elasticity, we then obtain different values for $b_1 = -\frac{1}{\varepsilon_1^{LD}}\frac{w_1}{N_1}$. We let this elasticity vary from -0.2 to -0.8. Similar calculations are done to obtain values for b_2. In the results presented here, we assume labor demand elasticities are the same in Brussels and in Flanders, so we can write ε^{LD}. Letting the absolute value of labor demand elasticity in one region rise relative to the other region will slightly change the results in the benefit of the former region.