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# Congestion, wage rigidities and the provision of public intermediate goods

Johannes Pauser \*

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**Abstract** This paper examines efficiency in the provision and utilization of a congestible public input in a symmetric tax competition framework with wage rigidities. Despite the fact that also lump-sum taxation is available for regional governments, second-best efficiency emerges only as a special case in the non-cooperative equilibrium. In the special case with Cobb-Douglas production, the congestion technology can be shown to be crucial for the analysis of efficiency in the decentralized equilibrium. Assuming decreasing marginal congestion, efficiency in the non-cooperative equilibrium is determined alone by the production and congestion elasticities. In contrast, factor prices such as the level of the wage rigidity and corresponding employment levels are, in addition, important to determine whether both provision and utilization levels of the public input are efficient in case of increasing marginal congestion.

*JEL classification:* H41; H21; H25

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# 1. Introduction

The stimulation of employment or job creation are frequently mentioned as key reasons by policy makers for competing for mobile capital and attracting foreign direct investment (FDI). In doing so, business incentives that predominantly focus on both tax cuts and the provision of productivity-enhancing infrastructure are offered to the productive sector. So far, however, a large part of the tax competition literature still focuses on tax competition with (corporate) taxes and abstracts from governmental provision of productive public goods. Moreover, the assumption of perfect labor markets with full employment in the competing jurisdiction is introduced in a large part of the work, thereby neglecting jobs creation and unemployment as key factors to engage in tax competition.

With respect to the first argument, the empirical study of Hauptmeier et al. (2012) finds that it is indeed reasonable to assume that governments compete for foreign direct investment using both taxes and public inputs. Perhaps the latest prominent example to illustrate the second point are the newly introduced tax cuts in the U.S. aimed at attracting foreign direct investment (FDI) *and* to create or bring (back) jobs to the U.S. With the Tax Cuts and Jobs Act (TCJA) released in 2017, the U.S. federal corporate income tax rate has been reduced from 35 percent to 21 percent.

As already emphasized, although unemployment is a non-negligible reason to engage in the competition for foreign direct investment, and numerous policy measures aim at strengthening local labor market conditions and to stimulate employment, tax competition with labor market distortions is only considered in a few studies, and it is well-known from this work that modifying the standard tax competition framework by allowing for unemployment adds a further source of inefficiency to the analysis (cf., e.g. Ogawa et al. (2006a), Eichner and Upmann (2012), Exbrayat et al. (2012)).

This paper aims to examine efficiency in public input provision (e.g., productive infrastructure)<sup>1</sup> in the presence of congestion and employment externalities, when the labor market is characterized by wage rigidities and involuntary unemployment. As minimum wages are binding in the U.S. and in most of the EU member states, this institutional setting of the labor market should be of some relevance.<sup>2</sup> Moreover, with respect to the financing of the public service, it will be assumed that distortionary capital taxation and lump-sum taxation is available for regional governments.

In addition to the consideration of public input provision under the presence of unemployment, the paper departs from the standard tax competition model also in that it examines both efficiency in the provision *and* utilization of a public input that is subject to congestion, and therefore, two dimensions of an optimal policy with productive public goods. In the subsequent analysis also both the provision and utilization level of a congestible public input enter the production technology, each of which exhibits a productivity-enhancing

<sup>1</sup>'Public input' and 'productive infrastructure' will be regarded as synonymous in the paper.

<sup>2</sup>Wage rigidities have been considered, for instance, in Ogawa et al. 2006a; 2006b and Moriconi and Sato (2009).

effect. However, public input utilization is also associated with a negative congestion effect as it decreases the quality of the infrastructure for all other firms, resulting in a loss in aggregate production.

In the public finance literature, it is well-known since at least Oakland (1972) that many publicly-provided goods are subject to (at least some degree of) congestion. This view is shared, for instance, by Stiglitz (1988), Barro and Sala-I-Martin (1992), Glomm and Ravikumar (1994), and Feehan (1989). Edwards (1990) analyzes in detail five specifications of the congestion function, including decreasing and increasing marginal congestion.<sup>3</sup>

The specification of the congestion technology is also important in the present analysis, as it turns out that whether congestion decelerates or accelerates as infrastructure utilization increases is also crucial for the analysis of efficiency in tax competition with public inputs and with unemployment in the competing jurisdictions. It turns out therefore, that the implications for the design of an optimal policy from the viewpoint of a regional policy maker depend also on the specification of the congestion technology, and in detail on the fact whether congestion increases or decreases at the margin.

It has been considered reasonable to allow for potential congestion effects also in some recent work on tax competition. Prominent examples include Sinn (1997), who incorporates congestion in a cost function and links it to the production factor capital in a framework with full employment. Congestion is included in a cost function also in the study of Matsumoto (2000), where crowding is caused by the number of firms in the jurisdiction. Borger et al. (2005) focus on the special case of a parallel road network and study strategic tolling by individual countries under various tolling schemes. Bjorvatn and Schjelderup (2002) consider a tax competition setting with international spillovers in public goods provision and show that spillovers may under some circumstances also eliminate tax competition. The introduction of congestion costs in an extension of their basic model may lead to public good provision in excess of the optimal amount. This occurs under a rather specific definition of congestion, where an increase in the number of firms crowds out the amount of the public good available for consumers. In contrast to the previously cited studies, congestion is caused by the utilization rate of the public input in the private sector, that will also be determined endogenously in the non-cooperative equilibrium in symmetric tax competition with unemployment. Moreover the congestion effect is incorporated into the production technology, so that congestion is also associated with a production loss in the economy.

The paper proceeds with the introduction of a model to study symmetric tax competition under the presence of externalities arising from capital mobility, congestion, and unemployment. Before the analysis of tax competition, conditions for second-best efficiency with respect to the provision and utilization level of a congestible public input are derived from the viewpoint of the social planner (Section 3.1). Section 3.2 focuses on the decentralized equilibrium with source-based capital and lump sum taxes, assuming general specifications

<sup>3</sup>A summary with important specifications of the congestion technologies is provided, for instance, in Reiter and Weichenrieder (1999).

of the production and congestion technologies. Tax competition with Cobb-Douglas production and the two well-known specifications of increasing and decreasing marginal congestion is analyzed in Section 3.3. Section 4 concludes the paper.

## 2. The model

Consider symmetric tax competition. Each of the  $i = 1 \dots n$  identical regions in the economy inhabits an identical number  $\bar{Z}_i$  of immobile individuals. The capital stock  $\bar{K}$  of the economy is perfectly mobile between regions, and the amount of capital in the representative jurisdiction ( $\bar{K}^i$ ) shall be distributed equally between the  $\bar{Z}_i$  individuals. The net-of-tax price of capital will be denoted with  $\bar{r}$  and is considered exogenous in each jurisdiction. Following, for instance, Eichner and Upmann (2012) and Ogawa et al. (2006a), it is assumed that each individual receives, in addition, an equal share of total firm profits  $\pi^i$  specified in detail below.

Each of the individuals aims to provide one unit of labor. However, due to the presence of wage rigidities and the wage rate  $\bar{w}^i$ , which is determined above the market-clearing rate, only  $L^i < \bar{Z}^i$  of the individuals will be employed in the representative region. Both types of individuals receive income from firm profits and capital. Employed individuals receive, in addition, wage payments  $\bar{w}^i$ .<sup>4</sup> Assuming further that head taxes  $t^i$  are available for regional governments, one has for the per-capita budget constraint of an employed ( $c_e^i$ ) and unemployed ( $c_u^i$ ) individual:

$$c_e^i = \bar{w}^i - t^i + \bar{r} \frac{\bar{K}^i}{\bar{Z}_i} + \frac{\pi^i}{\bar{Z}_i}; \quad c_u^i = c_e^i - \bar{w}^i. \quad (1)$$

Aggregate production in the representative jurisdiction can be characterized by the following technology:<sup>5</sup>

$$F^i = F^i(L^i, K^i, N^i, Q^i), \quad (2)$$

with

$$Q^i = Q^i(B^i, N^i), \quad Q_B^i > 0, \quad Q_N^i < 0 \quad (3)$$

as the quality of the infrastructure facility.<sup>6</sup> The quality index  $Q^i(\cdot)$  is introduced to account for the potential congestion effect associated with infrastructure utilization. Increasing the rate of infrastructure utilization  $N^i$  diminishes infrastructure quality, which will have a

<sup>4</sup>As, for instance, in Ogawa et al. (2006a), the analysis abstracts from leisure as a potential input in the utility function of individuals, and assumes that the reservation wage rate is zero. This leaves the qualitative results of the analysis unchanged.

<sup>5</sup>It is assumed that firm profits are not generated by the public input so that, as a consequence, the number of firms can be normalized to unity (cf. Aronsson and Wehke (2008)).

<sup>6</sup>Partial derivatives are denoted with subscripts. It is assumed that the production function possesses continuous first- and second order partial derivatives.

negative effect on output assuming that  $F_Q^i > 0$ . In contrast, infrastructure quality and, as a consequence, output will increase as the quantity (i.e., the capacity)  $B^i$  of the infrastructure facility increases (i.e. increasing public input provision has a decongesting effect).

The rate of infrastructure utilization  $N^i$  enters the production function also directly, which captures the productivity-enhancing effect of infrastructure utilization ( $F_N^i > 0$ ).<sup>7</sup> Moreover, production increases as labor or capital increase ( $F_L^i, F_K^i > 0$ ). In addition, negative signs for the second-order derivatives and positive signs for the cross-derivatives are assumed with respect to the four production factors  $L^i, K^i, N^i, Q^i$ . The production function exhibits decreasing returns to scale with respect to the first three production factors,  $L^i, K^i$ , and  $N^i$ . With this assumptions on the returns to scale in aggregate production, one derives:

$$F_{LL}^i F_{NN}^i > (F_{LN}^i)^2, F_{LL}^i F_{KK}^i > (F_{LK}^i)^2, F_{KK}^i F_{NN}^i > (F_{KN}^i)^2, \quad (4)$$

which will be useful for the subsequent analysis.

Identical, price-taking firms maximize profits for given factor prices of labor ( $w^i$ ), capital ( $R^i$ ) and fixed (private) costs of infrastructure utilization ( $v^i$ ). With the price of the final good equal to one, firm profits will amount to:

$$\pi^i = F[L^i, K^i, N^i, Q^i(B^i, N^i)] - \bar{v}^i N^i - R^i K^i - \bar{w}^i L^i. \quad (5)$$

The profit-maximizing condition with respect to capital reads:

$$F_K^i(\cdot) = R^i, \quad (6)$$

where the price of capital consists of the (net-of-tax) interest rate  $\bar{r}$  and a source-based capital tax  $T^i$ :  $R^i = \bar{r} + T^i$ . Maximizing firm profits with respect to labor yields

$$F_L^i(\cdot) = \bar{w}^i, \quad (7)$$

which implicitly defines  $L^i$  as a function of  $K^i, N^i, B^i, \bar{w}^i$ . In detail, one has from the implicit function theorem

$$\left. \frac{dL^i}{dK^i} \right|_{(7)} = -\frac{F_{KL}^i}{F_{LL}^i} > 0, \quad \left. \frac{dL^i}{dB^i} \right|_{(7)} = -\frac{F_{LQ}^i Q_B^i}{F_{LL}^i} > 0, \quad \left. \frac{dL^i}{dN^i} \right|_{(7)} = -\frac{F_{LN}^i + F_{LQ}^i Q_N^i}{F_{LL}^i}, \quad (8)$$

where the notation  $|_{(7)}$  indicates that the derivations are obtained from the profit maximization condition for the optimal employment of labor. As obvious from (8), positive

<sup>7</sup>Observe with respect to this effect, that Fernald (1999), for instance, has pointed out that in the U.S. transport-intensive industries tend to benefit more from investments in the road network (i.e. in infrastructure) than industries with lower road utilization rates. Note that  $F_N^i$  denotes the derivation of the production function with respect to the third production factor, i.e.,  $F_N^i$  will be used as a short notation for  $F_N^i|_{Q^i=\bar{Q}^i}$ .

signs for the reactions of labor demand to an increase in capital and infrastructure quantity can be derived. This follows from our assumption of positive cross-derivatives and negative second-order derivatives.

In contrast, the reaction of labor demand to an increase in infrastructure utilization (last equation in (8)) remains ambiguous because of two countervailing effects. First, the (direct) marginal product of labor increases as infrastructure utilization increases ( $F_{LN}^i > 0$ ), which will increase labor demand. Second, infrastructure quality declines as infrastructure utilization increases, which induces a negative effect on the marginal product of labor and labor demand ( $F_{LQ}^i Q_N^i < 0$ ).

Assuming further that firms face a fixed user cost  $\bar{v}^i$  for public input utilization  $N^i$  and that in the maximization problem the quality index ( $Q^i$ ) is assumed exogenous by the firms,

$$F_N^i(\cdot) = \bar{v}^i \quad (9)$$

can be derived as the third profit maximizing condition. Therefore, from the viewpoint of the individual firm, public input utilization will be optimal if the private marginal product of infrastructure utilization is equal to the private user cost  $\bar{v}^i$ .

### 3. Tax competition

#### 3.1. The social planner

In what follows, in order to have a benchmark for the tax competition analysis in this section, we derive conditions for the constrained (second-best) efficient provision and utilization levels of the congestible public input from the viewpoint of the social planner. The term "constrained efficient" (or "second-best efficient") is introduced to account for the fact that the first-best allocation with full employment is not attainable in a framework with wage rigidities in the competing jurisdictions. The social planner maximizes output less user costs for infrastructure utilization ( $\bar{v}^i N^i$ ) and the cost of infrastructure provision ( $B^i$ ), accounting for the fact that the amount of capital is fixed and mobile between regions. In addition, the planner accounts for the labor market distortions due to the wage rigidities in the  $n$  regions. One unit of the final good can be transformed into one unit of the private consumption good or into one unit of the public input. With this information the conditions for the constrained (second-best) efficient provision and utilization levels of the congestible public input from the viewpoint of the social planner are derived as<sup>8</sup>

$$F_Q^i Q_B^i + \bar{w}^i \left. \frac{dL^i}{dB^i} \right|_{(7)} = 1 \quad (10)$$

<sup>8</sup>Equations (10) and (11) are derived in Appendix A. It is assumed that the second-order conditions for a maximum are satisfied (This issue will be also discussed in section 3.3, which assumes specific functional forms for the production and congestion technologies.).

and

$$F_N^i + F_Q^i Q_N^i + \bar{w}^i \left. \frac{dL^i}{dN^i} \right|_{(7)} = \bar{v}^i, \quad (11)$$

respectively. Equation (10) formalizes the modified Samuelson-condition for efficiency in public input provision, which equates the social marginal product to the marginal cost of public input provision, where the latter has been assumed to be equal to one. According to equation (11) the degree of congestion and infrastructure utilization will be optimal if the social marginal product of infrastructure utilization equals the cost of infrastructure utilization. The social marginal product of infrastructure utilization consists of three components: i) the private marginal product of infrastructure utilization ( $F_N^i$ ), ii) the loss in production resulting from the diminished infrastructure quality ( $F_Q^i Q_N^i$ ), and iii) the change in the wage bill resulting from a marginal increase in infrastructure utilization ( $\bar{w}^i dL^i/dN^i|_{(7)}$ ).

### 3.2. General production and congestion technologies

Let us assume in analogy to, for instance, Zodrow and Mieszkowski (1986) that regional policy makers have a source-based capital tax and a lump sum tax at their disposal. Revenue from both instruments will be used to finance the public input so that one has for the balanced-budget constraint in a representative region:

$$B^i = t^i \bar{Z}^i + T^i K^i. \quad (12)$$

Regional governments maximize the weighted utility of individuals. With the absence of public consumption goods, the representative government maximizes  $W^i = L^i c_e^i + (\bar{P}^i - L^i) c_u^i$ , which leads to:

$$W^i = L^i \bar{w}^i - t^i \bar{P}^i + \bar{r} \bar{K}^i + \pi^i. \quad (13)$$

Assuming that the capital tax and the quantity of infrastructure are the strategic parameters in the Nash game between jurisdictions, the maximization problem of a representative government reads:

$$\begin{aligned} \max_{T^i, B^i} : \quad & W^i = F^i \{L^i(T^i, B^i), K^i(T^i, B^i), N^i(T^i, B^i), Q^i[N^i(T^i, B^i), B^i]\} \\ & - \bar{v}^i N^i(T^i, B^i) - \bar{r} [K^i(T^i, B^i) - \bar{K}^i] - B^i, \end{aligned} \quad (14)$$

which is obtained after substitution of (5) and (12) into (13). Solving the maximization problem, the equilibrium capital tax rate in symmetric tax competition with head and capital-tax



financing can be derived as:<sup>9</sup>

$$T^i = -\bar{w}^i \frac{\partial L^i / \partial T^i}{\partial K^i / \partial T^i} - F_Q^i Q_N^i \frac{\partial N^i / \partial T^i}{\partial K^i / \partial T^i}. \quad (15)$$

For the provision rule with the public input in the decentralized equilibrium, one has:

$$F_Q^i Q_B^i = 1 - \bar{w}^i \frac{\partial L^i}{\partial B^i} - T^i \frac{\partial K^i}{\partial B^i} - F_Q^i Q_N^i \frac{\partial N^i}{\partial B^i}. \quad (16)$$

As a first result, due to the multiple externalities in the decentralized framework and with the general specifications of the production (2) and congestion (3) technologies, the sign of the equilibrium capital tax rate (15) remains ambiguous. This is because the comparative statics analysis with respect to the changes in the capital tax and in the public input provision level remain inconclusive.

The first term on the RHS of (15) captures the incentives for the taxation of capital that arise from the effect of capital taxation on the amount of capital invested and on employment. The second term on the RHS of (15) captures the incentive to use source-based capital taxes to reduce congestion, i.e. as a congestion tax. Observe therefore that infrastructure utilization and, as a consequence, the production loss from congestion will be affected by the capital tax rate. In detail, we find from the comparative statics analysis that capital and infrastructure utilization decline as source-based capital-taxes are increased, implying that jurisdictions would select a positive tax according to the second term in (15).

With the derivation of  $\partial L^i / \partial B^i > 0$ , i.e. from the fact that infrastructure provision increases employment and thereby total wage payments, an incentive to increase infrastructure provision can be derived from the second term on the RHS of (16). In addition, according to the third term on the RHS, jurisdictions will increase public input provision to attract capital ( $\partial K^i / \partial B^i > 0$ ). Moreover, as congestion also increases with higher public input provision levels, an incentive arises to decrease infrastructure provision (last term on the RHS of (16)). This follows from the fact that infrastructure provision will also induce higher public input utilization levels ( $\partial N^i / \partial B^i > 0$ ) contributing to congestion and a loss in production.

Despite the ambiguous results presented above, the characterization of the equilibrium conditions can be simplified further and expressed more conveniently. First, using (15) in (16) and the results of the comparative statics analysis, the condition for optimal public-input provision in the non-cooperative equilibrium can be stated as:

$$F_Q^i Q_B^i = 1 - \bar{w}^i \left. \frac{dL^i}{dB^i} \right|_{(7),(9)} - F_Q^i Q_N^i \left. \frac{dN^i}{dB^i} \right|_{(7),(9)}. \quad (17)$$

<sup>9</sup>Appendix B contains a derivation. The effects of a change in policy parameters  $T^i$  and  $B^i$  on the endogenous variables  $K^i$ ,  $N^i$ , and  $L^i$  can be derived from the three profit maximizing conditions and the balanced-budget constraint.

The employment effect from a marginal increase in  $B^i$  that is derived from the profit maximization condition for the optimal employment of labor (7) and optimal public input utilization (9) decomposes into two effects:

$$\left. \frac{dL^i}{dB^i} \right|_{(7),(9)} = \left. \frac{dL^i}{dB^i} \right|_{(7)} + \left. \frac{dL^i}{dN^i} \right|_{(7)} \left. \frac{dN^i}{dB^i} \right|_{(7),(9)}. \quad (18)$$

The first effect on the RHS is obtained from the labor market equation (7) and works through an increase in the marginal product of labor. The second effect works through the change in the public input utilization level, and the induced (direct and indirect) effects on the marginal product of labor.

Combining (18) with equations (10), (11) and (17), the condition under which efficiency in the non-cooperative equilibrium coincides with efficiency from the viewpoint of the social planner can be expressed in the following convenient form:

$$\bar{w}^i \left. \frac{dL^i}{dN^i} \right|_{(7)} = -F_Q^i Q_N^i. \quad (19)$$

**Proposition 1.** *Assume symmetric tax competition with general production and congestion technologies as specified in (2) and (3). Efficiency in the decentralized equilibrium will depend on the magnitude of both the shift in labor demand and the congestion externality associated with a variation in infrastructure utilization. In the special case where total wage gains from a marginal increase public input utilization are equal to the corresponding production loss owing to congestion, the decentralized equilibrium will be second-best efficient.*

Note that equation (19) constitutes a special case and situations where one effect dominates the other are at least as reasonable. For instance, if the congestion effect is (close to) zero, e.g. for pure public goods or when higher public input utilization levels cause only a minor increase in the production loss, then the tendency to provide public inputs in excess of the optimal amount will be relatively large, provided that  $\bar{w}^i \cdot (dL^i/dN^i|_{(7)}) > 0$  (ceteris paribus). This is because it is more likely in this case that the positive employment effect dominates the negative congestion effect that arises from a marginal increase in public input utilization, which will then cause overprovision of the public input.<sup>10</sup>

Note from (9) and (11) that the individual optimal public-input utilization rate is socially optimal in the special case where (19) holds. In contrast, underutilization will occur if  $\bar{w}^i \cdot (dL^i/dN^i|_{(7)}) > -F_Q^i Q_N^i$  and overutilization if  $\bar{w}^i \cdot (dL^i/dN^i|_{(7)}) < -F_Q^i Q_N^i$  holds. In addition, public inputs will be overprovided in the former and underprovided in the latter case.

<sup>10</sup>This can be seen after substitution of (18) into (17) and a comparison of the result with efficiency condition (10).

### 3.3. Cobb-Douglas production with two well-known specifications of the congestion technology

Owing to the general specifications of the production and congestion technologies, clear-cut results for the provision and utilization of infrastructure as well as the extent of capital taxation in the decentralized equilibrium with source-based capital taxes and head taxes could not be derived. For an assessment of the potential deviation (and its direction) from the optimal policy of the social planner, it is crucial to quantify the magnitude of the congestion externality and the shift in labor demand that is associated with a variation in infrastructure utilization. Assuming Cobb-Douglas production and two well-known specifications of the congestion technology, one can relate the magnitude of the production and congestion elasticities and — depending on the specification of the congestion function — also the level of the wage rigidity (and the corresponding employment level in the competing jurisdictions) to the provision and utilization levels of the public input in the decentralized equilibrium.

With the general production technology, the effects of an increase in the utilization rate on the production loss due to congestion and on the overall marginal productivity of infrastructure utilization can be derived as:

$$\begin{aligned} \frac{\partial(-F_Q^i Q_N^i)}{\partial N^i} &= -Q_N^i(F_{QN}^i + F_{QQ}^i Q_N^i) - F_Q^i Q_{NN}^i \quad \text{and} \\ \frac{\partial(F_N^i + F_Q^i Q_N^i)}{\partial N^i} &= F_{NN}^i + Q_N^i(2F_{NQ}^i + F_{QQ}^i Q_N^i) + F_Q^i Q_{NN}^i, \end{aligned} \quad (20)$$

respectively. Obviously, the loss in production due to congestion ( $-F_Q^i Q_N^i$ ) increases and the overall marginal productivity of infrastructure utilization ( $F_N^i + F_Q^i Q_N^i$ ) decreases as  $N^i$  increases if the congestion technology can be characterized by increasing marginal congestion (IMC). For decreasing marginal congestion (DMC) the situation is not that obvious unless we become more specific on both the production and congestion technology in the productive sector.<sup>11</sup> Assume therefore the following Cobb-Douglas specification of the production technology (2):<sup>12 13</sup>

$$F = L^\alpha K^\beta N^\delta [Q(N, B)]^\tau, \quad (21)$$

with  $0 < \alpha, \beta, \delta, \tau < 1$  and  $\alpha + \beta + \delta < 1$ . The profit maximising condition with respect to

<sup>11</sup>The fact whether congestion decelerates ( $Q_{NN}^i > 0$ ) or accelerates ( $Q_{NN}^i < 0$ ) in infrastructure utilization is therefore an important issue. These cases are also referred to as DMC and IMC in the literature (see, for instance, Edwards 1990).

<sup>12</sup>In order to simplify the notation the superscript  $i$  will be suppressed in the following unless necessary for clarification.

<sup>13</sup>It has been assumed for simplicity that the productivity parameter is equal to one. Accounting for the specification of the congestion technology specified below, a special case of (21) emerges if output elasticities of infrastructure usage ( $N^i$ ) and the stock of infrastructure ( $B^i$ ) are identical ( $\delta = \tau$ ). This is assumed, for instance, by Chatterjee and Morshed (2011), who examine optimal fiscal policy with private and government provision of infrastructure.

labor (see equation (7)) in the Cobb-Douglas model reads  $\alpha L^{\alpha-1} K^{\beta} N^{\delta} [Q(N, B)]^{\tau} = \bar{w}$ .

In what follows, I borrow the specifications of the congestion technologies of DMC and IMC from Edwards (1990) and modify and reinterpret them to adjust to our problem. DMC and IMC will be specified as

$$Q = N^{\eta} B \quad (22)$$

and

$$Q = B (2 - e^{\eta(1-N)}), \quad (23)$$

respectively, with  $-1 \leq \eta \leq 0$  as the degree of congestion.<sup>14</sup> For the production loss due to congestion, one gets:

$$-F_Q Q_N = -\tau L^{\alpha} K^{\beta} N^{\delta-1} Q^{\tau} \epsilon_{Q_N} \quad (24)$$

where

$$\epsilon_{Q_N} \equiv \frac{\partial Q}{\partial N} \frac{N}{Q}$$

has been defined as the elasticity of infrastructure quality with respect to infrastructure utilization. The elasticity is a function of  $\eta$  and  $N$  in case of IMC with  $\epsilon_{Q_N} = \frac{\eta e^{\eta(N-1)} N}{2 - e^{\eta(N-1)}} < 0$  and  $\partial \epsilon_{Q_N} / \partial N < 0$ . In contrast,  $\epsilon_{Q_N} = \eta < 0$  ( $\partial \epsilon_{Q_N} / \partial N = 0$ ) is derived for DMC.

As emphasized in section 2,  $F_N$  denotes the partial derivative of  $F(\cdot)$  with respect to  $N$  if  $Q$  is constant (i.e.,  $F_N$  is short for  $F_N|_{Q=\bar{Q}}$ ). Therefore, with the productivity-enhancing (direct) effect from infrastructure utilization

$$F_N = \delta L^{\alpha} K^{\beta} N^{\delta-1} Q^{\tau} \quad (25)$$

and (24), one derives

$$F_N + F_Q Q_N = L^{\alpha} K^{\beta} N^{\delta-1} Q^{\tau} (\delta + \tau \epsilon_{Q_N}) \quad (26)$$

for the overall marginal product of infrastructure usage. As will be emphasized also later, the overall marginal product of infrastructure utilization can also turn negative for high degrees of infrastructure utilization in case of IMC.

Examining the effect of infrastructure usage on employment as derived in (8), one gets

<sup>14</sup>It is straightforward to derive  $Q_N < 0, Q_{NN} > 0$  from the former and  $Q_N, Q_{NN} < 0$  from the latter specification ( $\eta \neq 0$ ). Both have the property that the service derived from infrastructure provision is equal to infrastructure capacity ( $Q = B$ ) if  $N = 1$ . For a utilization rate ( $N$ ) above (below) one, the quality index ( $Q$ ) will be below (above) the infrastructure provision level ( $B$ ) if  $\eta \neq 0$ . In the case where the infrastructure facility is non-congestible ( $\eta = 0$ ), one derives  $Q = B$ . For  $\eta = -1$ , infrastructure is fully congestible like a private good. In addition, it is assumed that  $(2 - e^{\eta(1-N)}) > 0$  in case of IMC, which puts an upper threshold on  $N$  and excludes the possibility that a negative service ( $Q$ ) is derived from infrastructure provision (see equation (23)).

with Cobb-Douglas production:

$$\left. \frac{dL}{dN} \right|_{(\tau)} = -\frac{L(\delta + \tau \epsilon_{Q_N})}{N(\alpha - 1)}. \quad (27)$$

Because  $\partial \epsilon_{Q_N} / \partial N < 0$  holds for IMC,  $dL/dN|_{(\tau)}$  turns negative if infrastructure utilization is sufficiently large.<sup>15</sup> With the labor market equation  $\bar{w} = \alpha L^{\alpha-1} K^\beta N^\delta Q^\tau$ , and equations (26) and (27), one obtains

$$F_N + F_Q Q_N + \bar{w} \left. \frac{dL}{dN} \right|_{(\tau)} = L^\alpha K^\beta N^{\delta-1} Q^\tau (\delta + \tau \epsilon_{Q_N}) \left(1 - \frac{\alpha}{\alpha - 1}\right) \quad (28)$$

for the social marginal product of infrastructure utilization as derived on the LHS in (11). In analogy, we can write the social marginal product of infrastructure provision derived on the LHS in (10) as

$$F_Q Q_B + \bar{w} \left. \frac{dL}{dB} \right|_{(\tau)} = L^\alpha K^\beta N^\delta Q^\tau \frac{\tau}{B} \left(1 - \frac{\alpha}{\alpha - 1}\right), \quad (29)$$

with

$$F_Q Q_B = L^\alpha K^\beta N^\delta Q^\tau \frac{\tau}{B} \quad \text{and} \quad \left. \frac{dL}{dB} \right|_{(\tau)} = -\frac{\tau L}{B(\alpha - 1)} \quad (30)$$

as the direct and indirect effects from an increase in infrastructure provision.

### 3.3.1 A short graphical illustration

With the Cobb-Douglas forms of the conditions for efficiency in infrastructure provision (10) and the labor market equation (7), one can express the social marginal product of infrastructure utilization (28) as a function of  $N$  and the parameters  $\alpha, \delta, \tau, \eta, \bar{w}, K$ .<sup>16</sup> Assuming specific parameter values  $\alpha = 0.25, \delta = 0.25, \tau = 0.25, \eta = -0.05, \bar{w} = 0.5, \bar{v} = 0.1$  (and  $K = 1$ ), which have been chosen for illustrative purposes, Figure 1 contains a plot of the production loss and the change in the wage bill arising from a marginal increase in infrastructure utilization ( $-F_Q Q_N$  and  $\bar{w} dL/dN|_{(\tau)}$ , respectively) and both the individual ( $F_N$ ) and the social marginal product ( $F_N + F_Q Q_N + \bar{w} dL/dN|_{(\tau)}$ ) of infrastructure utilization as a function of  $N$ , given that the Samuelson condition is fulfilled. Assuming specific parameter values for  $\alpha, \delta, \tau, \eta, \bar{w}$ , and  $\bar{v}$  (the marginal cost (MC) of infrastructure utilization), one

<sup>15</sup>The overall marginal product is either positive, negative or zero for any  $N$  in case of DMC, and it will be assumed that  $F_N + F_Q Q_N > 0$ , i.e.  $\delta + \tau \eta > 0$  (In case of DMC, the second-order conditions for a maximum with respect to  $N$  in the maximization problem of the social planner are not satisfied if  $\delta + \tau \eta < 0$ ).

<sup>16</sup>Due to the fact that capital is a fixed factor from the viewpoint of the social planner, it will be set equal to one in each jurisdiction in the following. Assuming symmetric tax competition, the amount of capital invested in the representative jurisdiction will also be equal to one in the decentralized equilibrium.

can, moreover, solve for the optimal quantities  $N$ ,  $B$  and  $L$  from the viewpoint of the social planner (closed-form solution).<sup>17</sup>

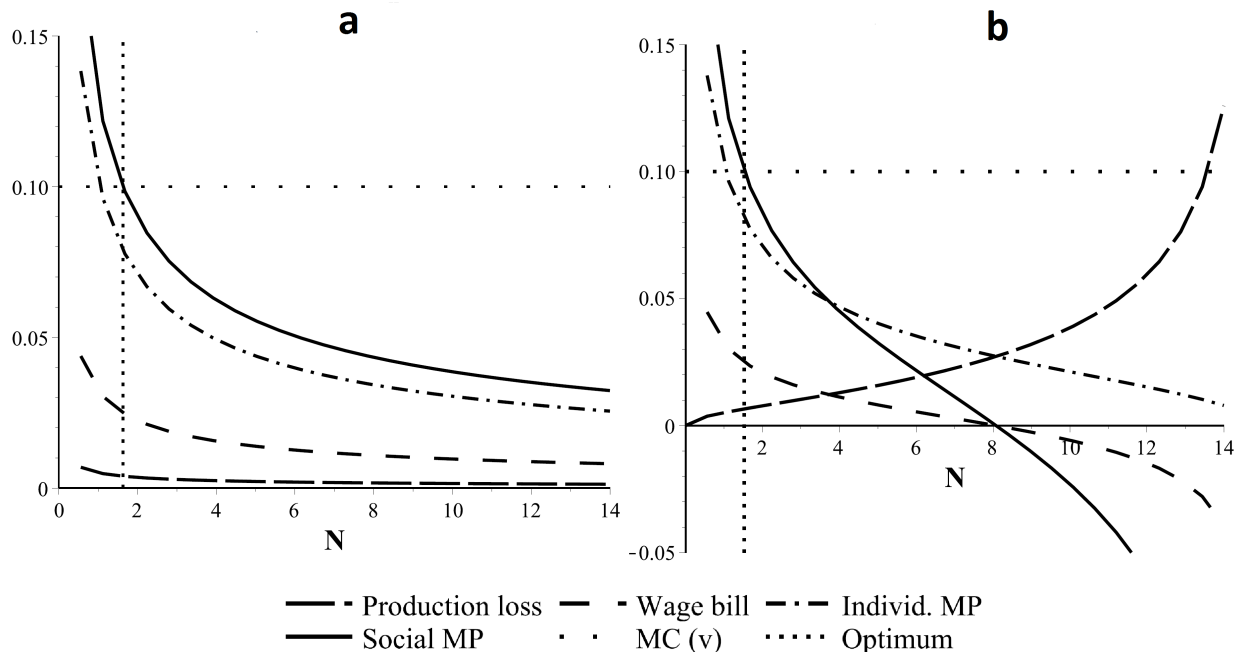


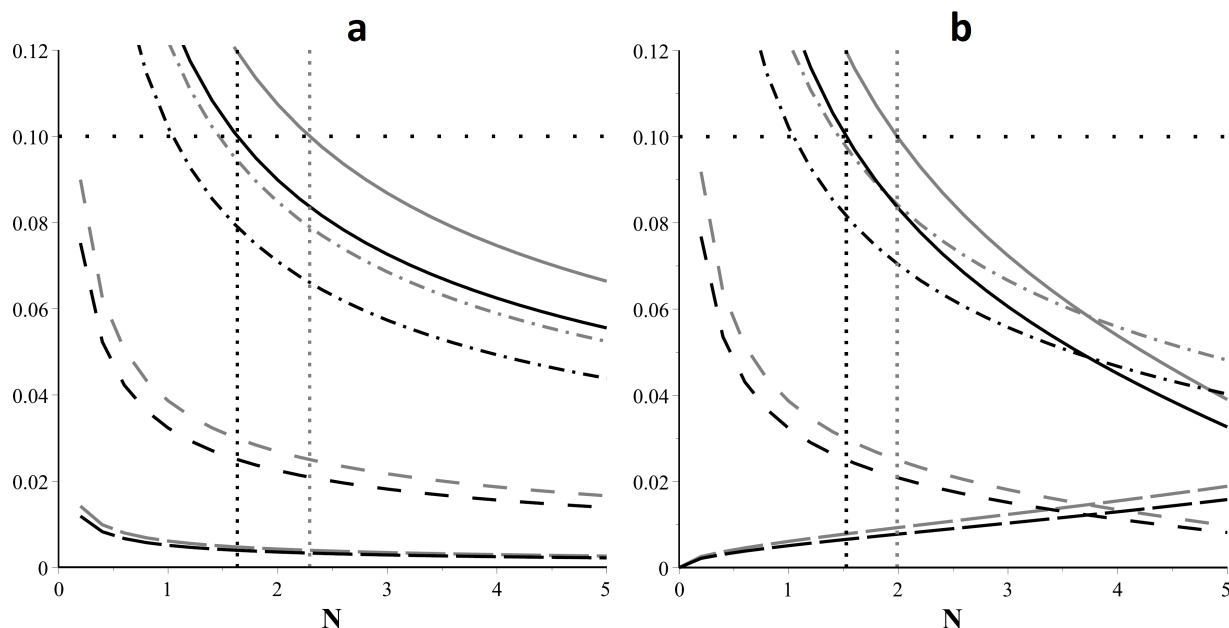
Figure 1: Production loss, change in the wage bill arising from a marginal increase in infrastructure utilization, individual and social marginal product of infrastructure utilization, and the socially optimal infrastructure utilization level for DMC (part a) and IMC (part b)

Figure 1 also depicts the socially optimal infrastructure utilization  $N$ , which depends on the congestion technology, although, for the assumed private user cost ( $\bar{v} = 0.1$ ) it is almost identical for both specifications (approximately  $N = 1.5$ ). Firms' demand for infrastructure usage can be derived from the individual marginal product (MP) of infrastructure utilization, which is largely unaffected by the congestion technology as the production loss and the change in labor productivity and the corresponding effect on the wage bill arising from individual infrastructure utilization are not taken into account into the firms' decision on optimal infrastructure usage. As obvious from Figure 1, the individual MP is always below the social MP of infrastructure utilization for the selected production and congestion elasticities in the case of DMC (part a). This is not the case for IMC (part b), where the individual MP is below the social MP only for sufficiently low utilization levels. With this congestion technology, heavy infrastructure utilization significantly suppresses the benefits

<sup>17</sup>The equilibrium values  $N$ ,  $B$  and  $L$  are obtained by equating (28) and (29) to their marginal costs ( $\bar{v}$  and 1, respectively), and by using the labor market equation (7) as the third equation. Note that the conclusions drawn in this section are independent of the parameter specifications.

of infrastructure utilization due to its negative effect on production and a potential negative effect on labor productivity. As a result, the social MP of infrastructure utilization turns negative for approximately  $N > 8$  in this example. For the assumed costs of infrastructure utilization ( $\bar{v}=0.1$ ), the individual optimal infrastructure utilization (intersection individual MP with MC ( $\bar{v}$ )) is below the socially optimal infrastructure utilization in both cases, i.e. the benefits from an increase in the wage bill that stem from a marginal increase in infrastructure utilization (still) outweigh the increase in the production loss.

In addition to user costs, optimal infrastructure utilization is also sensitive to the level of the wage rigidity. Assuming that the fixed wage is less binding and unemployment is low in the competing jurisdictions, optimal infrastructure utilization will be higher compared to a framework with a higher wage rate and unemployment (for both specifications of the congestion technology). This can be taken from Figure 2, which replicates the constrained efficient outcome for  $\bar{w} = 0.5$  (black) and depicts, in addition, constrained efficiency for a lower wage rate of  $\bar{w} = 0.35$  (grey). Observe that the rise of the negative congestion



*Notes:* Black graphs depict the high wage rate scenario ( $w=.5$ ) and gray graphs the low wage scenario ( $w=.35$ ); the legend of Figure 1 applies.

Figure 2: Effects of a variation in the wage rate on the socially optimal infrastructure utilization in case of DMC (part a) and IMC (part b)

externality (production loss) resulting from a lower wage rate is relative moderate compared to the rise in both the individual MP and the change in the wage bill. As a consequence, the social MP of infrastructure utilization (the sum of the three components) is higher and optimal utilization rises to approximately  $N = 2.3$  (DMC) and  $N = 2.0$  (IMC).

In case of IMC, the individual optimal infrastructure utilization is equal to the socially optimal utilization at approximately  $N = 3.7$ . Note, however, that at this utilization level, marginal costs exceed the MP of infrastructure utilization. Efficiency in the decentralized equilibrium would require either lower costs of infrastructure utilization (roughly  $\bar{v} = 0.06$  for  $\bar{w} = 0.35$  or  $\bar{v} = 0.05$  for  $\bar{w} = 0.5$ ), or a wage rate that is sufficiently low (provided that for this wage rate unemployment prevails). As can be taken from Figure 2, decreasing the wage rate shifts the point of intersection of the individual and social MP of infrastructure utilization vertically upward. Then, for a sufficiently low wage rate, the individual and social MP intersect at that point that is equal to the MC of infrastructure utilization.<sup>18</sup>

### 3.3.2 Efficiency in the decentralized equilibrium

Using the derived expressions for the production loss, the change in the wage bill from infrastructure utilization, and the labor market equation, we are able to determine the conditions for under- and overutilization of infrastructure, as well as all related results in the decentralized equilibrium. Equation (19) formalizes this condition for general production and congestion technologies.

#### *Decreasing marginal congestion (DMC)*

Using equation (19) and the derivations above, it is straightforward to show that whether the production loss ( $-F_Q Q_N$ ) exceeds the benefits from an increase infrastructure utilization ( $dL/dN|_{(\tau)}$ ), or vice versa, will depend alone on the magnitude of the production elasticities and the congestion parameter. In detail, one derives:

$$\alpha\delta \begin{matrix} \geq \\ \leq \end{matrix} -\eta\tau \quad \Leftrightarrow \quad \bar{w} \, dL/dN|_{(\tau)} \begin{matrix} \geq \\ \leq \end{matrix} -F_Q Q_N. \quad (31)$$

**Proposition 2.** *Assume Cobb-Douglas production and decreasing marginal congestion (DMC) as specified in (21) and (22). Efficiency in the decentralized equilibrium with capital and lump sum taxes will be determined solely by the magnitude of the production and congestion elasticities. In the special case where  $\alpha\delta = -\eta\tau$  holds, the non-cooperative equilibrium is second-best efficient. In contrast, public inputs will be underutilized (overutilized) in the private sector and overprovided (underprovided) by the public sector if  $\alpha\delta > (<) -\eta\tau$ . Efficiency in the decentralized equilibrium will be independent of the wage rate and corresponding unemployment levels.*

Observe that the term  $\eta\tau$  expresses the percentage decline in output caused by a one percent increase in infrastructure utilization and the corresponding decline in infrastructure quality. In addition to the decline in output, larger parameter values of  $\tau$  and  $\eta$  will also weaken the potential employment gain from infrastructure utilization because congestion causes also the

<sup>18</sup>In the selected example, the decentralized equilibrium is efficient if  $\bar{w} = 0.119$  (see the numerical examples discussed below.).



labor productivity to decline.

*Increasing marginal congestion (IMC).*

If congestion increases at the margin (IMC), output elasticities, the congestion parameter *and* the level of infrastructure utilization  $N$  will be crucial to determine whether decentralized policies are efficient from the viewpoint of the social planner. For this specification of the congestion technology, one derives:

$$\alpha\delta \begin{matrix} \geq \\ \leq \end{matrix} -\tau\epsilon_{Q_N}(\eta, N) \quad \Leftrightarrow \quad \bar{w} \left. \frac{dL}{dN} \right|_{(\tau)} \begin{matrix} \geq \\ \leq \end{matrix} -F_Q Q_N. \quad (32)$$

**Proposition 3.** *Assuming Cobb-Douglas-production (21) and increasing marginal congestion (IMC) (23), efficiency in the decentralized equilibrium will be determined by the production and congestion elasticities and the factor prices  $\bar{w}$  and  $\bar{v}$ . Efficiency in the decentralized framework is obtained in the special case where  $\alpha\delta = -\tau\epsilon_{Q_N}(\eta, N)$ . Underprovision and overutilization (overprovision and underutilization) of the public input will be obtained in case of  $\alpha\delta < (>)-\tau\epsilon_{Q_N}(\eta, N)$ . The tendency to overprovide public inputs will increase with the level of the wage rigidity and the corresponding unemployment rate in the competing jurisdictions.*

Observe that according to (32), the more intensive infrastructure utilization  $N$  (and the larger the elasticities  $\tau$  and  $-\eta$ ), the larger will be the negative congestion effect relative to the positive employment effect associated with infrastructure utilization, and the more likely it is that infrastructure will be underprovided and used in excess of the optimal level by the private firms (*ceteris paribus*). The elasticities  $\alpha$ ,  $\delta$ ,  $\eta$ ,  $\tau$  together with equilibrium infrastructure utilization  $N$  will therefore determine whether the decentralized equilibrium with capital and head tax financing is efficient. Because equilibrium infrastructure utilization declines in  $\bar{w}$  and  $\bar{v}$ , it follows that the tendency to overprovide infrastructure increases as  $\bar{w}$  or  $\bar{v}$  increase.<sup>19</sup>

The underlying mechanism is that in the low wage / unemployment scenarios also optimal infrastructure utilization rates will be higher due to the complementarity of production factors (see also Figure 2 for the CE). As a consequence, also the negative production externality will be higher in case of IMC compared to the high wage scenario in case of IMC (but not in case of DMC), and regional governments have a greater incentive to use the level of infrastructure provision as a means to reduce the negative congestion externality in the low wage rate scenarios as a consequence, i.e., the tendency to underprovide increases (*ceteris paribus*).

<sup>19</sup>Note therefore that  $\epsilon_{Q_N} = \epsilon_{Q_N}(\eta, N)$  with  $\epsilon_{Q_N} < 0$  and  $\partial\epsilon_{Q_N}/\partial N < 0$ , and that equilibrium infrastructure utilization  $N$  is a function of  $\alpha$ ,  $\delta$ ,  $\eta$ ,  $\tau$ ,  $\bar{w}$  and  $\bar{v}$ . The effect of a change in  $\bar{w}$  and  $\bar{v}$  on optimal infrastructure utilization has been analyzed also graphically in Figure 2. More on the mechanism of a change in the level of the wage rate rigidity will be presented in the numerical analysis below.

### 3.3.3 Some numerical examples

Tables 1 to 3 in Appendix D depict some key statistics for the two congestion technologies, and both the constrained efficient equilibrium (CE) and the decentralized equilibrium (DE). Scenarios denoted with A and C characterize equilibria assuming DMC, with a relatively high wage rate (and unemployment) in scenarios A and a lower wage rate in scenarios C. If full employment is assumed at  $\bar{P} = L = 1.5$ , for instance, some level of unemployment will always be present at the selected wage rates in the economy.<sup>20</sup> In case of IMC, the analysis distinguishes between three alternative wage regimes (scenarios B, D, and E). In addition to the high (B) and low (D) unemployment scenarios, the third set of scenarios (E) characterizes equilibria with the specific wage rate that guarantees efficiency of the decentralized equilibrium. It is included to supplement the graphical analysis and the arguments provided above. Columns 2A/C (DMC) and 2B/D (IMC) show statistics with  $\bar{w} = 0.5$  and  $\bar{w} = 0.35$  and a moderate degree of congestion ( $\eta = -0.05$ ), such as analyzed above for the CE. In addition to the CE, statistics of the DE are shown for each scenario in the second column.

In principle, there are two main dimensions to compare the statistics. The first is across scenarios (for the CE *or* the DE) and the second is within a scenario (between the CE *and* the DE). For instance, the comparison of 1A and 2A indicates changes in the statistics triggered by a rise in the degree of congestion from  $\eta = -0.05$  (2A) to  $\eta = -0.25$  (1A) in case of DMC. Within any scenario, one can analyze changes in the statistics that arise from the fact that the optimal policies of the social planner (CE) and the decentralized policy maker (DE) are not identical.

Scenarios 3A/B and 3C/D show results for a degree of congestion equal to zero, i.e., for infrastructure facilities with properties similar to a pure public good. Naturally, both congestion technologies yield identical statistics in this case. Scenarios 4 and 5 consider further variations in production elasticities and the congestion parameter. As I consider IMC as the more interesting specification of congestion, scenarios 6, 7 and 8 have been added for this specification of the congestion technology.

For the chosen specifications of the congestion and production technologies, wage rates and the price of infrastructure utilization, I have solved for the optimal infrastructure utilization / provision and employment levels ( $N, B, L$ ) in both the CE and the DE. These values can then be used in a second step to calculate the direct, indirect and social MP of infrastructure utilization / provision and some additional statistics such as production ( $Y$ ) and welfare ( $W_e$ ) levels or the relative shares of  $B, N$  and  $L$  of total output ( $B/Y, N/Y, L/Y$ ).<sup>21</sup> With the identified externalities in the decentralized framework, welfare is generally

<sup>20</sup>Employment ratios are below  $L = 1.5$  in all scenarios and they are particularly sensitive to changes in the wage rate. In Table 1, wage rates are determined at  $\bar{w} = 0.5$ , except for scenarios with output elasticities of labor that are more in the range of economically meaningful values (5A, 5B, 8B). In these cases employment rates would be much higher at the wage rate  $\bar{w} = 0.5$ .

<sup>21</sup>Output is calculated as  $Y = L^\alpha K^\beta N^\delta Q^\tau - vN$ , and welfare as specified in equation (13). As emphasized above, all individuals are assumed to own an identical share of the economy's capital stock and in the symmetric equilibrium the invested amount of capital is equal to the initial capital endowment ( $\bar{X}\bar{P} - \bar{r}K =$

lower in the DE than in the CE (scenarios A, B, C, D except 1A/C). This is not necessarily the case for output, which may well be higher in the DE.

In the DE, also the equilibrium tax rates  $(T, t)$ , and the elasticities of  $K$ ,  $L$  and  $N$  with respect to the policy instruments  $T$  and  $B$  are provided, using results of the comparative statics analysis. Observe that the elasticities  $K$ ,  $L$  and  $N$  with respect to  $B$  are identical. This is not the case for the elasticities of the three variables with respect to  $T$ . The reason is that  $L$  and  $N$  are affected by a change in  $T$  only indirectly through the perceived variation in the amount of capital ( $K$ ) invested. Due to its direct effect on the marginal cost of capital, the elasticities of capital with respect to the second policy parameter, the capital tax, are larger in all scenarios.

Focusing on the CE, it turns out that the equilibrium values  $L$ ,  $B$  and  $N$  are lower if congestion increases at the margin (*ceteris paribus*). This follows from the fact that in the equilibrium the social MP of infrastructure utilization is lower for this specification of the congestion technology. As a consequence, also  $L$  and  $B$  will be lower in case of IMC. Comparing the CE with the DE, it becomes obvious that due to the multiple externalities in the decentralized framework, quantities  $B$ ,  $N$  and  $L$  differ more or less markedly from those that would be chosen by the social planner. As apparent from the analysis above, distortions in infrastructure provision and utilization may only be caused by the magnitude of the output elasticities  $\alpha, \delta, \tau, \eta$  in case of DMC.<sup>22</sup> Efficiency in the DE is obtained only in scenarios 1A and 1C because  $\alpha\delta = -\eta\tau$  holds in this case. As emphasized above, the level of the wage rate  $\bar{w}$  and infrastructure utilization costs  $\bar{v}$  are crucial, in addition, to analyse efficiency of the DE in case of IMC. Underprovision with infrastructure in the DE (scenarios 1B/D, 4D, 6B/D, 7B/D, 8D) is associated with overutilization in the private sector. The reverse is true in the scenarios with overprovision of infrastructure.

As analyzed above, the results of tax competition are also sensitive to the level of the wage rigidity (and the level of unemployment) in case of IMC. Tax competition between regions that can be characterized by a relatively high level of unemployment is considered in scenarios A and B, and scenarios C and D depict the results of tax competition between regions with a relatively low wage rate (second column in each scenario). With respect to the policy of the central planner (CE), one finds that the optimal infrastructure provision level  $B$  and the optimal quantities  $N$  and  $L$  are lower when the wage rate is more binding for both congestion technologies. As derived analytically above, comparison of the social MP of infrastructure utilization / provision between the CE and the DE indicates that a change in the wage rate will not affect efficiency in the decentralized equilibrium with DMC but with IMC. As emphasized earlier, with DMC the DE is either efficient (1A/C) or inefficient (2A/C, 3A/C, 4A/C, 5A/C), independent of the level of the wage rigidity and utilization

0).

<sup>22</sup>Observe therefore that while equilibrium values of  $B$ ,  $L$ , and  $N$  differ between the low and high wage scenarios, this is not the case for the social MP of  $B$  and  $N$  (lines "Social MP of  $B$ " and "Social MP of  $N$ "). The degree of under-/overprovision and under-/overutilization of infrastructure is independent of  $\bar{w}$  (or  $\bar{v}$ ) in case of DMC.

costs. For the second specification of congestion, underprovision weakens (1B/D, 6B/D, 7B/D), is reversed (4B/D, 8B/D), or overprovision becomes even more severe (2B/D, 5B/D) in the scenarios with the higher wage rate relative to the low wage scenarios. For instance, infrastructure is moderately underprovided and overutilized for a wage rate of  $\bar{w} = 0.5$  (1B), while, with a less binding fixed wage of  $\bar{w} = 0.2$ , underprovision and overutilization becomes more severe (1D).

If infrastructure is underprovided and congestion increases at the margin, one can more-over determine the wage rate above the current wage rate for that the decentralized equilibrium is efficient (given unemployment prevails at that wage rate). Decentralized equilibria with wage rates that are determined exactly at that level where identical statistics are derived for the CE and the DE (for given parameter values  $\alpha, \delta, \tau, \eta, \bar{v}$ ) are shown in Table 3 (scenarios *E*). For instance, in scenario 1E, the DE is efficient for  $w = 0.521$ , while underprovision with infrastructure occurs at  $w = 0.20$  (scenario 1D) and, to a lesser extent, at  $w = 0.50$  (scenario 1B). Higher wage rates, however, will generally result in lower equilibrium values of  $B, N, L$  and, in addition, welfare. It follows that despite the obtained results in the DE in scenarios *E*, this should not be misinterpreted as a recommendation to increase the level of the wage rigidity in the jurisdictions.

A few remarks are in order with respect to the two scenarios with a rather high degree of congestion, close to that of private goods (scenarios 6 and 7 for IMC). In contrast to all other cases, equilibrium capital tax rates, which are derived analytically in equation (15), may turn positive in both scenarios (6D and 7D). This stems from a strong incentive to use the capital tax to reduce congestion (i.e., as a congestion tax), which overcompensates the incentive to subsidise capital to increase employment. Due to the discussed effects from congestion, it is optimal from the viewpoint of the representative regional government to raise the quantity of productive infrastructure as the wage rate becomes more binding in the scenario with the highest congestion parameter (DE, examples 6B/D). In contrast, it is always optimal to reduce the (absolute) quantity of infrastructure from the viewpoint of the social planner (CE) if the fixed wage is increased.

## 4. Conclusion

The paper examines efficiency in the provision of a congestible public input in symmetric tax competition under the presence of unemployment due to wage rigidities. Equilibrium capital tax rates are derived and two dimensions of an efficient infrastructure policy are examined through the analysis of both infrastructure provision and utilization in the decentralized equilibrium and when capital and lump-sum taxation is available for regional governments. Assuming general production and congestion functions, infrastructure provision and utilization levels remain ambiguous due to countervailing externalities resulting from unemployment and congestion.

Unlike in the standard tax competition models (e.g., Zodrow and Mieszkowski (1986)), the availability of lump-sum taxation in addition to distortionary capital taxes is not sufficient to guarantee second-best efficiency in the decentralized framework. If, however, unem-

ployment (e.g. due to wage rigidities) remains the only source for potential inefficiency, tax competition with capital and head taxes and the provision of public consumption goods still guarantees efficiency (e.g. Ogawa 2006, Eichner 2012). With the introduction of the additional assumption that public goods are productive (i.e. public inputs), however, this result is challenged, and a further source of inefficiency arises if the public input is also subject to congestion.

Introducing specific production (Cobb-Douglas) and two well-known congestion technologies (decreasing and increasing marginal congestion), conditions for under-, (over-) and efficiency in public input provision and utilization in the decentralized equilibrium have been derived. It turned out that efficiency in the decentralized equilibrium depends alone on the magnitude of the production and congestion externalities if congestion can be characterized by decreasing marginal congestion. In case of the more interesting specification with increasing marginal congestion the optimal policy of the regional policy maker will also depend on the level of the wage rigidity and therefore on the fact whether tax competition in a high or low unemployment scenario is considered. Tax competition between economies with high wage rates and unemployment levels is less likely to result in underprovision of productive infrastructure in the jurisdictions as public input provision also serves as a tool to increase employment and wage payments. If congestion decreases at the margin, potential distortions in the decentralized framework are independent of the level of the wage rigidity.

The present study has examined efficiency in the non-cooperative equilibrium in the absence of congestion pricing, e.g. the consideration of user fees for firms also to enable a comparison with of the results with the standard tax competition literature. However, as the exclusion of users is feasible for a large part of publicly-provided goods, the introduction of user charges provides an interesting extension to the present analysis.

Other areas of future research involve the analysis of the sensitivity of the results under alternative institutional settings of the labor market, or the examination of the mix of (congestible) public goods, when governments provide both productive and consumptive public goods, such as pioneered, for instance, by Keen and Marchand (1997).

## Appendix A: Second-best efficiency

The central planner maximises the Lagrangian

$$\begin{aligned} L(K^i, N^i, B^i, L^i) = & \sum_{i=1}^n \{ F^i[L^i, K^i, N^i, Q^i(B^i, N^i)] - \bar{v}^i N^i - B^i \} \\ & - \lambda \left[ \sum_{i=1}^q K_i - \bar{K} \right] - \lambda^i [ \bar{w}^i - F_L^i(L^i, K^i, N^i, Q^i(B^i, N^i)) ] \end{aligned} \quad (33)$$

where  $\lambda$  and  $\lambda^i$  are the Lagrange multipliers. Maximising with respect to  $K^i, N^i, B^i, L^i$  yields:

$$F_K^i - \lambda + \lambda^i F_{LK}^i = 0, \quad (34)$$

$$F_N^i + F_Q^i Q_N^i + \lambda^i (F_{LN}^i + F_{LQ}^i Q_N^i) - \bar{v}^i = 0, \quad (35)$$

$$F_Q^i Q_B^i - 1 + \lambda^i F_{LQ}^i Q_B^i = 0, \quad (36)$$

and

$$F_L^i + \lambda^i F_{LL}^i = 0 \quad \forall i \in q. \quad (37)$$

Using  $\lambda^i$  from (37), and  $F_L^i = \bar{w}^i$  in (34) – (36) yields:<sup>23</sup>

$$F_K^i - \bar{w}^i F_{LK}^i / F_{LL}^i = F_K^j - \bar{w}^j F_{LK}^j / F_{LL}^j \quad \forall i, j \in n; i \neq j, \quad (38)$$

$$F_N^i + F_Q^i Q_N^i - \bar{w}^i (F_{LN}^i + F_{LQ}^i Q_N^i) / F_{LL}^i = \bar{v}^i \quad (39)$$

$$F_Q^i Q_B^i - \bar{w}^i F_{LQ}^i Q_B^i / F_{LL}^i = 1. \quad (40)$$

Substitution of (8) into (39) and (40) yields (10) and (11).

## Appendix B: Non-cooperative equilibrium

From (14) we derive with the profit maximizing conditions for firms (6), (7), and (9) the first-order conditions for a maximum (for an interior solution):

$$\frac{\partial W^i}{\partial T^i} = \underbrace{(F_K^i - \bar{r})}_{=T^i} \frac{\partial K^i}{\partial T^i} + \underbrace{F_L^i}_{=\bar{w}^i} \frac{\partial L^i}{\partial T^i} + F_Q^i Q_N^i \frac{\partial N^i}{\partial T^i} + \underbrace{(F_N^i - \bar{v}^i)}_{=0} \frac{\partial N^i}{\partial T^i} = 0 \quad (41)$$

and

$$\frac{\partial W^i}{\partial B^i} = \underbrace{(F_K^i - \bar{r})}_{=T^i} \frac{\partial K^i}{\partial B^i} + \underbrace{F_L^i}_{=\bar{w}^i} \frac{\partial L^i}{\partial B^i} + F_Q^i Q_B^i + F_Q^i Q_N^i \frac{\partial N^i}{\partial B^i} + \underbrace{(F_N^i - \bar{v}^i)}_{=0} \frac{\partial N^i}{\partial B^i} - 1 = 0. \quad (42)$$

Rearranging and simplifying yields the conditions (15) and (16).

In what follows, we derive the provision rule (17) in the non-cooperative equilibrium. Substitution of (15) into (16) yields:

$$F_Q^i Q_B^i = 1 - \bar{w}^i \frac{(K_T^i L_B^i - L_T^i K_B^i)}{K_T^i} - F_Q^i Q_N^i \frac{(K_T^i N_B^i - K_B^i N_T^i)}{K_T^i}, \quad (43)$$

<sup>23</sup>Equation (38) follows from  $F_K^i - \bar{w}^i F_{LK}^i / F_{LL}^i = \lambda \quad \forall i \in q$ .

where  $K_T^i, K_B^i, L_T^i, L_B^i, N_T^i$  and  $N_B^i$  are derived from (6), (7), (9), and (12), using comparative statics analysis, from which one obtains:

$$\text{sgn}K_T^i = \text{sgn}N_T^i \neq \text{sgn}K_B^i = \text{sgn}N_B^i = \text{sgn}L_B^i.$$

The more meaningful case is  $K_T^i, N_T^i < 0$ , and  $K_B^i, N_B^i, L_B^i > 0$  as in the case with opposite signs, there would be no incentives to provide infrastructure, and regional tax authorities would always increase capital taxes (because of  $K_B^i < 0$  and  $K_T^i > 0$ ). In addition, we derive  $L_T^i < 0$  unless the change in the overall marginal product of labor to an increase in  $N^i$  is strongly negative. In detail, one obtains for  $K_T^i, N_T^i, L_T^i$ :

$$K_T^i = \frac{(F_{LL}^i F_{NQ}^i - F_{LN}^i F_{LQ}^i)Q_N^i + F_{LL}^i F_{NN}^i - F_{LN}^i{}^2}{D},$$

$$N_T^i = \frac{F_{KL}^i F_{LN}^i - F_{KN}^i F_{LL}^i}{D},$$

$$L_T^i = \frac{F_{KN}^i (F_{LN}^i + F_{LQ}^i Q_N^i) - F_{LK}^i (F_{NN}^i + F_{NQ}^i Q_N^i)}{D},$$

with

$$D = \left( F_{KK}^i F_{LL}^i - F_{KL}^i{}^2 \right) (F_{NQ}^i Q_N^i + F_{NN}^i) + (F_{KL}^i F_{KN}^i - F_{LN}^i F_{KK}^i) (F_{LQ}^i Q_N^i + F_{LN}^i) \\ + (F_{KL}^i F_{LN}^i - F_{KN}^i F_{LL}^i) (F_{KQ}^i Q_N^i + F_{KN}^i).$$

With the results of the comparative statics analysis, the efficiency condition with respect to public input provision can alternatively be stated as:<sup>24</sup>

$$F_Q^i Q_B^i = 1 - \bar{w}^i \frac{(F_{LN}^i F_{NQ}^i - F_{LQ}^i F_{NN}^i)Q_B^i}{F_{LL}^i F_{NN}^i - F_{LN}^i{}^2 + (F_{LL}^i F_{NQ}^i - F_{LN}^i F_{LQ}^i)Q_N^i} \\ - F_Q^i Q_N^i \frac{(F_{LN}^i F_{LQ}^i - F_{LL}^i F_{NQ}^i)Q_B^i}{F_{LL}^i F_{NN}^i - F_{LN}^i{}^2 + (F_{LL}^i F_{NQ}^i - F_{LN}^i F_{LQ}^i)Q_N^i} \quad (44)$$

Total differentiation of (7) and (9) yields:

$$F_{LK}^i dK^i + F_{LL}^i dL^i + F_{LQ}^i Q_B^i dB^i + (F_{LN}^i + F_{LQ}^i Q_N^i) dN^i = 0, \quad (45)$$

and

$$F_{KN}^i dK^i + F_{LN}^i dL^i + F_{NQ}^i Q_B^i dB^i + (F_{NN}^i + F_{NQ}^i Q_N^i) dN^i = 0. \quad (46)$$

<sup>24</sup>A detailed derivation is provided upon request.

Next we use both equations to derive  $\frac{dL^i}{dB^i}\Big|_{(7),(9)}$  and  $\frac{dN^i}{dB^i}\Big|_{(7),(9)}$  (the notation  $|_{(7),(9)}$  indicates that (7) and (9) have been used for the derivation):<sup>25</sup>

$$\begin{pmatrix} F_{LL}^i & F_{LN}^i + F_{LQ}^i Q_N^i \\ F_{LN}^i & F_{NN}^i + F_{NQ}^i Q_N^i \end{pmatrix} \begin{pmatrix} dL^i/dB^i|_{(7),(9)} & dL^i/dK^i|_{(7),(9)} \\ dN^i/dB^i|_{(7),(9)} & dN^i/dK^i|_{(7),(9)} \end{pmatrix} = \begin{pmatrix} -F_{LQ}^i Q_B^i & -F_{LK}^i \\ -F_{NQ}^i Q_B^i & -F_{KN}^i \end{pmatrix}, \quad (47)$$

which yields:

$$\frac{dL^i}{dB^i}\Big|_{(7),(9)} = \frac{(F_{LN}^i F_{NQ}^i - F_{LQ}^i F_{NN}^i) Q_B^i}{F_{LL}^i F_{NN}^i - F_{LN}^i{}^2 + (F_{LL}^i F_{NQ}^i - F_{LN}^i F_{LQ}^i) Q_N^i} > 0, \quad (48)$$

$$\frac{dN^i}{dB^i}\Big|_{(7),(9)} = \frac{(F_{LN}^i F_{LQ}^i - F_{LL}^i F_{NQ}^i) Q_B^i}{F_{LL}^i F_{NN}^i - F_{LN}^i{}^2 + (F_{LL}^i F_{NQ}^i - F_{LN}^i F_{LQ}^i) Q_N^i} > 0. \quad (49)$$

Observe from (44), (48) and (49) that the condition for efficiency in public input provision can be presented as in (17). Observe further that, as indicated in (48) and (49), the demand for labor and public input utilization increase as public input provision increases. This follows from the specification of the production and congestion technologies (i.e., positive first-order and cross-derivatives, negative second-order derivatives, and because of  $Q_B^i > 0$ ,  $Q_N^i < 0$ , and  $F_{LL}^i F_{NN}^i - F_{LN}^i{}^2 > 0$ ).

<sup>25</sup>In addition,  $\frac{dL^i}{dK^i}\Big|_{(7),(9)}$  and  $\frac{dN^i}{dK^i}\Big|_{(7),(9)}$  can be derived from (45) and (46).



## Appendix D: Numerical examples.

Equilibrium (CE / DE)	DMC								IMC							
	1A	2A	3A	4A	5A	1B	2B	3B	4B	5B	6B	7B	8B			
User price ( $v$ )	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100		
Prod. elasticity of L ( $\alpha$ )	0,250	0,250	0,250	0,250	0,400	0,250	0,250	0,250	0,400	0,400	0,700	0,250	0,250	0,600		
Prod. elasticity of K ( $\beta$ )	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100		
Prod. elasticity of N ( $\delta$ )	0,250	0,250	0,250	0,200	0,100	0,250	0,250	0,250	0,200	0,200	0,100	0,250	0,250	0,200		
Congest. parameter ( $\eta$ )	-0,250	-0,050	0,000	-0,300	-0,500	-0,250	-0,050	0,000	-0,300	-0,500	-0,300	-0,999	-0,999	-0,300		
Prod. elasticity of B ( $\tau$ )	0,250	0,250	0,250	0,200	0,100	0,250	0,250	0,250	0,200	0,200	0,100	0,250	0,250	0,200		
Wage rate ( $w$ )	0,500	0,500	0,500	0,500	0,640	0,500	0,500	0,500	0,500	0,640	0,500	0,500	0,500	0,600		
Elasticity of Q ( $\epsilon_{QW}$ )	-0,250	-0,050	0,000	-0,300	-0,500	-0,257	-0,261	-0,080	-0,057	0,000	0,000	-0,327	-0,265	-0,595		
Infra. quantity (Q)	0,137	0,168	0,165	0,185	0,176	0,136	0,136	0,161	0,164	0,185	0,176	0,154	0,167	0,256		
Social MP of N	0,100	0,100	0,127	0,100	0,133	0,100	0,099	0,100	0,126	0,100	0,133	0,100	0,122	0,100		
Social MP of B	1,000	1,000	0,911	1,000	0,889	1,000	1,005	1,000	0,914	1,000	0,889	1,000	0,944	1,000		
Direct MP of B	0,750	0,750	0,688	0,750	0,667	0,750	0,754	0,750	0,686	0,750	0,667	0,600	0,566	0,300		
Indirect MP of B	0,250	0,250	0,228	0,250	0,222	0,250	0,251	0,250	0,229	0,250	0,222	0,400	0,378	0,700		
Production loss	0,025	0,004	0,005	0,000	0,000	0,026	0,026	0,007	0,006	0,000	0,000	0,029	0,027	0,044		
Direct (overall) MP of N	0,075	0,075	0,095	0,075	0,100	0,060	0,070	0,075	0,094	0,075	0,100	0,060	0,073	0,030		
Indirect MP of N	0,025	0,025	0,032	0,025	0,033	0,040	0,047	0,070	0,117	0,025	0,025	0,031	0,025	0,033		
Infra. quantity (B)	0,138	0,172	0,166	0,185	0,176	0,160	0,159	0,289	0,277	0,137	0,137	0,166	0,165	0,185		
Infra. utilisation (N)	1,033	1,631	1,136	1,852	1,172	1,122	0,915	1,443	0,769	1,018	1,029	1,524	1,132	1,852		
Employment (L)	0,207	0,207	0,258	0,227	0,278	0,234	0,385	0,366	0,947	0,841	0,205	0,206	0,249	0,226		
Capital tax ( $T$ )	-0,014	-0,021	-0,023	-0,023	-0,034	-0,013	-0,021	-0,023	-0,035	-0,028	-0,003	-0,003	-0,005	-0,112		
Interest rate ( $r$ )	0,055	0,066	0,070	0,080	0,277	0,055	0,066	0,070	0,082	0,307	0,040	0,042	0,042	0,176		
Welfare ( $W$ , $\epsilon$ )	0,172	0,180	0,175	0,185	0,176	0,172	0,172	0,179	0,174	0,185	0,176	0,208	0,207	0,428		
Output (Y)	0,310	0,310	0,352	0,370	0,352	0,369	0,366	0,722	0,692	0,309	0,309	0,345	0,340	0,370		
B/Y	0,444	0,488	0,488	0,500	0,500	0,435	0,435	0,400	0,400	0,443	0,442	0,481	0,486	0,500		
L/Y	0,667	0,732	0,667	0,750	0,667	1,043	1,000	1,312	1,215	0,665	0,667	0,721	0,667	0,750		
N/Y	3,333	4,634	3,333	5,000	3,333	3,043	2,500	2,000	1,111	3,293	3,333	4,420	3,333	2,891		
Head tax (H)	0,152	0,187	0,199	0,199	0,193	0,150	0,150	0,186	0,199	0,535	0,535	0,535	0,535	0,463		
Elastic. of K w.r.t. B	0,541	0,606	0,625	0,625	0,556	0,537	0,603	0,625	0,567	0,754	0,754	0,754	0,754	1,043		
Elastic. of K w.r.t. T	-0,405	-0,576	-0,625	-0,625	-0,944	-0,397	-0,569	-0,625	-0,569	-5,029	-0,983	-0,983	-0,983	-2,650		
Elastic. of L, N w.r.t. T	-0,072	-0,112	-0,125	-0,205	-1,733	-0,070	-0,111	-0,125	-0,217	-2,161	-0,014	-0,014	-0,022	-0,908		

Table 1: Numerical example with Cobb-Douglas production (high wage rate).



IMC																
Equilibrium (CE / DE)	CE	DE	CE	DE	CE	DE	CE	DE	CE	DE	CE	DE				
Scenario	1E		2E		3E		4E		5E		6E		7E		8E	
User price ( $v$ )	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100
Prod. elasticity of L ( $\alpha$ )	0,250	0,250	0,250	0,250	0,250	0,250	0,400	0,400	0,700	0,700	0,250	0,250	0,250	0,250	0,600	0,600
Prod. elasticity of K ( $\beta$ )	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100
Prod. elasticity of N ( $\delta$ )	0,250	0,250	0,250	0,250	0,250	0,250	0,200	0,200	0,100	0,100	0,250	0,250	0,250	0,200	0,200	0,200
Congest. parameter ( $\eta$ )	-0,250	-0,250	-0,050	-0,050	0,000	0,000	-0,300	-0,300	-0,500	-0,500	-0,999	-0,999	-0,800	-0,800	-0,300	-0,300
Prod. elasticity of B ( $\tau$ )	0,250	0,250	0,250	0,250	0,250	0,250	0,200	0,200	0,100	0,100	0,250	0,250	0,250	0,250	0,200	0,200
Wage rate ( $w$ )	0,521	0,521	0,119	0,119			0,411	0,411	0,577	0,577	1,316	1,316	1,181	1,181	0,568	0,568
Elasticity of Q ( $\epsilon_{QN}$ )	-0,250	-0,250	-0,250	-0,250			-0,400	-0,400	-0,700	-0,700	-0,250	-0,250	-0,250	-0,250	-0,600	-0,600
Infras. quality (Q)	0,133	0,133	0,424	0,424			0,186	0,186	0,355	0,355	0,099	0,099	0,098	0,098	0,312	0,312
Social MP of N	0,100	0,100	0,100	0,100			0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100
Social MP of B	1,000	1,000	1,000	1,000			1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Direct MP of B	0,750	0,750	0,750	0,750			0,600	0,600	0,300	0,300	0,750	0,750	0,750	0,750	0,400	0,400
Indirect MP of B	0,250	0,250	0,250	0,250			0,400	0,400	0,700	0,700	0,250	0,250	0,250	0,250	0,600	0,600
Production loss	0,025	0,025	0,025	0,025			0,040	0,040	0,070	0,070	0,025	0,025	0,025	0,025	0,060	0,060
Direct (overall) MP of N	0,075	0,075	0,075	0,075			0,060	0,060	0,030	0,030	0,075	0,075	0,075	0,075	0,040	0,040
Indirect MP of N	0,025	0,025	0,025	0,025			0,040	0,040	0,070	0,070	0,025	0,025	0,025	0,025	0,060	0,060
Infras. quantity (B)	0,133	0,133	0,497	0,497			0,198	0,198	0,390	0,390	0,072	0,072	0,076	0,076	0,368	0,368
Infras. utilisation (N)	1,000	1,000	3,726	3,726			1,187	1,187	1,171	1,171	0,541	0,541	0,569	0,569	1,472	1,472
Employment (L)	0,192	0,192	3,121	3,121			0,577	0,577	1,420	1,420	0,041	0,041	0,048	0,048	0,778	0,778
Capital tax (T)		-0,013		-0,050				-0,040		-0,273		-0,007		-0,008		-0,110
Interest rate ( $r$ )		0,053		0,199				0,099		0,390		0,029		0,030		0,184
Welfare ( $W^e$ )	0,167	0,167	0,621	0,621			0,277	0,277	0,663	0,663	0,090	0,090	0,095	0,095	0,221	0,221
Output (Y)	0,300	0,300	1,118	1,118			0,475	0,475	1,054	1,054	0,162	0,162	0,171	0,171	0,589	0,589
B/Y	0,444	0,444	0,444	0,444			0,417	0,417	0,370	0,370	0,444	0,444	0,444	0,444	0,625	0,625
L/Y	0,640	0,640	2,792	2,792			1,215	1,215	1,347	1,347	0,253	0,253	0,282	0,282	1,321	1,321
N/Y	3,333	3,333	3,333	3,333			2,500	2,500	1,111	1,111	3,333	3,333	3,333	3,333	2,500	2,500
Head tax (H)		0,147		0,546				0,237		0,663		0,079		0,084		0,478
Elastic. of K w.r.t. B		0,541		0,541				0,526		0,588		0,541		0,541		0,909
Elastic. of L w.r.t. T		-0,405		-0,405				-0,842		-3,706		-0,405		-0,405		-2,182
Elastic. of L, N w.r.t. T		-0,072		-0,072				-0,175		-1,373		-0,072		-0,072		-0,682

Table 3: Numerical example with Cobb-Douglas production (wage rate that guarantees efficiency of the DE).

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