This paper examines efficiency in the provision and utilisation of productive infrastructure in an international tax competition setting with employment and congestion externalities. In a framework where infrastructure quality and infrastructure utilisation enhance production, the approach derives the conditions for constrained- and first-best efficiency in environments with and without unemployment from rigid wages. For a basic tax competition setting with head and source-based capital taxes, the level of the equilibrium capital tax rates and of the infrastructure provision and utilisation levels are ambiguous and depend on the magnitude of both externalities. If the governments’ toolkit of fiscal instruments is enriched with a user charge for firms both the employment of capital and the utilisation of infrastructure may be subsidised in the non-cooperative equilibrium. In such a policy framework, the non-cooperative equilibrium can be shown to be constrained efficient as user charges alleviate the inefficiency arising from congestion, and are used to manipulate infrastructure utilisation appropriately to stimulate employment.

Keywords: Unemployment, tax competition, public inputs, user charges

JEL classification: H 41, H 21, H 25

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1. Introduction

Producers and consumers benefit from a subsidised price for infrastructure utilisation in some countries. In Germany, for instance, a recently introduced surcharge for the financing of renewable energy sources (the ”EEG-surcharge”) has been reduced for energy-intensive companies. Currently, only companies from the manufacturing sector with an electricity consumption in excess of one GWh/a and costs amounting to 14 percent of the gross added value, are eligible for a reduction in the surcharge (European Commission 2013). In 2013, the European Commission has started an investigation of the case in order to proof the compatibility of this ’state aid’ for some companies with EU rules. An issue seen was the possible distortion in competition between companies that benefit from the reduction and those that don’t. Recently, the European Commission has declared the reductions in the surcharge ”for the major part compatible with the new Environmental and Energy Aid Guidelines” (European Commission 2014). However, some of the beneficiaries have to pay back received reductions in order to avoid distortion in competition. Quantitatively more important, and relevant for producers and consumers, the IEA has documented worldwide fossil fuel subsidies for the last ten years (IEA 2014). As a consequence of these energy subsidies, which were estimated 548 billion U.S. Dollar in 2013, and implemented mainly to promote economic growth, also the price of infrastructure utilisation (e.g., the price for road usage in this case) is depressed in the countries concerned.

Policy makers — especially those of economies that suffer from high and persistent unemployment rates — frequently express their fear of (further) employment losses in industries that rely heavily on infrastructure that is expensive to use. In a common argument, disadvantages for the employment of capital and labour may, above all, occur in open economies that compete with other regions where infrastructure utilisation is less costly.\(^1\) This paper presents a framework where in an environment with unemployment and capital mobility incentives may arise for governments to depress the price for the utilisation of productive infrastructures in order to contribute towards improving foreign direct investments and (as a consequence) employment in a region. Addressing the interplay between the competition for foreign direct investments, unemployment, congestion, and the provision of a productive infrastructure facility, the analysis reveals new implications for the design of an optimal decentralised policy with user charges. The latter are still rarely considered as a strategic instrument in the literature on fiscal competition (cf. e.g., Fuest and Kolmar 2007), despite their capability to internalise externalities (e.g., congestion or environmental), and to generate additional funds for regional governments.

Typically, while households and firms choose their individual optimal utilisation levels of an infrastructure facility, given the price of infrastructure utilisation, governments decide upon the optimal capacity or quantity of the facility. The subsequent analysis also identifies

\(^1\)International competition has also been put forward as a reason for the approval of reductions in the surcharge for energy-intensive industries by the European Commission.
two dimensions of an optimal infrastructure policy: efficiency in infrastructure utilisation in the private sector, and efficiency in infrastructure provision by the public sector. Inefficiencies may arise if potential externalities — for instance those associated with capital mobility, labour market distortions and congestion — remain unaccounted by the users of infrastructure.

Similarly to some recent work (cf. e.g., Exbrayat et al. 2012), potential labour market distortions are considered as a realistic and necessary feature in the fiscal competition model. Given high and persistent unemployment in some European states, unemployment can moreover be seen as one of the key drivers for a government’s engagement in fiscal competition for foreign direct investments. For the European Union, where statutory minimum wages are binding in most of the member states, wage rigidities can be put forward as one of the reasons for unemployment (cf. e.g., Ogawa et al. (2006a,b) and Moriconi and Sato (2009)).

A further issue for an efficient infrastructure policy arises from the fact that infrastructure is typically subject to some degree of congestion. Although infrastructure has some properties of pure public goods, it is well known that there are few facilities that are both non-rival and non-excludable such as in the sense of Samuelson or Musgrave. There is a broad consensus in the public finance literature that a large part of the infrastructure is at least partly congestible, and the work that deals with the efficient provision and funding of infrastructure (e.g., the literature on fiscal competition) frequently accounts for congestion externalities.

Technical progress has enabled the exclusion of users from many infrastructure facilities, making usage-based financing possible, and user fees have been identified as an efficient instrument to internalise congestion costs in some studies. It is also a result of this paper that the role of user charges is not negligible in a decentralised policy framework. However, in the present setting, usage-based financing of infrastructure may not only serve as a tool to correct for congestion but also to stimulate employment through the channel of manipulating infrastructure utilisation appropriately in the private sector.

In the fiscal competition literature assuming competitive labour markets, Sinn (1997) has examined the provision of a congestible infrastructure facility (e.g., a highway). Private user costs of infrastructure decrease in the capacity of infrastructure, but infrastructure does not exhibit a productivity-enhancing effect as a factor in the production function of firms, such as in the present analysis. As a further difference, congestion is tied to the mobile factor of production (capital) in the framework of Sinn (1997).\footnote{A further study that assumes competitive labour markets where infrastructure provision reduces private user costs but is not considered as a factor in the production process of firms is Pauser (2013). In contrast, the utilisation of infrastructure is productive in the latter.} The focus in the analysis of Matsumoto (2000) is on public input provision in the presence of congestion externalities when source-based capital taxes and a profit tax are available for regional governments. An increasing number of firms causes congestion in the form that the cost of governmental public input provision is increasing in the quantity of the public input and in the number of firms in the private sector. As a main result, provision levels of the public input turn out to
be inefficiently low in the equilibrium. Using statistics of the federal government’s reliance on user charges in the U.S., Huber and Runkel (2009) emphasise on the relevance of user charges for public good financing. In a model of symmetric tax competition, source-based capital taxes and user charges are available for the provision of a public consumption good that is congestible, and where additional users can be excluded. In their case, where the users of the public good are heterogenous households, the reliance on user fees increases with the number of countries that engage in tax competition, and a coordinated decrease in user fees by all countries raises welfare. Fuest and Kolmar (2007) have analysed a fiscal competition model with user fees and source-based capital taxes as strategic instruments. In their framework regional governments have to invest in exclusion and provide spillover (consumption) goods. They conclude that there is over-investment in exclusion and that spillover goods are underprovided. However, in contrast to the present paper, the authors abstract from unemployment, congestion, and from public goods that serve as inputs in the production process of firms. Similarly, Takahashi (2004) considers user charges for the provision of a non-congestible public good which is considered to be infrastructure, however, like the previously cited work, with a rather different focus, where governments decide in a two-stage game whether to invest in the public good in the first stage, and determine user fees in the second stage.

Excludable public inputs have been incorporated in the production process of the private sector also in the literature on endogenous growth. Recently, Hung and Chen (2013) examined governmental provision of excludable and non-excludable public inputs in a growth model where taxes on output and user charges on the per-unit utilisation of excludable public inputs are available for financing. The representative firm chooses the level of public input utilisation, and the efficient utilisation can be obtained with a user charge on firms that increases with the degree of congestion of the public input. The last aspect is also a feature of the present paper, however, it introduces a different (and perhaps also more innovative) specification of the production and congestion technologies, builds on the fiscal competition literature, and allows for labour market distortions.

For the specification of the production technology, the present analysis makes use of the empirical finding that, in addition to the provision level (i.e., the capacity) of infrastructure, also the intensity of infrastructure utilisation may exhibit a productivity-enhancing effect. Fernald (1999), for instance, found that in case of an expansion of the road network in the U.S., productivity growth is higher in vehicle-intensive industries relative to less vehicle-intensive industries, i.e., in industries that use the facility more extensively compared to others. While the quantity of public capital (e.g., infrastructure) has been frequently considered as a production factor in the literature on endogenous growth, international trade, or fiscal competition, the analysis introduces an additional factor that captures infrastructure utilisation in the private sector. As it is reasonable to assume for some infrastructure

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3 With help of this finding, Fernald (1999) was also able to proof that a rise in aggregate output is caused by higher public capital levels rather than vice versa.

4 In the most common approach in the literature, the specification of the production function with infras-
facilities that the level of infrastructure utilisation plays a significant role in the production process of firms, the intensity of infrastructure utilisation is furthermore considered as a non-trivial variable in the maximisation process of firms. In this respect one may think of the firms’ number of trips on the public road and rail network, or their requested data volume that is transmitted through the telecommunication network. In contrast to utilisation levels, the quantity of the infrastructure is exogenous for the single firm and it will be determined by benevolent governments maximising the utility of employed and unemployed individuals.

As a further feature of the present approach, the public input enters production indirectly, using a quality index for infrastructure. The introduced index is a positive function of infrastructure capacity and a negative function of the intensity of infrastructure utilisation, and the productivity-enhancing effect of infrastructure provision raises with the quality of the facility. For the firms, (direct) costs are only associated with the utilisation but not with the provision of infrastructure. Infrastructure utilisation by a respective firm triggers, however, negative congestion externalities in the sense that it decreases the quality of the infrastructure for all other firms, exhibiting a negative effect on production.\(^5\)

Owing to the specification of the production and congestion technologies, and the selected labour market model, decentralised policies are challenged by the externalities associated with capital mobility, congestion, and unemployment. It turns out that this changes also the incentives for the implementation of user charges and capital taxes in the non-cooperative equilibrium.

The paper proceeds with the presentation of a model of interjurisdictional competition assuming unemployment arising from wage rigidities. Section 3 derives the conditions for (constrained) efficiency, consisting of the conditions for optimal provision and utilisation levels of a congestible infrastructure facility, and a condition for the efficient capital allocation. Section 4 analyses the non-cooperative equilibrium, focusing first on the setting with source-based capital and head taxes (section 4.1). In section 4.2, the paper derives and analyses the decentralised equilibrium under the assumption that also usage-dependent financing of infrastructure is feasible. Section 5 discusses policy implications and implementation issues, and concludes the paper.

2. The model

Assume an economy with a large number \((i = 1, \ldots, q)\) of small and identical jurisdictions that engage in tax competition, and that are price-takers on the capital market (symmetric tax structure assumes three production factors, where in addition to the private production factors, capital and labour, public capital is introduced as a third production factor.

\(^5\)Therefore, as for the definition of congestion, I follow a large part of the literature (see, for instance, Small and Verhoef (2007, p. 63): “A rather general economic definition of congestion is that it occurs when the quality of service of a facility depends on the intensity of use.”) With respect to the term quality of infrastructure, the present analysis abstracts from alternative factors that may have an influence on the quality of infrastructure, such as the age or the accessibility of a facility.
competition). Each region is home to an identical number of immobile individuals $\bar{P}^i$ with identical preferences. The fixed total amount of capital ($\bar{K}$) in the economy is mobile across jurisdictions, and $K^i$ denotes the amount of capital invested in each region ($\sum_{i=1}^q K^i = \bar{K}$). The net-of-tax interest rate on capital ($r^i$) is exogenous from the viewpoint of a single jurisdiction ($r^i = \bar{r}$).

**Households.** All individuals possess an identical share of the aggregate capital stock, and of land ($\bar{R}^i$) in their region. The identical per-capita income from capital denoted with $\bar{X}$, and $z^i \cdot \bar{R}^i / \bar{P}^i$ is the identical per-capita income from land owned in the home region, where $z^i$ is the (net-of-tax) price of land. Labour markets in the jurisdictions are distorted from a fixed wage ($\bar{w}^i$) above the competitive wage rate, as a consequence of which only $L^i < \bar{P}^i$ households are employed ($\bar{P}^i - L^i$ households are unemployed) in each region. Employed households supply one unit of labour inelastically and receive the wage rate $\bar{w}^i$. Assuming a head tax $H^i$ on both types of individuals, and that all sources of income are used for individual consumption $l^i$, the private budget constraint of an inhabitant in region $i$ reads:

$$l^i_1 = \bar{w}^i + \bar{X} + z^i \frac{\bar{R}^i}{\bar{P}^i} - H^i$$  \hspace{1cm} (1)

if she/he is employed, and

$$l^i_2 = l^i_1 - \bar{w}^i$$  \hspace{1cm} (2)

if unemployed. Without a public consumption good, utility ($u$) of the representative individual depends on private consumption only: $u = u(l^i)$, with $u_l > 0$ and $u_{ll} < 0$.

**Production.** For the production conditions in a representative region with a large number of firms, we introduce the technology:

$$F = F[L, K, \bar{R}, N, Q(B, N)].$$  \hspace{1cm} (3)

Equation (3) discloses some novel aspects for the specification of the production technology with public intermediate goods. In the fiscal competition literature it is common to incorporate capital ($K$), labour ($L$), and sometimes land ($\bar{R}$) in the production process of the private sector. While capital is mobile, the production factor labour is immobile between competing jurisdictions, and will be determined endogenously at some level below the number of individuals in the jurisdiction ($L < \bar{P}$). This is due to the binding fixed wage, which is determined above the market-clearing rate. The production factor land is exogenous in each jurisdiction ($R = \bar{R}$). In addition, such as for the physical factors of production ($L, K, \bar{R}$), increasing infrastructure utilisation ($N$) in the private sector and the quality ($Q$) of the infrastructure enhances output. With respect to the production factor $N$ one may think of the aggregate private demand on data volume that is transmitted through the public telecommunication network to the firms in a region, or, considering a transportation facility,
the total number of the firms’ trips on the regions’s road or rail network.

However, in addition to the positive effect, increasing the intensity of infrastructure utilisation is also associated with a negative effect on output. This arises from the decline in infrastructure quality $Q(B, N)$ as $Q_N(B, N) < 0$ holds. The quality of the infrastructure is, in contrast, increasing in the quantity (i.e., the capacity) $B$ of the publicly provided facility. In other words, an increase in $B$ has a decongesting effect on the facility ($Q_B(B, N) > 0$).\footnote{The quantity $B$ may be measured by the total length of the fibre optic cable for the former, or the total length of the road network for the latter example of an infrastructure facility. Both have been used as approximations for an economy’s stock of infrastructure in the literature.}

In case of the telecommunication infrastructure, quality can be approximated as a negative function of the time to down- or upload a certain amount of data (i.e., as a positive function of the down- or upload speed). For the transportation infrastructure, quality may be expressed as a negative function of the average time to travel a certain distance on a road.\footnote{The specification of the production and congestion technologies according to (3) is also related to Oakland’s (1972) specification of a congestible public consumption good as an input in the utility function of the households, and it contains elements from the economic theory of club goods.}

For the first- and second-order derivatives of $F(\cdot)$, we assume

\begin{equation}
F_\rho > 0, F_{\rho \rho} < 0, F_{\rho \nu} > 0,
\end{equation}

with $\rho, \nu = L, K, \bar{R}, N, Q$, and $\rho \neq \nu$.\footnote{$F(\cdot)$ shall also possess continuous first- and second order partial derivatives. Note that $F_N$ is the derivation of the production function with respect to the fourth production factor, i.e., for a constant quality ($Q = \bar{Q}$). Further details on the production technology will be outlined below.}

It is well known that the question whether production factors are complements ($F_{\rho \nu} > 0$) or substitutes ($F_{\rho \nu} < 0$) in production is crucial for the derivation of key results, such as the provision level with public goods in the decentralised equilibrium (cf. e.g., Ogawa et al. 2006a). I assume that $F_{\rho \nu} > 0$ is more plausible. Results can, however, easily be derived for the case that factor inputs are substitutes in production. Expression (4) explicitly includes positive and diminishing marginal products in infrastructure utilisation $N$, and in infrastructure quality $Q$, such as for the (physical) factors of production $(L, K, \bar{R})$. Using the example of the telecommunication infrastructure, the intuition behind $F_{NN} < 0$ is that increasing the data volume from zero to one gigabyte/month is more productive than the increase from one thousand to one thousand and one gigabyte/month or so.\footnote{In other words, the demand for infrastructure utilisation decreases with the intensity of utilisation (see also Pauser (2013) who focuses on the provision of transport infrastructure in a less complex framework with competitive labour markets.)

$F(\cdot)$ exhibits constant returns to scale with respect to the first four production factors $(L, K, \bar{R},$ and $N)$ and increasing returns to scale with respect to all five production factors. This is similar to the ‘creation of atmosphere’ specification of public inputs (Meade 1952),
however, additional production factors are assumed in the present setting.\(^\text{11}\) In addition,

\[ F_{\sigma\sigma}F_{\delta\delta} > (F_{\sigma\delta})^2, \tag{5} \]

with \(\sigma, \delta = L, K, \bar{R}, N\) and \(\sigma \neq \delta\) is assumed, which follows also from the fact that \(F(\cdot)\) exhibits decreasing returns to scale in any two (and also any three) of the production factors \(\sigma\) and \(\delta\). Assuming fixed per-unit costs of infrastructure utilisation \(c_0,\)\(^\text{12}\) and a source-based capital tax \(T,\) the per-unit costs for the employment of labour, capital, land, and for infrastructure utilisation are \(\bar{w}, \bar{r} + T, z,\) and \(c_0,\) respectively. Firms maximise their profits

\[ \pi = F[L, K, \bar{R}, N, Q(B, N)] - c_0N - (\bar{r} + T)K - \bar{w}L - z\bar{R} \tag{6} \]

with respect to \(K, L,\) and \(N,\) from which we derive the first-order conditions:\(^\text{13}\)

\[ F_K[L, K, \bar{R}, N, Q(B, N)] = \bar{r} + T, \tag{7} \]

\[ F_L[L, K, \bar{R}, N, Q(B, N)] = \bar{w}, \tag{8} \]

and

\[ F_N[L, K, \bar{R}, N, Q(B, N)] = c_0. \tag{9} \]

In addition to the well-known profit-maximising conditions for the optimal employment of capital (7) and labour (8), (9) determines the optimal utilisation intensity of productive infrastructure (the congestible public input) by the private sector: Firms will increase infrastructure utilisation up to the point where the benefits of increasing infrastructure utilisation by one unit (left-hand side (LHS)) are equal to the private user costs (right-hand side (RHS)). In addition, we derive

\[ z\bar{R} = F[L, K, \bar{R}, N, Q(B, N)] - c_0N - (\bar{r} + T)K - \bar{w}L \tag{10} \]

for the rents that accrue to land ownership in the long-run competitive equilibrium \((\pi = 0).\)

### 3. First- and second-best optima

This section derives the first- and second-best efficient situations that will be used as benchmarks for the results obtained by decentralised policy setting (the non-cooperative equilibrium), and which are discussed in section 4.

\(^{11}\)For an overview over the specifications of the production technology with a (congestible) public input (using homogeneous production functions), see also Feehan (1989) and Colombier and Pickhardt (2005).

\(^{12}\)Assuming in an alternative scenario that the costs of infrastructure utilisation are endogenous and depend on infrastructure utilisation and the capacity of infrastructure provision does not change the quality of results.

\(^{13}\)In the maximisation problem, infrastructure quality \((Q)\) is considered exogenous by the firms.
**First-best optimum.** In the following, an outcome will be characterised as first-best efficient if the welfare of all $\sum_{i=1}^{q} \bar{P}_i$ households in the economy is maximal, assuming full employment with no distortions in the regional labour markets. In this case, the central planner faces the maximisation problem:\(^{14}\)

$$\max_{K^i, N^i, B^i} : \sum_{i=1}^{q} \left\{ F[L^i, K^i, \bar{R}_i, N^i, Q^i(B^i, N^i)] - c^i_0 N^i - B^i \right\}$$

s.t. : $\sum_{i=1}^{q} K^i = \bar{K}$. \hspace{1cm} (11)

Solving the problem yields the (first-best) efficiency conditions:

$$F^i_K = F^j_K \quad \forall i, j \in q$$

(12)

$$F^i_N + F^i_Q Q^i = c^i_0 \quad \forall i \in q$$

(13)

and

$$F^i_Q Q^i B^i = 1 \quad \forall i \in q.$$ \hspace{1cm} (14)

Equation (12) is the well-known condition for efficiency in the allocation of capital between jurisdictions. Equation (13) states that for the optimal infrastructure utilisation (i.e., the efficient degree of congestion) the productivity increase from increasing infrastructure utilisation by one unit ($F^i_N$) plus the loss in production resulting from the diminished quality of the infrastructure ($F^i_Q Q^i$) must be equal to the private cost ($c^i_0$) in each jurisdiction. The modified Samuelson-condition for the optimal provision of the public input (14) requires that the benefit of public input provision is equal to its marginal cost in each jurisdiction. The former is equal to the increase in production that is obtained from the resulting rise in infrastructure quality. The cost of the provision of an additional unit of the infrastructure is equal to the marginal rate of transformation between the final good and infrastructure, which is assumed to be equal to one.

**Second-best optimum.** In contrast, in a situation with unemployment, the central planner needs also to account for the labour market situation in all $q$ jurisdictions. Taking into account also the profit-maximising condition (8), the maximisation problem can be stated

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\(^{14}\)According to equation (11), the central planner maximises the net-output in the economy, that is calculated as the output $F(\cdot)$ less the user costs for infrastructure utilisation $c^i_0 N^i$, and the cost of infrastructure provision $B^i$. In his objective, he accounts for the fact that the amount of capital is fixed and mobile between regions.
as:

\[
\max_{K^i,N^i,B^i,L^i} : \sum_{i=1}^{q} \left\{ F_i^i[L^i, K^i, R^i, N^i, Q^i(B^i, N^i)] - c_0^i N^i - B^i \right\}
\]

s.t. \[
\sum_{i=1}^{q} K^i = \bar{K},
\]

\[w^i = F_i^i[L^i, K^i, R^i, N^i, Q^i(B^i, N^i)] \quad \forall i \in q.
\]

The constrained efficient outcome, which will also be referred to as second-best efficient, can be characterised by the following three conditions: \(^{15}\)

\[F_i^K + w^i \frac{dL^i}{dK^i} = F_j^j + w^j \frac{dL^j}{dK^j} \quad \forall i, j \in q, \tag{16}\]

\[F_i^N + F_i^Q N^i + w^i \frac{dL^i}{dN^i} = c_0^i \quad \forall i \in q, \tag{17}\]

\[F_i^Q B^i + w^i \frac{dL^i}{dB^i} = 1 \quad \forall i \in q, \tag{18}\]

where

\[
\frac{dL^i_w}{dK^i} = \frac{F_i^{K_L}}{F_i^{L_L}}, \quad \frac{dL^i_w}{dN^i} = -\frac{F_i^{L_N} + F_i^{L_Q} Q^i}{F_i^{L_L}}, \quad \frac{dL^i}{dB^i} = -\frac{F_i^{L_Q} Q^i_B}{F_i^{L_L}} \tag{19}\]

are the reactions of employment to an isolated increase in \(\kappa^i\), that can be derived from the profit maximisation condition (8), with \(\kappa^i\) as any of the factor inputs \((K^i, N^i, B^i)\). According to (19), labour demand increases in the capital endowment \((dL^i_w/dK^i > 0)\) and in infrastructure provision \((dL^i_w/dB^i > 0)\) because augmenting capital or the quantity of infrastructure increases the marginal product of labour. This is because labour and capital, as well as labour and infrastructure quality, are complements in production \((F_i^L K^i, F_i^L Q^i N^i > 0)\), and \(Q_B > 0\).

The sign of the reaction of labour demand to infrastructure utilisation \((dL^i_w/dN^i)\) depends on two countervailing effects. If the direct effect of increasing infrastructure utilisation on the marginal product of labour \((F_i^{L_N} > 0)\) outweighs the indirect effect that is associated with congestion \((F_i^{L_Q} Q^i_N < 0)\), the overall marginal product of labour increases in infrastructure utilisation \((F_i^{L_N} + F_i^{L_Q} Q^i_N > 0)\) and labour demand increases in infrastructure utilisation \((dL^i_w/dN^i > 0)\). The indirect effect accounts for the fact that an increase in infrastructure utilisation decreases infrastructure quality (ceteris paribus), which has a negative effect on output and, therefore, labour demand (and on the demand for other private inputs). \(^{16}\) Scenarios, where the overall marginal product of labour falls if infrastructure

\(^{15}\) ‘Constrained efficient’ therefore accounts for the fact that, such as in regional governments, the central planner’s objective is subject to the labour market distortions from the wage rigidity. Equations (16), (17), (18), and (19) are derived in Appendix A.

\(^{16}\) Observe from \(F_Q(\cdot) = F_{L_Q}(\cdot) L + F_{K_Q}(\cdot) K + F_{N_Q}(\cdot) N + F_{R_Q}(\cdot) R\), which can be derived from the Euler
utilisation is (further) increased may, for instance, occur when the decline in infrastructure quality is relatively large, contributing to a fall in the marginal productivity of labour in excess of the positive (direct) effect associated with infrastructure utilisation \(|F_{LN}^i| > F_{LN}^i\). This can be the case for already heavily utilised infrastructure networks (if \(Q_{NN}^i < 0\)).

Observe that the LHS of (16) – (18), that can be interpreted as the benefits of a marginal increase in \(\kappa^i\), include the term \(\bar{w}dL_w^i/d\kappa^i\), which is absent in the scenario assuming full employment.\(^{17}\) Implications for efficiency, i.e., the efficient quantity of \(\kappa^i\) in an economy, therefore arise also from the change in employment and the corresponding change in the wage sum that is associated with the marginal increase in \(\kappa^i\). For instance, while \(F_{Q}^iQ_{B}^i < 1\) indicates overprovision relative to the first-best provision rule (14), this is not necessarily the case when, due to unemployment in the competing jurisdictions, the second-best provision rule (18) is the relevant benchmark.

4. The non-cooperative equilibrium

4.1. Absence of user charges

We are now examining the case where decentralised jurisdictions are providing infrastructure to the productive sector in their regions. The tax competition literature frequently assumes that source-based capital taxes and head taxes are available for public good financing. One aim of this section is to compare the implications of the present framework with the results of the early tax competition literature assuming the availability of both tax instruments.\(^{18}\) A tax competition setting that abstracts from user charges can be appropriate, for instance, for infrastructure facilities that are not excludable (but may be congestible), or if user fees are politically not feasible or desirable. In a framework with benevolent governments that maximise the weighted utility of the employed and unemployed households, the utilitarian welfare function reads:

\[
W = \bar{w}L + \bar{X}P + z\bar{R} - H\bar{P}. \tag{20}
\]

If a source-based capital tax \((T)\) and a head tax \((H)\) are available for public input financing, the balanced-budget constraint of a representative government can be expressed as:

\[
B = TK + HP. \tag{21}
\]

\(^{17}\)This becomes obvious from the comparison of (12) – (14) with (16) – (18).

\(^{18}\)Zodrow and Mieszkowski (1986), for instance, have shown that for a basic tax competition framework (production function with capital and one fixed factor, non-congested public goods, and competitive labour markets) the decentralised equilibrium is efficient when both instruments are available while for sole capital-tax financing underprovision with public goods occurs.
Using (10) and (21) in (20), and assuming that the capital tax and the quantity of the infrastructure are the strategic parameters in the Nash game between jurisdictions, the maximisation problem of a representative government reads:

$$\max_{T,B} : W = F[L, K, \bar{R}, N, Q(N, B)] - c_0N - \bar{r}K - B + \bar{X}\bar{P}.$$  (22)

Governments in each of the \(q\) jurisdictions solve the maximisation problem (22), accounting for the reaction of the endogenous variables to a change in policy parameters: \(K = K(T, B)\), \(L = L(T, B)\), and \(N = N(T, B)\).

**Proposition 1.** In a framework with head and capital taxes, the representative government chooses the capital tax rate

$$T = -\bar{w}\frac{dL_0}{dK} - F_{Q}Q_{N}\frac{dN_0}{dK},$$  (23)

and provides infrastructure according to the provision rule

$$F_{Q}Q_{B} = 1 - \bar{w}\frac{dL_0}{dB} - F_{Q}Q_{N}\frac{dN_0}{dB},$$  (24)

where

$$\frac{dL_0}{dB}, \frac{dN_0}{dB}, \frac{dL_0}{dK}, \frac{dN_0}{dK}$$  (25)

indicate the change in the number of employed households and in infrastructure utilisation resulting from a marginal increase in infrastructure provision and the capital endowment as derived from the profit maximisation conditions (8) and (9).

The intuition behind Proposition 1 is as follows.\(^{19}\) Observe first that the sign of the equilibrium capital tax (23) is ambiguous and depends on possibly countervailing effects. The first term on the RHS captures the incentives for the taxation of capital that arise from the induced variation in the capital endowment and its effects on employment. In detail, capital inflows resulting from lower capital taxation augment the labour demand in a region \((dL_0/dK > 0)\) if the marginal product of labour and of infrastructure utilisation increase in the capital endowment \((F_{KL}, F_{KN} > 0)\), which is granted by equation (4), and if also the reaction of employment to infrastructure utilisation \((dL_0/dN)\) is positive, or at least not below a certain negative threshold value.\(^{20}\) As a consequence, an incentive to subsidise capital arises from a negative relationship between capital taxes and employment, and the capital tax rate is the lower, the higher the level of the fixed wage rate \(\bar{w}\). Should the reaction of employment to a rise in infrastructure utilisation be strongly negative, however, the

\(^{19}\)Proposition 1 is derived in Appendix B.

\(^{20}\)This can be seen from equation (53) in Appendix B. Technically, this means that the reaction in the overall marginal productivity of labour to an increase in \(N\) must not be strongly negative (see also equation (19) and the discussion of equation (26) below.).
representative government selects a positive tax to increase employment (ceteris paribus). Of course, changing capital taxes in one jurisdiction affects the capital endowment in all other regions, causing an effect on the labour demand there, i.e., there is an employment externality associated with capital taxation from the first term on the RHS of (23). In detail, this follows from $dK^j/dT^i > 0$, affecting labour demand in the neighbouring regions according to $dL^i_0/dK^j \geq 0$.21

In contrast, according to the second term on the RHS of (23), jurisdictions will choose a positive capital tax rate in the non-cooperative equilibrium as a consequence of the loss in production resulting from rising levels in infrastructure usage ($N$). Because of $dN_0/dK > 0$ the demand for infrastructure utilisation falls in the capital tax rate. As a consequence, it is desirable for the representative government to tax capital in order to reduce congestion. The higher the production loss from a decline in infrastructure quality, and the more capital outflows reduce infrastructure utilisation (thereby increasing infrastructure quality), the higher the optimal capital tax rate. Observe that also the second term is associated with an externality in the neighbouring regions. As denoted above, higher capital tax rates in one region increase the capital endowment in all other jurisdictions ($dK^j/dT^i > 0$). As a consequence, firms located in the neighbouring jurisdictions will increase infrastructure utilisation ($dN^j_0/dK^j > 0$).

Equation (24) determines the provision level with infrastructure in the equilibrium that depends on the wage rate ($\bar{w}$), the congestion externality ($F_Q Q_N$), as well as on the reactions of employment and the intensity of infrastructure utilisation to a policy-induced rise in the infrastructure capacity, $dL_0/dB$ and $dN_0/dB$, respectively.22 The latter two effects are positive as infrastructure provision enhances the marginal productivities of labour and of infrastructure utilisation through the channel of an augmented infrastructure quality ($F_L Q, F_N Q > 0$; see equation (4)). As a consequence, an incentive to increase infrastructure provision arises from the fact that infrastructure provision levels can be used to stimulate employment, and, as a consequence, to increase the wage sum for newly hired workers (second term on the RHS of (24)). In contrast, the fact that governments can use the quantity of infrastructure as a tool to reduce congestion (by means of reducing infrastructure utilisation) creates an incentive to decrease infrastructure provision (third term on the RHS of (24)). Whether overprovision, underprovision, or even efficiency in public input provision occurs in the decentralised equilibrium, depends on the magnitude of the four terms specified above.

To assess this issue in greater detail, observe that in equations (23) and (24), which characterise the non-cooperative equilibrium, $dL_0/dK$ and $dL_0/dB$ can be presented as:

$$\frac{dL_0}{dK} = \frac{dL}{dK} + \frac{dL}{dN} \frac{dN_0}{dK},$$

(26)

21 If $dL^i_0/dK^j = 0$, there is no employment externality associated with capital taxation.

22 Equations (51) and (52) contain a detailed derivation of both terms.
\[
\frac{d L_0}{d B} = \frac{d L_w}{d B} + \frac{d L_w}{d N} \frac{d N_0}{d B}.
\]  

(27)

From (19) we know that employment increases in the capital endowment \((dL_w/dK > 0)\) and from a policy-induced increase in infrastructure provision \((dL_w/dB > 0)\) as both increase the marginal productivity of labour. In addition to these direct effects associated with the increase in capital and the quantity of infrastructure, the indirect effects (second terms on the RHS of (26) and (27)) account for the fact that also infrastructure utilisation may have an effect on employment \((dL_w/dN \lesssim 0)\), and infrastructure utilisation becomes more intense as the capital endowment or the provision with infrastructure rises \((dN_0/dK, dN_0/dB > 0)\).

Observe from (27), (24) and (18) that the incentive to increase the wage payments by manipulating infrastructure provision \((\bar{w} \cdot dL_0/dB)\) contributes to overprovision (underprovision / efficiency in infrastructure provision) if a positive (negative / no) employment effect arises from higher infrastructure utilisation in the private sector. In this case the indirect effect of infrastructure provision on employment in equation (27) is positive (negative / zero).

In analogy, according to (26), (23) and (16), depending on the magnitude by which wage payments can be raised through a change in the capital tax \((\bar{w} \cdot dL_0/dK)\), capital will be taxed in excess (below / according to) the level that guarantees efficiency in the allocation of capital \((T = -\bar{w} \cdot dL_w/dK)\) if a positive (negative / no) employment effect arises from higher infrastructure utilisation. This is the case if the indirect effect of capital on employment is positive (negative / zero).

Accounting also for the incentives to raise capital taxes and to reduce infrastructure provision levels in order to reduce congestion,\(^{23}\) one derives from (23), (24), (26), and (27):

\[
\bar{w} \frac{d L_w}{d N} \gtrless - F_Q Q_N \quad \Leftrightarrow \quad T \lesssim -\bar{w} \frac{d L_w}{d K} \quad \Leftrightarrow \quad F_Q Q_B \gtrsim 1 - \bar{w} \frac{d L_w}{d B}.
\]  

(28)

Infrastructure will be overprovided (underprovided / provided efficiently) and capital will be taxed below (above / according to) the level that guarantees efficiency in the allocation of capital from an increase in infrastructure utilisation \((\bar{w} \cdot dL_w/dN)\) exceed (are dominated by / are equal to) the resulting production loss \((- F_Q Q_N)\) in the representative jurisdiction.

Of course, overprovision or efficiency in infrastructure provision are only possible if unemployment is reduced by rising infrastructure utilisation levels \((dL_w/dN > 0)\) and for a sufficiently high wage rate \(\bar{w}\). The higher the exogenous fixed wage rate, and the more infrastructure usage stimulates employment, the higher the wage payments for newly hired workers that can be achieved by reducing capital taxes (first term on the RHS in (23)) and increasing infrastructure provision (second term on the RHS in (24)). The higher the production loss due to rising infrastructure utilisation levels in the private sector \((F_Q Q_N)\), however, the higher the incentive to reduce this production loss by raising capital taxes (second term on the RHS in (23)) and reducing infrastructure provision (third term on the RHS in (24)).\(^{24}\)

\(^{23}\)These effects are captured by the second term on the RHS of (23) and the third term on the RHS of (24).

\(^{24}\)For instance, infrastructure is provided in excess of the efficient amount and capital taxed at a suboptimal
Infrastructure will, in contrast, clearly be underprovided and capital taxed in excess of the optimal level if infrastructure utilisation does not exhibit an effect on employment or this effect is negative \( (\frac{dL_w}{dN} \leq 0) \) as in these cases the incentive to decrease congestion through the channel of decreasing infrastructure provision levels and raising capital taxation dominates the incentive to stimulate employment.\(^{25}\)

As firms choose the profit-maximising level of infrastructure utilisation according to (9), there is also no reason to assume that infrastructure usage is efficient as derived in (13). It remains to derive conditions for under- or overutilisation of infrastructure in the non-cooperative equilibrium without user charges. As obvious from the comparison of (9) and (13), efficiency in the utilisation of infrastructure is obtained in the special case where \( \bar{w} \cdot \frac{dL_w}{dN} = -F_Q Q_N \) holds. In addition, it is straightforward to determine the conditions for under- or overutilisation of the facility from both equations.

Summarising the results of this section, we find that in the non-cooperative equilibrium without user charges, infrastructure is underutilised (overutilised / utilised efficiently) in the private sector and provided in excess of (below / at) the efficient level by the representative government, which taxes capital below (above / at) the efficient level if, from a marginal increase in infrastructure utilisation, the variation in the wage bill due to the change in the number of workers exceeds (is below / is equal to) the production loss due to congestion.

4.2. Availability of user charges

Assuming now that the public input is excludable and regional governments opt to extend their set of available fiscal instruments by a user charge \( p \) for infrastructure utilisation. Maximising the modified function for firm profits with respect to \( p \) yields

\[
F_N[L, K, \bar{R}, N, Q(B, N)] = c_0 + p, \tag{11'}
\]

and the additional revenue \( pN \) is added on the income side of the balanced-budget constraint (21), yielding \( B = TK + HP + pN \). Proposition 2 characterises the optimal decentralised policy with the quantity of infrastructure, capital taxes, and user charges as strategic instruments in the (Nash) tax game.\(^{26}\)

**Proposition 2.** If the regional governments’ toolbox is extended by user charges (in addition to head and capital taxes), capital allocation, infrastructure provision, and infrastructure level if \( \bar{w} \frac{dL_w}{dN} > -F_Q Q_N \), i.e., if from an increase in the intensity of infrastructure utilisation, the wage payments for the newly employed exceeds the production loss due to congestion.

\(^{25}\)Using \( \frac{dL_w}{dN} = 0 \) and (27) in (24) yields with \( \frac{dN_a}{d\bar{R}} > 0, F_Q Q_N < 0 \): \( F_Q Q_B = 1 - \bar{w} \frac{dL_w}{d\bar{R}} - F_Q Q_N \frac{dN_a}{d\bar{R}} > 1 - \bar{w} \frac{dL_w}{d\bar{R}} \).

For \( \frac{dL_w}{dN} < 0 \), one obtains: \( F_Q Q_B = 1 - \bar{w} (\frac{dL_w}{d\bar{R}} + \frac{dL_w}{dN} \frac{dN}{d\bar{R}}) - F_Q Q_N \frac{dN}{d\bar{R}} > 1 - \bar{w} \frac{dL_w}{d\bar{R}} \).

\(^{26}\)For a proof of Proposition 2, see Appendix C.
utilisation are second-best efficient in each jurisdiction, and one derives:

\[ T = -\bar{w} \frac{dL_w}{dK}, \quad (30) \]

\[ p = -F_Q Q_N - \bar{w} \frac{dL_w}{dN}, \quad (31) \]

and

\[ F_Q Q_B = 1 - \bar{w} \frac{dL_w}{dB}. \quad (32) \]

It is straightforward to show that (30), (31), and (32) are in line with the conditions for second-best efficiency.\(^{27}\) According to (30), capital will now be subsidised in each region, resulting from an incentive to increase employment through the attraction of foreign capital. This follows from the fact that labour and capital are complements in production (see equation (19)).

Second, as now also user charges are available, this instrument will be used instead of the capital tax to account for the effects associated with congestion. More precisely, user charges serve the dual purpose of correcting for the loss in production due to congestion, and of exploiting the employment potential of infrastructure utilisation. Incentives to increase \( p \) arise from the first term because infrastructure usage and, as a consequence, losses in production drop as user charges increase. The sign of the second term depends on the fact whether labour demand increases or decreases in infrastructure utilisation, and therefore on the reaction of the overall marginal product of labour to a change in infrastructure utilisation (see equation (19) and its interpretation).

If employment increases in infrastructure utilisation, this creates an incentive to subsidise the price of infrastructure utilisation as infrastructure usage can be stimulated by reducing user fees. According to (31) it is then optimal for governments to implement positive (no, negative) user charges if, from a marginal increase in infrastructure utilisation, the loss in production due to congestion outweighs (offsets, is dominated by) the potential wage payments for newly hired workers. Scenarios where governments subsidise both infrastructure utilisation and the employment of capital may therefore be a realistic outcome in the non-cooperative equilibrium. The subsidisation of infrastructure usage will be attractive for governments if employment gains are relatively large, and congestion associated with increasing infrastructure utilisation is either absent (such as for pure public goods) or rather weak. If employment decreases in infrastructure utilisation, regional governments have an incentive to select positive user charges also from the second term on the RHS of (31). In that case a representative government can decrease congestion and increase employment by

\(^{27}\text{Inserting (30) into the profit maximisation condition of firms for the optimal employment of capital (7), and (31) into the profit maximisation condition for the optimal infrastructure utilisation (11') yields the second-best efficiency conditions (16) and (17). Equation (32) is identical to the second-best provision rule derived in equation (18).}
raising user fees.

In any of these cases, the optimal capital tax rate and user charge determined in (30) and (31) guarantee that the provision and utilisation levels of infrastructure, as well as the allocation of capital are second-best efficient according to (16) – (18). This is because user charges rather than the infrastructure provision level or the capital tax rate are used as an instrument to manipulate infrastructure utilisation levels appropriately, and the optimal user charge according to (31) accounts for the effects from infrastructure utilisation on employment and on production, which were the source of distortion in the last section.

5. Discussion and concluding remarks

This paper assesses the role of user charges as a strategic instrument in an international tax competition framework with congestible productive infrastructure, and labour market distortions. Using a framework where not only the quantity but also private utilisation levels and the quality of infrastructure are determinants in the production process of firms, the analysis derives the equilibrium capital tax rates, user charges, as well as the infrastructure utilisation and provision levels.

The approach identifies unemployment from wage rigidities as a potential reason why the process in reforms to rely more on usage-based financing of infrastructure is rather slow in some countries, despite the well-known advantages of user fees (e.g., to internalise congestion and other externalities, and to generate additional funds for the provision of public services). This is because in a non-cooperative environment with mobile capital, incentives to stimulate employment may counteract the positive effects of user-charge financing, and it may even be optimal to subsidise the price of infrastructure utilisation.

The assumption that capital and head taxes are available for infrastructure funding (section 4.1) builds on the early tax competition literature (cf. e.g., Zodrow and Mieszkowski (1986)). This is also to have a benchmark to study the changes induced by imperfections in labour markets, and the specification of the congestion and production technologies involving productive infrastructure. The findings indicate that the results of the basic tax competition literature cannot be generalised when one enriches the framework with more realistic assumptions on the labour market institution, the public good properties, and the production technology. For instance, efficiency in public input provision is obtained only as a special case in the decentralised equilibrium when lump-sum taxes and source-based capital taxes are available. In this special case, also infrastructure utilisation and the taxation of capital would be (second-best) efficient.

In the non-cooperative environment with user charges it can be optimal for regional policy makers to subsidise capital, infrastructure utilisation, or both. This implies, however, that governments will need to rely heavily on head tax financing, which is a problematic outcome for policy makers that are restricted from using head taxes (at a sufficient level). As a consequence, already Zodrow and Mieszkowski (1986) have analysed the scenario where the head tax is constrained to a suboptimal level in a basic tax competition setting with
capital and head taxes. In their case, public consumption goods that are provided according to the Samuelson-rule when non-distortionary head taxes are available, will be underprovided in the scenario with sole capital-tax financing.

The problem may be aggravated in the present framework as it is probably more likely that the revenue from head taxes is insufficient if some individuals do not receive income from labour. Therefore, and in order to alleviate the problems associated with distortionary capital taxation, it is crucial to improve the understanding of the implications of tax competition settings with alternative income sources for governments. For instance, in addition to usage-based financing of infrastructure, governments can implement a tax on the production factor land in the present framework. Analysing taxation in the U.S., Braid (1996) has argued that land taxation can be a realistic extension in an international tax competition setting. If the set of available policy instruments contains a unit tax on land instead of the head tax, the non-cooperative equilibrium remains as outlined in Propositions 1 and 2. In other words, decentralised equilibria remain unaffected by a substitution of the head tax for a tax on land. The reason for the identical outcome is that both head and land taxes are residence-based taxes with immobile and fixed tax bases ($\bar{P}_i$ and $\bar{R}_i$, respectively), and each individual owns an identical share of local land. A realistic extension of the model can therefore be derived from the fact that land is not exclusively owned by local residents, but also by absentee landlords.\footnote{The more restrictive assumption is still a common assumption in the fiscal competition literature.}

An interesting research question is also how the financial burden is distributed between capital taxes and user charges when both the taxation of households and land taxation are not feasible or the income of these taxes is not sufficient for the provision of infrastructure. However, given that with head and land taxes, the results hold for two autonomous revenue sources, the implications derived from the model should be of some relevance.

A further question that arises is to what extent in a framework with unemployment user charges alone can contribute to an efficient provision and/or utilisation level of productive infrastructure, such as in the sense of Mohring and Harwitz (1962), who presented a framework where the implementation of tolls is sufficient to cover the costs of roads, excluding any other financing mechanism. It also remains for future research to examine the sensitivity of the results through the consideration of alternative policy tools such as taxes on the production factor labour or some form of production taxes.

As governments need to invest in exclusion for some infrastructure facilities (e.g., a highway) before revenues from user charges can be collected, it is also possible to consider a modified framework where the exclusion of users is not costless. A second promising aspect, that has been analysed by Fuest and Kolmar (2007), is the examination of the implications of the provision of spillover public goods. A further promising area for future research can be a framework with governmental provision of public consumption goods rather than public inputs, or the consideration of both types of public goods.
6. Appendix

Appendix A: Second-best efficiency

The central planner maximises the Lagrangian

\[
L(K^i, N^i, B^i, L^i) = \sum_{i=1}^{q} \left\{ F^i[L^i, K^i, \bar{K}, N^i, Q^i(B^i, N^i)] - c^i_0 N^i - B^i \right\} - \lambda \left[ \sum_{i=1}^{q} K_i - \bar{K} \right] - \lambda^i \left[ w^i - F^i_L(L^i, K^i, \bar{K}, N^i, Q^i(B^i, N^i)) \right] \quad \forall i \in q,
\]

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

\[
F^i_K - \lambda + \lambda^i F^i_{LK} = 0 \quad \forall i \in q,
\]

\[
F^i_N + F^i_Q Q^i_N + \lambda^i(F^i_{LN} + F^i_{LQ} Q^i_N) - c^i_0 = 0 \quad \forall i \in q,
\]

\[
F^i_Q Q^i_B - 1 + \lambda^i F^i_{LQ} Q^i_B = 0 \quad \forall i \in q,
\]

and

\[
F^i_L + \lambda^i F^i_{LL} = 0 \quad \forall i \in q.
\]

Using \( \lambda^i \) from (37), and \( F^i_L = \bar{w}^i \) in (34) – (36) yields:

\[
F^i_K - w^i F^i_{LK} / F^i_{LL} = F^j_K - w^j F^j_{LK} / F^j_{LL} \quad \forall i, j \in q; i \neq j,
\]

\[
F^i_N + F^i_Q Q^i_N - w^i(F^i_{LN} + F^i_{LQ} Q^i_N) / F^i_{LL} = c^i_0 \quad \forall i \in q,
\]

\[
F^i_Q Q^i_B - w^i F^i_{LQ} Q^i_B / F^i_{LL} = 1 \quad \forall i \in q.
\]

Next, we determine the reaction of \( L^i \) to an isolated increase of \( \kappa^i \) from the profit maximisation condition (8). Total differentiation of (8) yields:

\[
F^i_{KL} dK^i + F^i_{LL} dL^i + (F^i_{LN} + F^i_{LQ} Q^i_N) dN^i + F^i_{LQ} Q^i_B dB^i = 0 \quad \forall i \in q.
\]

Dividing by \( dK^i \), and using \( dN^i / dK^i = dB^i / dK^i = 0 \) as we want to examine the reactions to a change in all of the variables \( \kappa^i \), yields:

\[
\frac{dL^i}{dK^i} = -\frac{F^i_{LK}}{F^i_{LL}} \quad \forall i \in q,
\]

where the index \( w \) denotes that we are looking at the changes of \( L^i \) as derived from the profit maximisation condition (8), resulting from an isolated change of \( K^i, B^i \) or \( N^i \). In analogy,

\[\text{Equation (38) follows from } F^i_{KL} - \bar{w}^i F^i_{LKL} / F^i_{LL} = \lambda \quad \forall i \in q.\]
we derive the remaining terms from (19):

\[
\frac{dL_w}{dN^i} = -\frac{F^i_{LN} + F^i_{LQ}Q_i}{F^i_{LL}}, \quad \frac{dL_w}{dB^i} = -\frac{F^i_{LQ}Q_i}{F^i_{LL}} \quad \forall i \in q.
\]

Finally, using (19) in (38) – (40) yields (16) – (18).

**Appendix B: Proposition 1**

Derivation of the utilitarian welfare function (22) with respect to \(T\) and \(B\), accounting for \(K = K(T, B), L = L(T, B),\) and \(N = N(T, B),\) and setting the result equal to zero yields:

\[
F_K K_T + F_L L_T + F_N N_T + F_Q Q_N N_T - c_0 N_T - \bar{r} K_T = 0,
\]

and

\[
F_K K_B + F_L L_B + F_N N_B + F_Q Q_N N_B + F_Q Q_B - c_0 N_B - \bar{r} K_B - 1 = 0.
\]

Using (7), (8), and (9) in (42) and (43) yields the following first-order conditions for a maximum (for an interior solution):

\[
-\bar{w} \frac{\partial L}{\partial T} - T \frac{\partial K}{\partial T} - F_Q Q_N \frac{\partial N}{\partial T} = 0
\]

and

\[
F_Q Q_B = 1 - \bar{w} \frac{\partial L}{\partial B} - T \frac{\partial K}{\partial B} - F_Q Q_N \frac{\partial N}{\partial B}.
\]

For the equilibrium capital tax rate we derive from (44):

\[
T = -\bar{w} \frac{\partial L/\partial T}{\partial K/\partial T} - F_Q Q_N \frac{\partial N/\partial T}{\partial K/\partial T}.
\]
The reactions of $L$ and $N$ as in Proposition 1. Total differentiation of (8) and (9) yields:

$$T = -\bar{w} \frac{F_{KN}(F_{LN} + F_{LQ}Q_N) - F_{LQ}(F_{NN} + F_{NQ}Q_N)}{F_{LL}F_{NN} - F_{LN}^2 + Q_N (F_{LL}F_{NQ} - F_{LN}F_{LQ})} - \frac{F_{QN}Q_N}{F_{LL}F_{NN} - F_{LN}^2 + Q_N (F_{LL}F_{NQ} - F_{LN}F_{LQ})}. \quad (47)$$

In the following we demonstrate that the equilibrium capital tax rate (47) can be presented as (23) in Proposition 1. Total differentiation of (8) and (9) yields:

$$F_{LK}dK + F_{LL}dL + F_{LQ}Q_BdB + (F_{LN} + F_{LQ}Q_N)dN = 0, \quad (48)$$

and

$$F_{KN}dK + F_{LN}dL + F_{NQ}Q_BdB + (F_{NN} + F_{NQ}Q_N)dN = 0. \quad (49)$$

The reactions of $L$ and $N$ to changes in $K$ or $B$ that are obtained from the profit maximising conditions (8) and (9) will be denoted with $\frac{dL_0}{dK}$, $\frac{dL_0}{dN}$, $\frac{dL_0}{dK}$, and can be derived from the system:

$$\begin{pmatrix} F_{LL} & F_{LN} + F_{LQ}Q_N \\ F_{LN} & F_{NN} + F_{NQ}Q_N \end{pmatrix} \begin{pmatrix} dL_0/dB \\ dL_0/dK \end{pmatrix} = \begin{pmatrix} -F_{LQ}Q_B & -F_{LK} \\ -F_{NQ}Q_B & -F_{KN} \end{pmatrix}, \quad (50)$$

from which we derive:

$$\frac{dL_0}{dB} = \frac{(F_{LN}F_{NQ} - F_{LQ}F_{NN})Q_B}{G}. \quad (51)$$

$K_T, N_T, L_T$ can be derived from (7), (8), (9), and (21), using comparative statics analysis. As a result, one obtains: sgn $K_T = $ sgn $N_T \neq $ sgn $K_B = $ sgn $N_B = $ sgn $L_B$. The more meaningful case is $K_T, N_T < 0$, and $K_B, N_B, L_B > 0$ as in the case with opposite signs, there are no incentives to provide infrastructure ($K_B < 0$), and regional tax authorities would always increase $T$ ($K_T > 0$). In addition, we derive $L_T < 0$ unless the change in the overall marginal product of labour to an increase in $N$ is strongly negative. In detail, one obtains for $K_T, N_T, L_T$:

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

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

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

with

$$D = \frac{(F_{KK}F_{LL} - F_{KL}^2)(F_{NQ}Q_N + F_{NN}) + (F_{KL}F_{KK} - F_{LN}F_{KK})(F_{LQ}Q_N + F_{LN}) + (F_{KL}F_{LN} - F_{KN}F_{LL})(F_{KQ}Q_N + F_{KN})}{D}.$$
\[
\frac{dN_0}{dB} = -\frac{(F_{LL}F_{NQ} - F_{LN}F_{LQ})Q_B}{G}, \quad (52)
\]
\[
\frac{dL_0}{dK} = \frac{F_{KN}(F_{LN} + F_{LQ}Q_N) - F_{LK}(F_{NN} + F_{NQ}Q_N)}{G}, \quad (53)
\]
\[
\frac{dN_0}{dK} = -\frac{F_{LL}F_{KN} - F_{LN}F_{LK}}{G}, \quad (54)
\]

with
\[
G = F_{LL}F_{NN} - F_{LN}^2 + (F_{LL}F_{NQ} - F_{LN}F_{LQ})Q_N. \quad (55)
\]

Finally, using (53) and (54) in (47) yields (23).\footnote{In addition \(\partial L/\partial T = (dL_0/dK)(\partial K/\partial T)\) and \(\partial N/\partial T = (dN_0/dK)(\partial K/\partial T)\) can be derived.}

Observe that as a direct consequence of (4) and (5), one obtains \(G > 0\). In detail, \(F_{LL}F_{NN} - F_{LN}^2 > 0\) follows from (5), and \(F_{NQ}, F_{LQ}, F_{LN} > 0\) from (4). If, in addition, \(F_{LN} + F_{LQ}Q_N > 0\) (i.e., the overall marginal product of labour increases in infrastructure utilisation), employment increases as infrastructure usage is raised (see, equation (19)), and the numerator of equation (53) is positive. Consequently, one derives \(\frac{dL_0}{dK} > 0\) (\(\frac{dL_0}{dB}, \frac{dN_0}{dB}, \frac{dN_0}{dK} > 0\) is immediately obvious.). If, in contrast, employment decreases in infrastructure utilisation (\(F_{LN} + F_{LQ}Q_N < 0\)), \(dL_0/dK\) still remains positive if \(|F_{KN}(F_{LN} + F_{LQ}Q_N)| < -F_{LK}(F_{NN} + F_{NQ}Q_N)\).

**Appendix C. Proposition 2.**

With the utilitarian welfare function (20) and the strategic policy instruments \(T, B, \) and \(p\), the first-order conditions for a maximum can be derived from:

\[
\max_{T,B,p} : \quad W = F[K,L,N,R,Q(N,B)] - c_0N - \bar{r}K - B + \bar{X}\bar{P}, \quad (56)
\]

with
\[
K = K(T,B,p), L = L(T,B,p), N = N(T,B,p), \quad (57)
\]

yielding:
\[
T\frac{\partial K}{\partial \gamma} = -\bar{w}\frac{\partial L}{\partial \gamma} - (p + F_{QQ}Q_N)\frac{\partial N}{\partial \gamma} \quad \gamma = (p,T), \quad (58)
\]

and
\[
F_{QQ}B = 1 - \bar{w}\frac{\partial L}{\partial B} - T\frac{\partial K}{\partial B} - (p + F_{QQ}Q_N)\frac{\partial N}{\partial B}. \quad (59)
\]

Finally, the equations (30), (31), and (32) of Proposition 2 can be derived from the three first-order conditions (58) and (59) and from the results of the comparative statics analysis (equation (57)), which can be derived from (7), (8), and (11'), and the modified public budget constraint.
References


